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Experimental Investigation of the Effect of Solar Photovoltaic Back Plate Cooling Using Passive Heatsink and Candle Wax as Phase Change Material

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ABSTRACT

Solar PV as a means of electricity generation has been widely adopted throughout the world, following its continuous cost reduction and international commitment to reduce production of Greenhouse Gases. However, the increment of operating temperature due to solar radiation and losses in absorption solar energy causes the performance of solar photovoltaic (PV) panels to deteriorate. This study evaluates the effect of applying two different cooling methods on solar PV panels, using passive heatsink and candle wax as phase change material (PCM), specifically in Malaysia weather condition. The results show heat sink cooling method in overall decreases its performance and the PCM method shows increase in performance.

Keywords: Solar PV, panel cooling, heatsink, PCM

I. INTRODUCTION

Photovoltaic (PV) transforms energy from solar radiation into electricity, using semiconductor materials possessing photovoltaic effect [1].It produces clean power without any harmful emission in the process, although the overall environmental effect including its manufacturing process and land use are still debatable. However, the abundance of energy from sunlight makes it worth pursuing, with the continuous effort of cost reduction and clean manufacturing process. A recent record low bid for a solar power plant at 2.42 cents a kilowatt hour [2] shows a promising trend for the adoption of solar PV to replace fossil fuel as a source of electricity. Despite this, the conversion efficiency is still relatively low compared to other sources of energy, where the conversion efficiency of single junction solar cells is in between the range of 6% to 25% where the latter is achieved under controlled and optimal operating conditions [3].

A. Solar PV in Malaysia

Malaysia, located on the equator of the earth, is favourable for solar PV installation, having sunlight all year long with solar insolation averaging at 5.5kWh/m2 or 15MJ/m2 daily [4]. Since the introduction of Feed-in-tariff, under the Renewable Energy Act of 2011, adoption of Solar PV has increased rapidly, starting at 31.58MW of installed capacity in 2012, growing to a cumulative of 230.59MW in 2015, resulting in 243GWh of cumulative generated capacity [5].

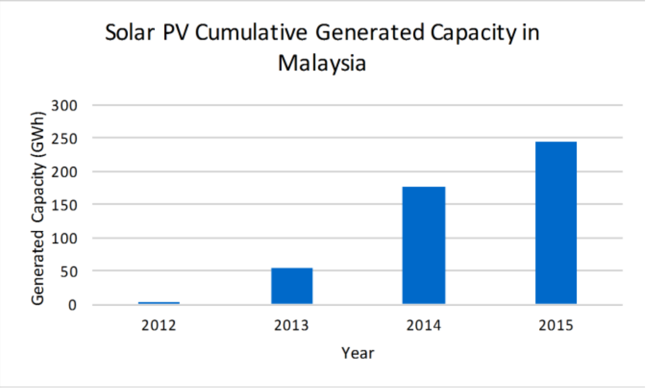

Figure 1: Cumulative Generated Capacity from Solar PV in Malaysia (source: SEDA Malaysia[5])

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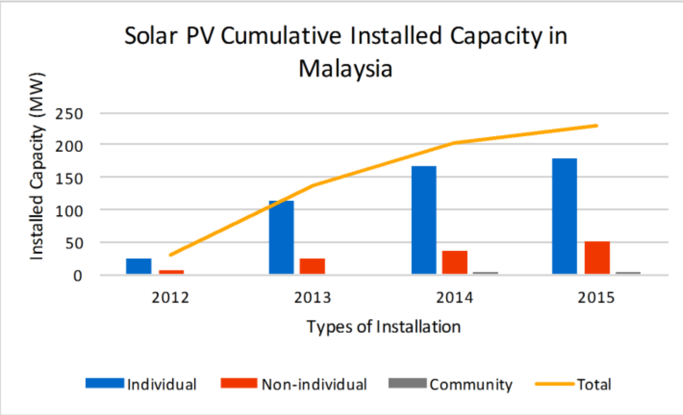


Figure 2: Cumulative installed capacity of Solar PV in Malaysia (source: SEDA Malaysia [5])

