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EXPERIMENTAL INVESTIGATION OF PV PANEL PERFORMANCE BY USING PCM WITH DIFFERENT FIN GEOMETRIES

Summary

During the photovoltaic (PV) conversion process, a significant amount of solar radiation is converted into heat, which increases the cell's temperature and reduces its efficiency. A system consisting of PCM and aluminium fins was developed to minimise power loss due to temperature increments. Using PCM as heat absorbers in this study, heat from photovoltaic panels was transferred more efficiently with aluminium fins. The PV panel temperature is regulated by this method in hot climates as a passive cooling method. To regulate the surface temperature of PV panels, RT28HC was used as PCM. The reference PV panel was compared with a container-integrated PV panel with PCM and flat aluminium fins and a container-integrated PV panel with PCM and perforated aluminium fins to regulate the temperature of the PV cells and improve the efficiency of the panels. In the laboratory, with an initial ambient temperature of 20 °C, an experiment was conducted for 60 minutes. The results of the experiment show that the average surface temperature of the PV panel decreased by 8.32 °C from 49.24 °C to 40.92 °C with flat fins and by 8.55 °C from 49.24 °C to 40.69 °C with perforated fins. The maximum electric power generation by the PV panels increased by 7.43 % compared to the usual PV panels from 1.48 W to 1.59 W with flat fins and by 9.46 % from 1.48 W to 1.62 W with perforated fins as the surface temperature of the PV panels decreased. The surface temperature and generated current, voltage, and power of the uncooled and cooled PV panels are plotted over time in this study.

Key words: *Phase change material (PCM), thermal management, aluminium fin, PV panel*

1. Introduction

As global temperatures rise and fossil fuels diminish, renewable energy sources are becoming increasingly popular. A number of solar energy developments have taken place over the past few years. Due to the clean nature and free availability of solar energy, photovoltaic modules are becoming increasingly common for producing electricity. In recent years, the cost of photovoltaic (PV) systems has decreased significantly, making the electrical energy supplied by PV systems competitive with traditional sources. As solar radiation enters the PV panel, some of it is absorbed by the semiconductor material at the back of the panel, which creates an electric current. Unabsorbed portions of incoming radiation are reflected back by the cell's surface. The temperature plays a significant role in the performance of a photovoltaic panel. The efficiency of a PV panel decreases as the operating temperature rises. A rise in temperature causes the silicone cells to be less able to generate electrical power. A PV module's conversion efficiency is typically limited to 5 %−20 % [1]. PV panel efficiency is therefore affected by factors such as the weather conditions, the class of solar cell, the cleaning of the cells, etc. There is only partial conversion of sunlight into energy on the panel, while the rest is dispersed as heat. It follows that temperature increases cause a decrease in the efficiency of solar cells and damage to the solar panel [2]. This leads to lower PV panel efficiency in hot climates. In this situation, it is necessary to regulate the temperature of the PV panel. In order to do this, active and passive cooling methods have been proposed. Use of electricity as a heat reduction method is one of the active methods. A passive method is usually used to reduce the solar panel's temperature in industrial applications. Not only do passive methods consume less energy than active methods, but they also require less maintenance. There are three different kinds of PCMs: organic, inorganic, and eutectic. A paraffin or non-paraffin-based material is organic, inorganic material is made up of hydrated salts or metals, and a eutectic material is a mixture of at least two materials. Paraffin, which is an organic PCM material, shows more advantages, such as resistance to chemical degradation and temperature regulation. It is therefore not surprising that paraffin plays a key role in electronic thermal management.