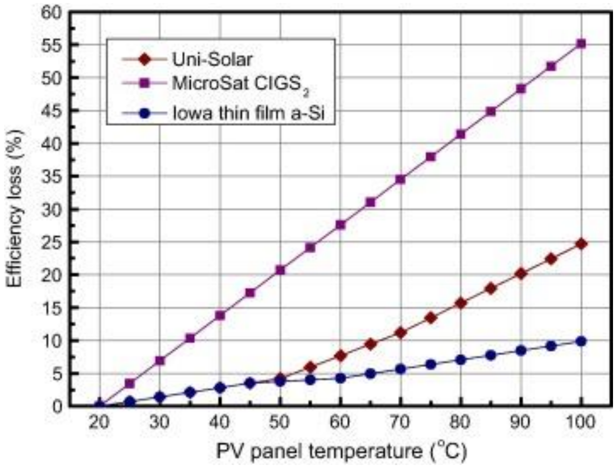


Figure 3: Efficiency loss of solar panel vs. panel temperature[8]

B. Losses due to Operating Temperature

PV cells absorbs 80% of the solar radiation but only a small portion of the energy is converted into electricity, with the remaining energy transformed into heat, increasing its temperature up to 40°C above the ambient temperature [6] The drawback of increased solar cell operating temperature includes its lifespan and power output [1] Estimating the output of solar PV accurately is complex due to multitude of environmental and operating conditions [7] that can affect it performance including cell temperature and wind. This complexity is added with the limited data available, hence a method that can achieve accurate estimates is essential [7]. Dubey et. al. concluded that with decreasing latitude, performance ratio of solar PV cells decreases and higher altitude will produce higher performance ratio due to its decreasing temperature [7].

C. Effect of Solar Panel Heating

It is a well-known fact that the performance of solar PV decreases as the operating temperature increases. However, based on studies, the degree of increment of losses compared to the temperature varies for different type of solar materials. A study by Du et. al. demonstrates the efficiency losses of three different types of solar cells materials, namely Uni-Solar, MicroSat CIGS2 and Iowa thin film a-Si.

The study shows that CIGS based solar cells has a linear increment of efficiency losses with respect to temperature, which is the highest affected and followed by Uni-Solar and and Iowa thin film a-Si. For the latter two, the increase of efficiency losses are similar before reaching 50 Celsius temperature, followed by larger efficiency losses by Uni-solar panel [8]. The increasing operating temperature causes reduction in open circuit voltage, fill factor hence the power output, resulting in losses in efficiency and permanent damage to the solar cells [9].

Radziemska demonstrated the effect of temperature to the voltage in his study, showing the power at various temperature against its voltage [3].

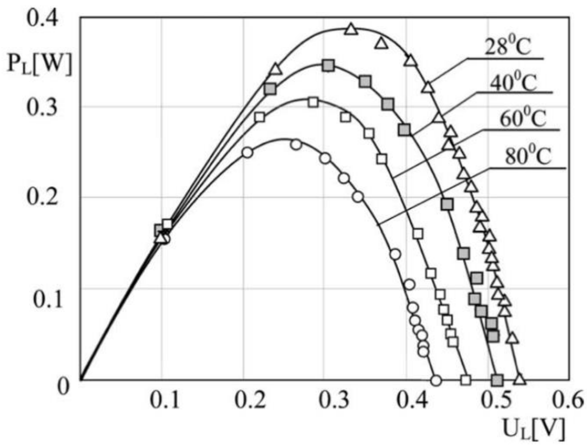


Figure 4: Power output of silicon solar cell at various temperatures [3]

D. Methods for Backplate Cooling

Due to this adverse effect of operating temperature to the performance and lifetime of solar PV cells, various studies and methods have been tried to reduce the operating temperature of solar PV cells. A study by Hasan et. al have summarized these cooling methods as in Table 1 below.

Table 1: Summary of solar cells cooling techniques [10]

	Advantages	Disadvantages
Natural air circulation (NAC)	Low initial cost, no maintenance, easy to integrate, longer life, no noise, no electricity consumption and passive heat exchange	low heat transfer rates, accumulation of dust in inlet grating further reducing heat transfer, dependent on wind direction and speed, low thermal conductivity and heat capacity of air, low mass flow rates of air and limited temperature reduction
Forced air circulation (FAC)	Higher heat transfer rate, independent of wind direction and speed, higher mass flow rates, higher temperature reduction	high initial cost for fans, ducts to handle large mass flow rates, high electrical consumption, maintenance cost, noisy, difficult to integrate
Hydraulic cooling (HC)	Higher heat transfer rate, higher mass flow rates, higher thermal conductivity and heat capacity of water, higher temperature reduction	Higher initial cost due to pumps, higher maintenance cost, higher electricity consumption, corrosion
Heat pipes (HP)	Passive heat exchange, low cost, easy to integrate	Low heat transfer rates, dust accumulation on the inlet grating, dependent on the wind speed and direction
Thermoelectric (Peltier) cooling (TEC)	No moving parts, noise free small size, easy to integrate, low maintenance costs, solid state heat transfer.	Heat transfer depends on ambient conditions, active systems, require electricity, reliability issues, costly for PV cooling, no heat storage capacity, requires efficient heat removal from warmer side for effective cooling.
PCM Thermal management	Higher heat transfer rates, higher heat absorption due to latent heating, isothermal natural of heat removal, no electricity consumption, passive heat exchange, no noise, no maintenance cost, on demand heat delivery.	Higher PCM cost compared to both, some PCMs are toxic, some PCMs have fire safety issues, some PCMs are strongly corrosive, PCMs may have disposal problem after their life cycle is complete.

This paper presents the study of the effect of applying two different cooling methods for solar PV panels, which are using heat sink for the first method and applying candle wax on the back plate of the solar PV for the second method. This cooling methods will be tested in Malaysia weather condition, as detailed in the following section. The second section of this paper describes the methodology of conducting this experiment and the fourth section will present the results, discussion followed by conclusion.

II. METHODS AND MATERIAL

A. Site Selection and tilt angle

The site selected was an open space located at TNB Research in Kajang, Selangor, Malaysia (coordinate: 2.965995, 101.733998). The location was free from any obstacles in proximity to avoid shadowing effect.

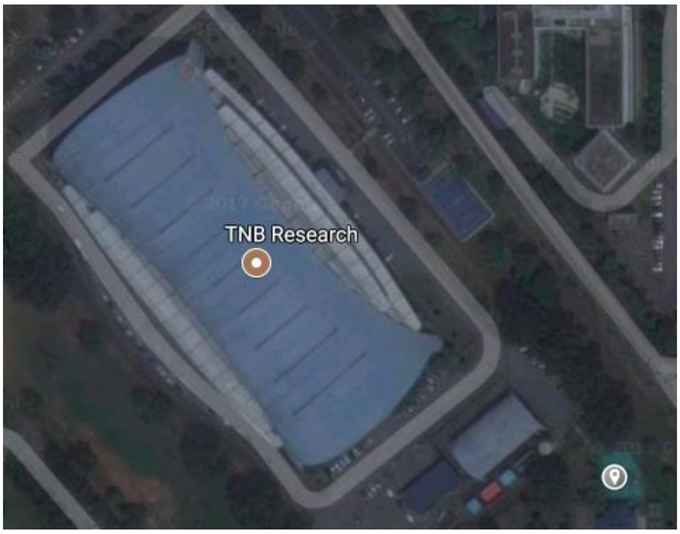


Figure 5: Location of experiment at TNB Research, Kajang, Selangor, Malaysia

The tilt angle was selected at 20 degrees facing south, as suggested by Khatib et al. [11]

B. Calibration

Two panels were used for the experiment, Panel 1 for the investigation of the cooling methods and Panel 2 as a control experiment without any back plate cooling. In making sure both panels are identical, an initial test was conducted to determine that the output power for both panels are similar under the same condition. The performance of both panels were determined:

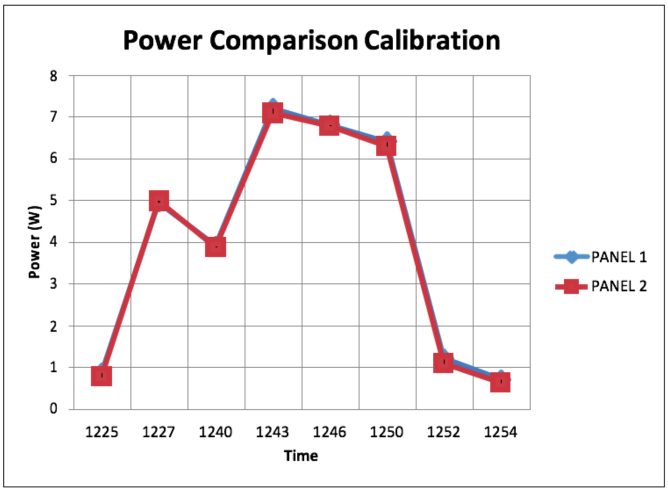


Figure 6: Power output for Panel 1 and Panel 2, both without any cooling methods applied

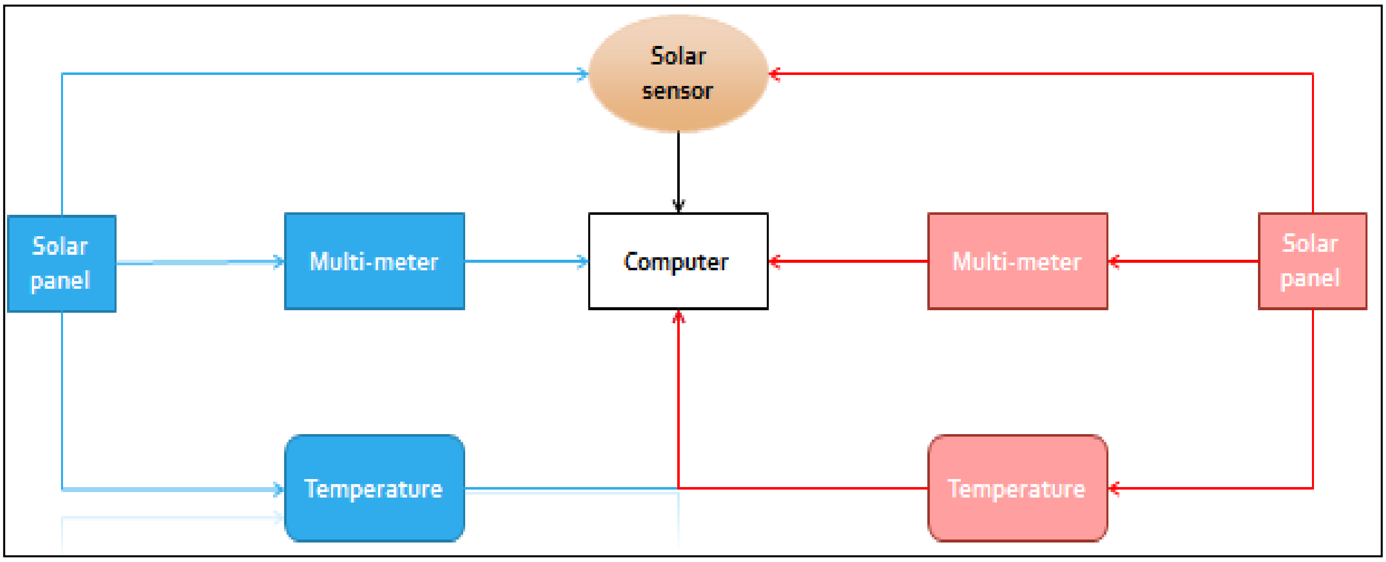
The output of both panels were virtually the same hence no calibration was deemed necessary.