Several studies have attempted to reduce the impact of high temperatures on PV efficiency. Using experimental methodology, this study examined the thermal performance of a solar air heater and found that the counterflow passage configuration provided the best thermal performance [3]. According to the research in [4], on polymer solar collectors and thermal performance, single cover plate collectors are more efficient than honeycomb cover plate collectors at lower reduced temperatures. A study by [5] evaluated the effects of PCM in finned graphite containers and found that when 920 W/m^2 of irradiation was used, PV module efficiency increased by 12.97 %. According to [6], the phase-changing material in the composite was paraffin filled with a copper foam matrix. Using copper matrixes in PCMs not only gives a more uniform temperature distribution, but also results in a lower charge time. PCM was also used by [7] where a PV module was cooled between 29 °C and 33 °C when solar radiation was 600 and 800 W/m^2. During the experiment, the average temperature decreased by 2.7 °C and output power increased by 3 %. The authors in [8] cooled the PV modules with different PCMs. It was concluded that the PCM melting point had to be near that of the typical operating temperature of PVs. The PCM was not recommended if its melting point was too low. Using nanofluids (ZnO and CuO) in a heat pipe, thermal efficiency was examined from various tilt angles [9]. Based on the results, a heat pipe tilted at 60° generates superior results. Various fin configurations were examined by [10] in order to improve heat transfer. Two PCMs used in combination with internal fin arrangements were evaluated in [11]. The shape-stabilised PCMs were prepared by impregnating aluminium foam containing stearic acid and paraffin in [12]. PCMs with stabilised shapes were investigated for their thermal properties. The PCM box cooled the surface temperature from 43.4 °C to 34.5 °C degrees, while the ambient temperature ranged from 16 °C to 24 °C, and an increase occurred in PV module efficiency from 18.1 % to 19 % in [13]. It was observed that the operating temperature of PV panels was influenced by wind speed, the tilt angle of the PV panel, and the convection of the PCM in [14]. Under conditions of wind speed of 4 m/s, 3 m/s, and 2 m/s, the temperature upper limit for operation is 52.32 °C, 53.53 °C, and 55.31 °C, respectively. Operating temperatures reach 54.32 °C, 54.88 °C, and 55.81 °C for tilt angles of 30°, 45°, and 60°, respectively. An analysis of passive cooling using PCMs which have a melting point of 20 °C, 25 °C, and 28 °C was performed by [15]. At 30 °C to 40 °C ambient temperature and 750 W/m^2 solar irradiation, module efficiency was enhanced by 5 %. In [16], heat transfer was investigated for three types of PCM boxes. The boxes included smooth tubes and sequent and gradual finned tubes. Heat transfer was found to be most effective when using staggered finned tubes in the PCM box. As a result of making use of paraffin wax for cooling the PV module surface, the authors in [17] found that module efficiency could be increased by 5.18 % by reducing the surface temperature by 23 °C. A method for reducing PV temperature was reported by [18] using Rubitherm 28 (RT-28). Under almost 900 W/m^2 solar irradiation and combined with a 25 °C ambient temperature, they managed to reduce the temperature by 4.7 °C and improve the output power by 7.28 %. Malvi CS et al. [19] reported techniques for enhancing heat transfer by using fins. Maria in [20] discusses a hybrid PV/T/PCM system using the PCM where the PCM is found to be the most effective method of removing heat from PV modules in the experimental results. Polyethylene glycol 1000 (PEG 1000) with a melting point of 30–40 °C was used by [21] to cool PV modules. The PV module temperature fell from 62 °C to 47 °C, resulting in an 8 % increase in efficiency. In [22], the two boxes contain PCM (RT-30) and water tubes, which are used to cool PV modules. In the case of the boxes containing only water or water and PCM, maximum temperatures were reduced by 47 % and 53 %, respectively, as were the efficiencies of the PV modules by 10.66 % and 12.6 %. Finned PCM containers for PV module cooling were able to reduce the temperature by up to 6.1 °C and improve conversion efficiency by up to 4.86 %, according to [23]. A container filled with Rubitherm (RT-42) reduced the PV temperature by 3.8 °C at a 15 °C ambient temperature and a light intensity of 1000 W/m^2, and module efficiency was 7.7 % higher [24]. The simulation by [25] shows the effect of PCM on vertical internal fins at a certain temperature. An analysis was presented by [26] of a PV cell with and without PCM by using numerical simulations. According to the results, PV efficiency improved by 6 %. An experiment conducted by [27] demonstrated a 14 % improvement in system efficiency when a PCM layer is incorporated into a Photovoltaic/Thermal panel system. In addition, according to [28], six different models were used to calculate the monthly average value of daily solar radiation in the city where our study was conducted.

Thermal and electrical performance between the PV/PCM with aluminium fin containers and reference PV performance are compared and the obtained experimental data are analysed and presented in this study. Finned structures were filled with RT28HC PCM for passive cooling. While the average PV panel surface temperature decreased by 12.2 °C with the flat fin structure, it fell by 13.3 °C with the perforated fin structure. In addition, current, voltage, and power analyses were made for both uncooled and cooled PV. Among these electrical properties, the generated power increased by 7.43 % with the flat fin structure and 9.46 % with the perforated fin structure compared to the uncooled PV panel.