C. Experimental Setup

Panel Specifications:

Maximum Power (Pmax)	20W
Voltage at Pmax (Vmp)	17.5V
Current at Pmax (Imp)	1.14A
Open Circuit Voltage (Voc)	21.6V
Short-circuit Current (Isc)	1.2A
Maximum System Voltage	1000VDC
Area 0.34mx0.34m	

The panels were connected to measuring devices, measuring the temperature, output voltage and output current. A sensor was also used to measure the solar irradiance. The setup of the experiment is as Figure 7.



Panel 1 was labeled with blue colored tape, indicating the panel with back plate cooling method applied and Panel 2 was labeled with red tape, indicating the control experiment, without any back plate cooling method applied.

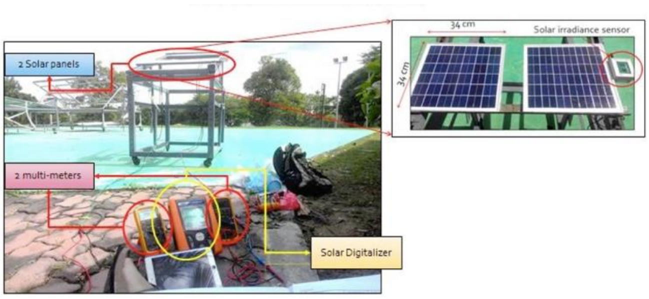


Figure 8: View of the test setup

III. RESULTS AND DISCUSSION

The results of this project were taken from the best two conditions in all of the experiments conducted. This is because the weather in November and December 2016 at Bangi were not consistently shiny. In this study, the cloudy weather will affect the output voltage and output current for both solar panels. The tables below show the reading of all parameters.

Power is calculated using:

$$P = I \times V$$

Efficiency is calculated using:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{I \times V}{E \times A} \times 100$$

where:

$$I = current; V = voltage$$
$$E = solar\ irradiance; A = area\ of\ panels$$

A. Performance of Heat Sink for Back Plate Cooling

Table 2: Parameters collected and calculated for Heat sink cooling method

Time	Solar Radiation	Temperature	Current	Voltage	Power output	Temperature	Current	Voltage	Power output
		Without Heatsink (Control)				With Heatsink			
(Hour)	(W/m2)	(°C)	(Amp)	(V)	(W)	(°C)	(Amp)	(V)	(W)
1105	312	39.4	0.331	4.53	1.4994	39.6	0.331	4.53	1.4994
1110	350	40.3	0.328	4.72	1.5482	33.5	0.328	4.72	1.5482
1115	367	41.8	0.352	4.71	1.6579	40	0.376	4.57	1.7183
1120	380	42.6	0.419	4.93	2.0657	41.9	0.431	4.64	1.9998
1125	630	43.9	0.609	5.76	3.5078	42	0.621	5.76	3.5770
1130	761	47.1	0.713	6.59	4.6987	43	0.691	6.71	4.6366
1135	465	49.2	0.446	5.11	2.2791	46	0.609	5.66	3.4469
1140	468	47.9	0.431	5.14	2.2153	48.6	0.452	5.03	2.2736
1145	542	46.1	0.467	5.12	2.3910	46	0.441	5.06	2.2315
1150	737	47.3	0.768	6.71	5.1533	48	0.784	6.44	5.0490

Table 3: Comparison between control panel and panel with heat sink

Time	Temperature Difference	Power Output Difference	Efficiency Difference
(Hour)	(°C)	(W)	%
1105	-0.2	0.0000	0.0000
1110	6.8	0.0000	0.0000
1115	1.8	0.0604	0.1424
1120	0.7	-0.0658	-0.1499
1125	1.9	0.0691	0.0949
1130	4.1	-0.0621	-0.0705
1135	3.2	1.1679	2.1726
1140	-0.7	0.0582	0.1076
1145	0.1	-0.1596	-0.2547
1150	-0.7	-0.1043	-0.1224

Table 2 shows the readings measured for Case 1, which is the investigation of performance of heat sink for back plate cooling of solar panels. Readings were recorded starting at 11.05 a.m. until 11.50 a.m. Irradiance was relatively low, ranging between 312W/m2 to 761W/m2. Irradiance increases from 11.05 a.m., peaking at 11.30 a.m., decreasing to 468W/m2 at 11.40 a.m. before increasing again to 737W/m2 at 11.50 a.m. Table 3 shows the comparison of the temperature, power output and efficiency difference between the control panel and panel with heat sink cooling method applied. The negative signs indicate degrading performance, meaning that the panel with heat sink either has higher temperature, lower power output or lower efficiency. Positive values mean the panel with heat sink cooling method applied has either lower temperature, higher power output, higher efficiency or all of them.

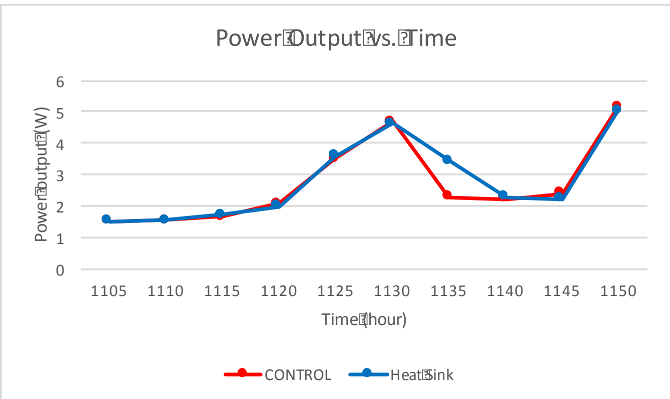


Figure 9: Power output vs. time for heat sink cooling method

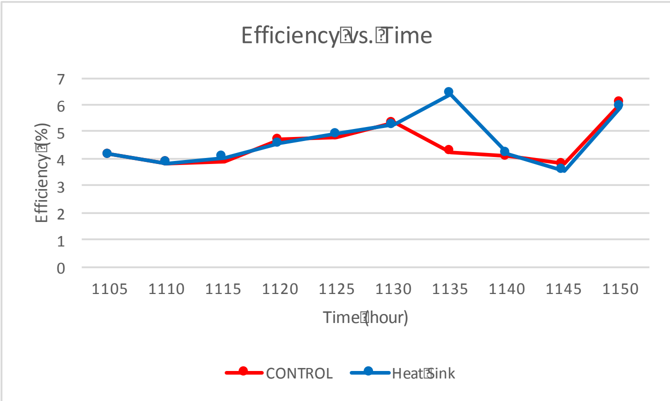


Figure 10: Panel Efficiency vs time for heat sink cooling method

Figure 9 shows the power output against time. Throughout the experiment, the power output for both panels are almost similar, indicating small difference in performance, except 11.35 a.m., where the power out of the panel with heatsink is at 3.4469W compared to 2.2791W for the control solar panel, which is 1.1679W higher. Figure 10 which shows the efficiency against the time, shows a similar trend, and at 11.35 a.m., shows a relatively higher efficiency for the panel with heatsink at 6.4124% compared to the control solar panel at 4.2398%, resulting in a 2.1726% increase. This correlates with the 3.2°C cooler temperature for the panel with heat sink. Although unrecorded, this decrease of temperature can be attributed to the blowing wind, removing the heat absorbed from the solar panel by the heat sink.