2. Method and materials

An organic PCM known as RT28HC is used in this work. In addition to being noncorrosive, this PCM can store a great deal of specific heat of solidification (250 kJ/kg). The PCM is filled in finned containers which are mounted on the back surface of a PV module. The container is made of aluminium and has high thermal conductivity. There are two types of containers, and in the first model, which is defined as MODULE A, the aluminium has a flat geometry, while in the second model, which is defined as MODULE B, it has a perforated geometry in the experimental setup. The PV module consists of (36 cm x 42 cm) mono-crystalline silicon cells and the specification of the PV cells is listed in Table 1. The finned containers are made of aluminium sheets with a thickness of 1 cm as referred to in [29]. A container made of aluminium with internal dimensions of (31 cm x 31 cm x 5 cm) is attached to the back of this panel. During the operation of the PV panel, waste heat accumulates at the back and is transmitted to the modules to absorb it. Fig. 1A shows the inner configuration and schematic view of the fin geometry of the MODULE A container and Fig. 1B shows the inner configuration and schematic view of the fin geometry of the MODULE B container. In this study on the PCM-containing fin structures of passive cooling PV panels, a new finned structure was designed to increase the heat transfer from the PV panels. This designed structure was obtained by drilling holes from the surface of the fins. The designed perforated fin structure aims to increase the heat transfer by increasing the mobility of the PCM within the finned structure. The experimental results of the flat and perforated fins with the temperature change and the increase in the power change of the panel were evaluated and it was found that the perforated fin structure had the advantage. Staggered hole geometry was chosen to gain better mobility of the PCM and heat transfer for the perforated fin (Module B). During the phase change from solid to liquid, the melted PCM moves towards the bottom of the container. When the PCM changes from liquid to solid, the PCM accumulates at the bottom of the container and the container surface may be damaged due to the solidification effect. By more frequently placing fins at the bottom of the container, potential damage can be prevented. The solid and liquid state of the PCM filled into the containers is shown in Fig. 2, and its physical and thermal properties are listed in Table 2. The PCM was filled into both containers at the same volume of 2100 cm^3.

Table 1 Specification of PV cell mono-crystalline

Property	**Value**
Peak power	25 W
Open circuit voltage (U_{oc})	24.62 V
Short circuit current (I_{sc})	1.28 A
Max. power voltage (U_{mp})	20.84 V
Max. power current (I_{mp})	1.23 A
Dimensions	360x420x20 mm
Mass	2 kg
Operating temperature	-40 ˚C - +85 ˚C

Fig. 1A

Fig. 1B

Fig. 1A Container with flat aluminium fins and schematic view of MODULE A. **Fig. 1B.** Container with perforated aluminium fins and schematic view of MODULE B

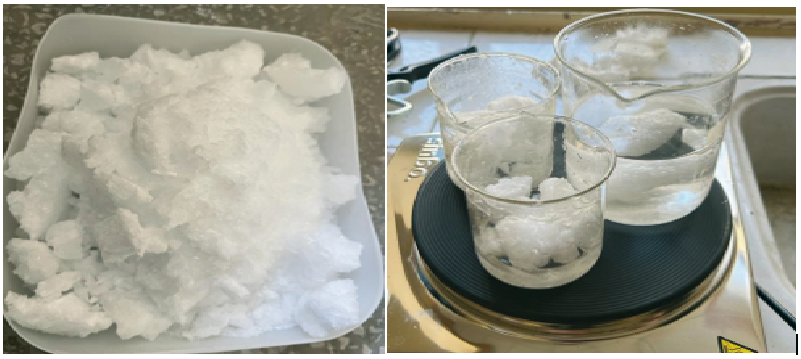

Fig. 2 The solid and liquid state of the PCM

Table 2 Characteristics of PCM material RT28HC

Property	**Value**
Melting / solidification temperature	27 - 29 °C
Specific heat of solidification	250 kJ kg^{-1}
Specific heat capacity	2 kJ kg^{-1}K^{-1}
Solid phase density	880 kg m^{-3}
Liquid phase density	770 kg m^{-3}
Thermal conductivity	0.2 W m^{-1} K^{-1}
Flash point of PCM	165 °C

3. Experimental setup

To avoid environmental factors such as wind speed and tilt angle, during the tests constant irradiance (600 W/m^2) was maintained indoors to demonstrate how the outcome changes. Contrary to many studies, two 120W LED projectors were used instead of halogen lamps as a radiation source. In tests using a halogen lamp, it has been observed that this lamp overheats and transmits the heat quickly to the PV panel. Thus, the surface temperature of the PV panel reaches the upper limit of operating conditions very quickly (the operating temperature range within the scope of PV panel label values is -40 to +85 °C). In the experiments performed with a halogen lamp, according to observations, there was no change in the phase state of the PCM during the first 10 minutes of the experiment. The reason for this is thought to be because the heat required for the phase change for the PCM was not reached during this time. Instead of halogen lamps, LED projectors were used as a light source because there is no sudden heating with LED projectors. Table 3 shows the results of the PV panel surface temperature tests performed under both the halogen lamp and LED projector within the first 10 minutes. As can be understood from these values, the use of halogen lamps as a light source causes a sudden increase in the surface temperature of the PV panel, and since the effects of this sudden increase on the PV panel surface are not at an acceptable level, the LED projector is preferred. One module used as a reference throughout the experiment was uncooled. PCM/finned containers were attached to the back surfaces of the other modules for cooling. A Mastech SM206 sensor was chosen to measure the light intensity and K-type thermocouples to measure the surface temperatures of the PV modules. A 22-ohm load resistor was employed to measure voltage and current values. A one-hour test was conducted with data being recorded every minute. Using an Agilent 349070A data logger, all the temperature and electrical data were logged and transferred to a computer. Finally, the output power can be determined by Eq. (1). The experimental setup is depicted in Fig. 3.

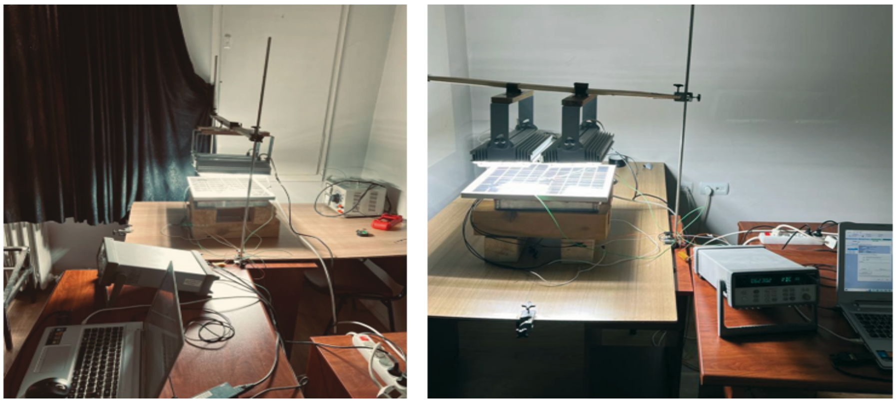

Fig. 3 Image of the experimental setup

$$P = UI \tag{1}$$

Table 3 PV panel surface temperature tests performed under both a halogen lamp and LED projector.

Time, min	Halogen lamp, °C	LED projector, °C
1	20.38	19.90
2	27.68	24.64
3	32.26	26.97
4	41.30	28.84
5	45.03	30.37
6	51.58	31.83
7	59.09	33.17
8	63.76	35.38
9	66.67	36.50
10	72.95	37.52

4. Result and discussion

4.1 PV thermal regulation

PV panel efficiency is affected by the surface temperature of the panels. A thermal regulator PCM was added to the containers to improve the performance and efficiency of the panel. In order to overcome the PCM's poor thermal conductivity, aluminium fins were attached to the containers as a means of enhancing thermal conduction. In both cooled and uncooled conditions, three PV modules were monitored for their temperatures. During cooling, PCM RT28HC absorbed heat and changed from a solid to liquid state as it absorbed heat in the finned container. Using phase change materials and aluminium fins with flat and perforated surfaces, the aim of the current experiments was to study PV temperature regulation. Adding PCM to the PV modules resulted in the absorption of heat stored and transferred from the PV module, thus lowering its temperature. At the end of the test, the PV module, MODULE A, and MODULE B reached 59.3 °C, 47.1 °C, and 46 °C, respectively. In modules A and B, the temperature profiles were similar to those of the PV reference module illustrated in Figure 4. Figure 5 shows the differences between the PV-PCM with the aluminium fin modules and the reference PCM module in terms of the reduction of the module temperature. The PV panel maximum temperature decreased by 12.2 °C from 59.3 °C to 47.1 °C with MODULE A, and by 13.3 °C from 59.3 °C to 46 °C with MODULE B. Furthermore, Fig. 6 demonstrates the fall of the PV panel surface temperature for MODULE A and MODULE B.