B. Performance of PCM (Candle Wax) for Back Plate Cooling

Table 4: Parameters collected and calculated for PCM (candle wax) cooling method

Time	Solar Radiation	Temperature	Current	Voltage	Power output	Temperature	Current	Voltage	Power output
		Without PCM				With PCM			
(Hour)	(W/m2)	(°C)	(Amp)	(V)	(W)	(°C)	(Amp)	(V)	(W)
1152	1600	48.7	1.17	20.12	23.5404	48.6	1.18	20.12	23.7416
1157	1600	49.2	1.16	20.21	23.4436	48.4	1.19	20.17	24.0023
1202	1600	47.3	1.16	20.36	23.6176	46	1.2	20.33	24.396
1207	1601	47.7	1.18	20.44	24.1192	47.2	1.18	20.44	24.1192
1212	1605	47	1.17	19.9	23.283	47	1.2	19.9	23.88
1217	1595	45.6	1.17	20.03	23.4351	45.4	1.17	20.03	23.4351
1222	1604	45.1	1.17	20.57	24.0669	43.1	1.2	20.57	24.684
1227	1602	46.8	1.14	20.4	23.256	46.6	1.16	20.43	23.6988
1232	1598	47.7	1.15	20.39	23.4485	47.3	1.2	20.35	24.42
1237	1590	50.8	1.14	20.07	22.8798	50.3	1.16	20.07	23.2812
1242	1592	50.3	1.15	19.86	22.839	50.3	1.16	19.85	23.026
1247	1597	45.5	1.12	20.16	22.5792	45.3	1.14	20.13	22.9482

Table 5: Comparison between control solar panel and panel with PCM

Time	Temperature Difference	Power Output Difference
(Hour)	(°C)	(W)
1152	0.1	0.2012
1157	0.8	0.5587
1202	1.3	0.7784
1207	0.5	0
1212	0	0.597
1217	0.2	0
1222	2	0.6171
1227	0.2	0.4428
1232	0.4	0.9715
1237	0.5	0.4014
1242	0	0.187
1247	0.2	0.369

Table 4 summarises the data collected and power output calculated for the reference panel and panel cooled with PCM. It is noted that the value of irradiance is irregular as the value is quite high. However, the temperature, current and voltage data is deemed normal. Readings were recorded starting at 11.52 a.m. until 12.47 p.m. Table 5 shows the differences between control solar panel and panel with PCM. It can be seen that the reduction in temperature in the PCM cooled panel resulted in higher power output, within the range of 0 – 0.9715W of increment for a 0 – 2°C temperature reduction. Also, a slight delay can be seen in the effect of temperature reduction to the power output increment. The highest percentage increment of power is 4.143%. Depending on the annual irradiance and cost of electricity, this percentage increment will have effect on the annual electricity generation and income or cost reduction.

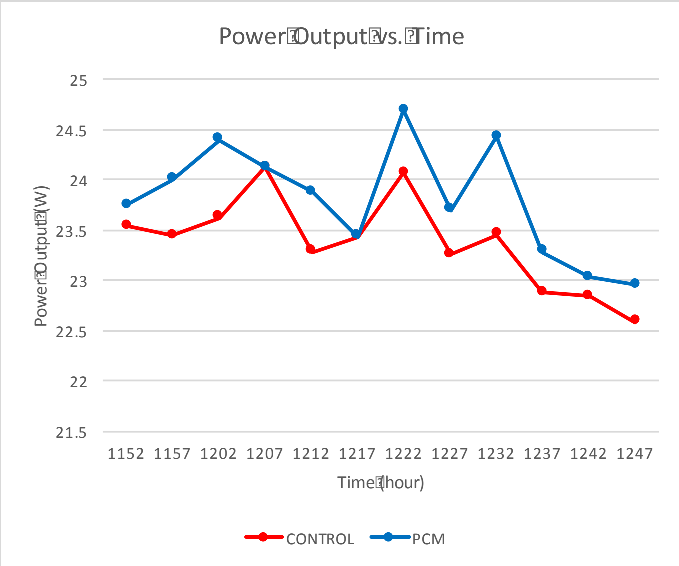


Figure 11: Power output vs. time for PCM cooling method

The power output peaked at 12.22 p.m. for PCM cooled panel and at 12.07 for control solar panel. It can be clearly seen that the power output for PCM cooled panel is higher compared to the control throughout most of the time.

IV.CONCLUSION

From this study, in can be concluded that cooling the panels do increase its power output and efficiency. For the cooling method using heat sink, the effect will depend on the removal of heat following the absorption from the panel. Failure to do so results in increase of temperature of the panel, producing lower power output and lower efficiency. For the panel with candle wax as PCM applied, improvement is shown in terms of power output and efficiency, as high as 4.143% of power increment.

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