4.2 PV output power

We examined the PV module performance with and without cooling during an hour-long experiment. Graphs were created based on the recorded electrical output powers. Table 4 illustrates the variations of the maximum current generated I_{mp}, the maximum voltage generated U_{mp}, and the maxximum power generated P_{max} with the temperature on the non-cooling panels and the cooling-based panels. The temperature or time-dependent changes in I_{mp} and V_{mp} for the cooled and uncooled PV panel are shown in Fig. 7 and Fig. 8, where the maximum generated power decreased as a result. A comparison of the output powers for the different modules can be found in Fig. 9. According to the electrical tests, the maximum power generation from the PV panels increased by 7.43 % and 9.46 % for the modules compared to the non-cooled PV panel, respectively.

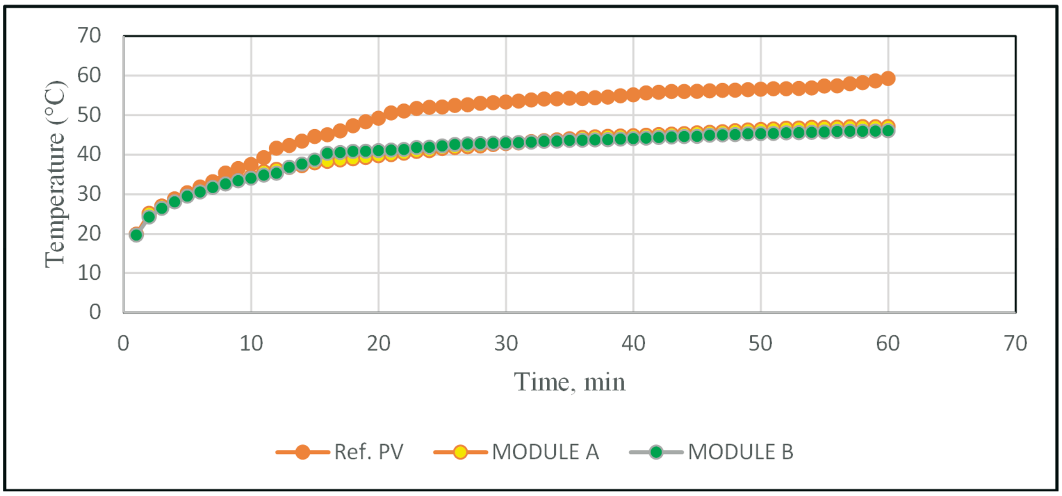

Fig. 4 Average temperature at the surface of the reference PV and the modules

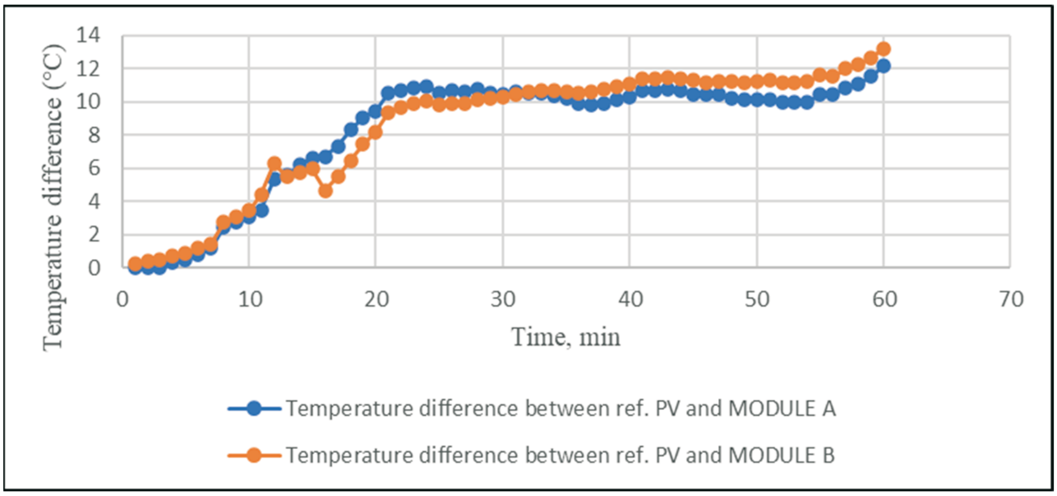

Fig. 5 Temperatures differences between the reference PV and the modules

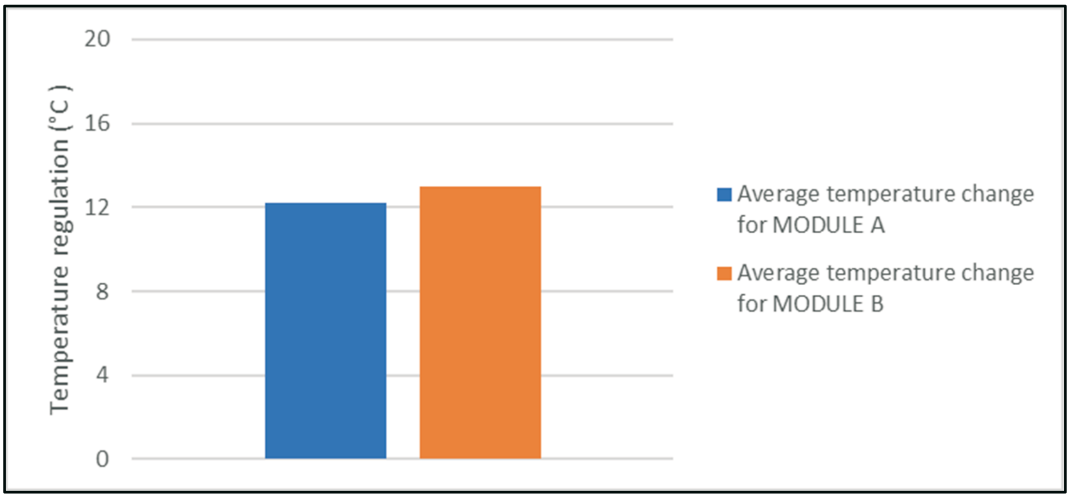

Fig. 6 Average temperature change for MODULE A and MODULE B

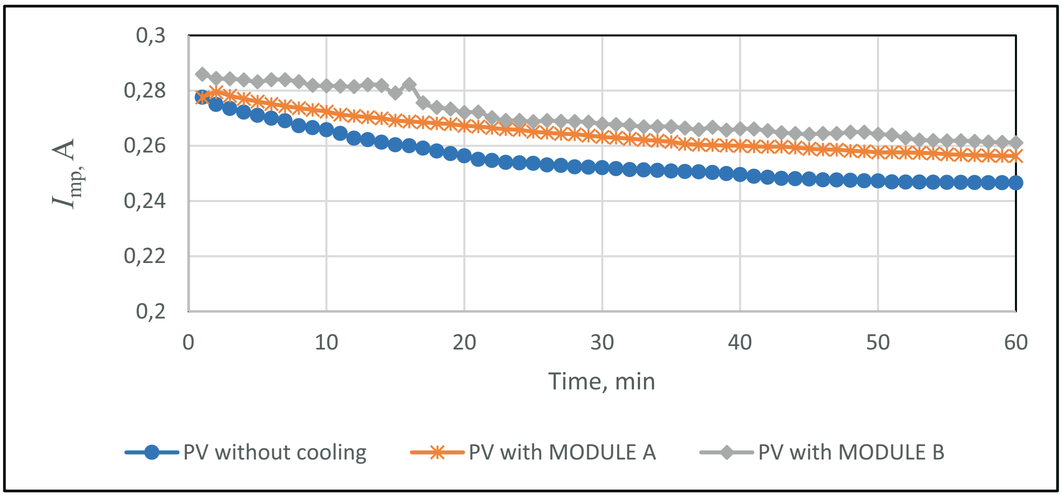

Fig. 7 Effect of using cooling and non-cooling on I_{mp} of the PV panel

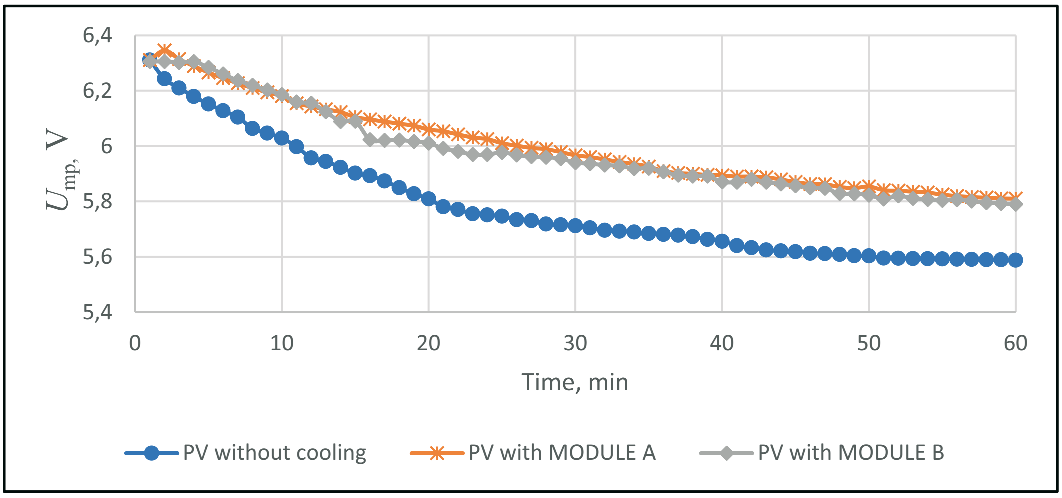

Fig. 8 Effect of using cooling and non-cooling on U_{mp} of the PV panel

Table 4 Overall comparison of uncooled and cooled PV panels

Time, min	PV without cooling			PV cooled with MODULE A			PV cooled with MODULE B		
	I_{mp}, A	U_{mp}, V	P_{max}, W	I_{mp}, A	U_{mp}, V	P_{max}, W	I_{mp}, A	U_{mp}, V	P_{max}, W
1	0.2776	6.3110	1.7519	0.2776	6.3110	1.7519	0.2859	6.3054	1.8027
2	0.2750	6.2434	1.7166	0.2794	6.3454	1.7731	0.2844	6.3057	1.7934
4	0.2722	6.1790	1.6819	0.2770	6.2886	1.7422	0.2839	6.3050	1.7898
6	0.2700	6.1275	1.6544	0.2752	6.2453	1.7186	0.2840	6.2604	1.7777
8	0.2673	6.0636	1.6207	0.2737	6.2099	1.6996	0.2832	6.2194	1.7615
10	0.2658	6.0286	1.6024	0.2724	6.1800	1.6835	0.2818	6.1857	1.7429
12	0.2627	5.9569	1.5650	0.2708	6.1432	1.6639	0.2814	6.1547	1.7321
14	0.2613	5.9230	1.5475	0.2700	6.1229	1.6530	0.2818	6.0890	1.7161
16	0.2600	5.8929	1.5320	0.2688	6.0961	1.6389	0.2822	6.0232	1.6998
18	0.2581	5.8498	1.5098	0.2682	6.0809	1.6307	0.2739	6.0220	1.6496
20	0.2564	5.8093	1.4892	0.2673	6.0600	1.6197	0.2721	6.0110	1.6355
22	0.2547	5.7708	1.4695	0.2665	6.0422	1.6103	0.2702	5.9812	1.6160
24	0.2538	5.7516	1.4599	0.2658	6.0255	1.6015	0.2692	5.9696	1.6071
26	0.2530	5.7341	1.4510	0.2648	6.0018	1.5890	0.2691	5.9678	1.6062
28	0.2524	5.7186	1.4431	0.2642	5.9891	1.5823	0.2688	5.9599	1.6020
30	0.2521	5.7122	1.4399	0.2632	5.9669	1.5707	0.2679	5.9405	1.5916
32	0.2513	5.6958	1.4316	0.2626	5.9519	1.5628	0.2675	5.9314	1.5867
34	0.2511	5.6896	1.4285	0.2618	5.9354	1.5541	0.2670	5.9191	1.5802
36	0.2507	5.6808	1.4241	0.2607	5.9097	1.5408	0.2664	5.9073	1.5739
38	0.2503	5.6728	1.4201	0.2603	5.8997	1.5355	0.2668	5.8919	1.5717
40	0.2496	5.6560	1.4117	0.2600	5.8941	1.5327	0.2661	5.8712	1.5626
42	0.2486	5.6328	1.4001	0.2597	5.8903	1.5295	0.2655	5.8802	1.5614
44	0.2481	5.6215	1.3945	0.2594	5.8796	1.5251	0.2645	5.8636	1.5507
46	0.2477	5.6129	1.3902	0.2587	5.8632	1.5166	0.2645	5.8501	1.5473
48	0.2475	5.6088	1.3881	0.2582	5.8527	1.5111	0.2649	5.8289	1.5442
50	0.2473	5.6035	1.3855	0.2576	5.8540	1.5081	0.2642	5.8232	1.5384
52	0.2469	5.5947	1.3812	0.2576	5.8387	1.5040	0.2629	5.8205	1.5301
54	0.2468	5.5931	1.3804	0.2573	5.8324	1.5007	0.2619	5.8074	1.5212
56	0.2467	5.5914	1.3795	0.2567	5.8196	1.4942	0.2619	5.8062	1.5206
58	0.2466	5.5898	1.3787	0.2565	5.8136	1.4911	0.2614	5.7959	1.5151
60	0.2466	5.5880	1.3779	0.2563	5.8106	1.4895	0.2611	5.7899	1.5119

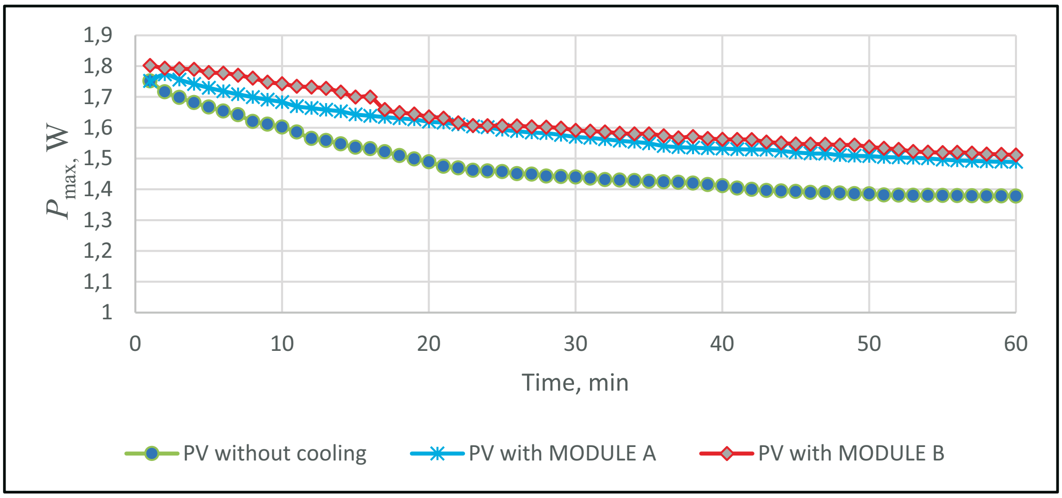

Fig. 9 Effect of using cooling and non-cooling on P_{max} of the PV panel

5. CONCLUSION

The aim of this study was to improve PV power generation by using aluminium fins and PCM to achieve passive cooling. In designed MODULE A and MODULE B containers, the passive cooling of PV modules with RT28HC was investigated. The PV modules were equipped with flat and perforated finned boxes containing RT28HC as the PCM. The conclusions of the study can be summarised as follows:

1. The heat from photovoltaic panels can be absorbed using PCM. When the PV panels are located in hot climate regions, this method acts as a passive cooling method. Due to the disadvantage of the PCM's low thermal conductivity, beside the specific heat of the solidification of the PCM, aluminium fins inside the PCM enhance the heat transfer.
2. It was shown that PCM with aluminium fins can reduce the panel temperatures compared to the non-cooled PV panel by 12.2 °C and 13.3 °C with MODULE A and MODULE B, respectively.
3. In addition, according to the electrical test results, maximum power generation from the PV panels increased by 7.43 % and 9.46 % for the modules compared to the non-cooled PV panel, respectively. It was found that the surface temperature of the PV panel cooled by MODULE A was 12.2 °C lower than the surface temperature of the uncooled PV panel. When the PV panel cooled with MODULE B was compared to the uncooled PV panel, the decrease in the surface temperature was determined to be 13.3 °C. These results show that the best cooling improvement for solar panels is provided by MODULE B.

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