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Experimental Study to Improve Solar Photovoltaic Performance by Utilizing PCM and Finned Wall

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ABSTRACT

The temperature of a photovoltaic (PV) module has a significant impact on the module's ability to produce electricity. PV cells module’s passive cooling is critical for increasing electrical efficiency and power output. In this work, two scenarios of the passive cooling technique were presented for use in the cooling of the monocrystalline silicon PV modules. An aluminium finned wall and a combination of aluminium finned wall with phase change material were connected to the backside of the PV in order to bring the working temperature down and maintain it under the hot climate conditions in southern Iraq. Paraffin wax was employed as a PCM placed into an aluminium container with internal and exterior longitudinal aluminium fins in order to enhance the PCM's poor thermal conductivity, speed up the rates at which it melts and solidifies, and increase the amount of heat that is dissipated through free convection heat transfer. The PV modules were simultaneously tested and compared with a PV reference module under different solar radiation. According to the findings, the average temperature of the PV-Aluminium Finned wall-PCM module is reduced by 19.9 degrees Celsius when compared with the temperature of the reference PV module. This results in an increase in the average maximum output power of up to 23.1% compared to an identical reference PV module. Furthermore, the average electrical efficiency of the PV-Aluminium Finned wall-PCM is enhanced by 23.2% during the testing time from 9:00 AM to 12:00 PM in July 2022 at maximum solar radiation of 1130.7 W/m^2 when compared with the PV reference module under the same conditions. This indicates a significant increase in both electrical and thermal performance. The testing took place in July 2022.

Keywords:
Photovoltaic panel cooling; phase change material; passive cooling; electrical efficiency; heat transfer; fins

1. Introduction

Energy is one of the basic requirements that humans need and one of the most basic factors for life and its continuity. One of the most important sources of traditional energy is fossil fuels, which recently constitute nearly three-quarters of the world’s energy [1]. The depletion of this fuel will eventually end, in addition to the carbon dioxide emissions resulting from burning fossil fuels, which are directly responsible for climate change. In addition to its negative impact on the environment

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and global warming [2]. The Photovoltaic (PV) system is one of the fastest expanding power systems on the planet today. PV cells is a method of generating electrical energy by converting solar radiation into direct electricity using semiconductors that carry the photovoltaic effect [3]. PV cells are undergoing great and rapid development in their design and capability in converting the solar intensity to useful power energy, so photovoltaics is one of the best ways to generate electrical energy by using solar cells. Therefore, PV modules are a good source for producing clean electricity where the solar radiation conversion efficiency ranges from 5% to 20% depending on the cell type [4]. The performance of the PV solar system is impacted by a wide variety of elements, including the surrounding temperature, wind speed, dust, and humidity levels [5]. Cooling a PV module can lower the cost of solar energy whenever the electrical efficiency of PV cells goes up as the temperature goes down. Cooling panels also keeps PV cells from reaching temperatures that do permanent damage [6]. Several cooling techniques have been attempted, such as using finned wall, water cooling, and phase-changing material, because they are the simplest passive cooling techniques. Rahul *et al.,* [7] showed that the use of water and air-cooling systems in conjunction with a PV solar panel improved both the power production and the efficiency of the system. Hasan *et al.,* [8] suggested a kind of PCM is yellow petroleum jelly. The performance of the system under Indonesia climate is studied. They found an increase in the yield of cells from 8.3% to 10.1%. Al-Waeli *et al.*, [9] performed a mathematical analysis of the heat transfer in a PV/T system. This system's cooling circuit is comprised of a variety of nanoparticles that have been combined with a variety of base fluids. The findings showed that an increase in heat transfer occurs when nano-Sic rather than nano-alumina or nano-CuO is introduced to the base fluids. Experiments were conducted by Duaa and Ammar [10] to improve the performance of PV modules by using aluminium foam fins that were attached to the back of the PV module. By adding 10 longitudinal fins, the power output was able to be enhanced by about 4.9%, and the surface temperature was able to be lowered by approximately 8.4%. Sharma (2015) *et al.,* [11] conducted experimental research to use PCM for the thermal regulation of PV systems. The PV module centre combined with PCM confinement was able to produce a decrease in the average temperature of 3.8 °C when compared to the system that did not use PCM. The relative electrical efficiency increased by 1.15% at 500 W/m^2, 4.20% at 750 W/m^2, and 6.80% at 1200 W/m^2. Kumar (2016) *et al.*, [12] examined a transient distribution of temperature and heat transfer for each PV/T solar system layer that was cooled by forced air. This was accomplished by constructing a comprehensive numerical model using the CFD methodology. It is anticipated that the decrease in the electrical efficiency of PV modules without cooling may be as high as 1.3% at higher levels of solar radiation and as low as 0.3% at lower levels of solar radiation.

A passive cooling mechanism was presented by Agyekum *et al.*, [13] as a method for the cooling of a photovoltaic panel. The suggested cooling system consists of aluminium fins and paraffin wax incorporated at the PV module's backside. The findings stated that the average temperature for the cooled panel during the course of the experiment is 36.62 °C, compared to 48.75 °C for the referenced PV module. This results in a decrease in temperature by an average of 12.13 °C for the cooled panel. In addition, the mentioned module has an average power output of 10.95 W, while the cooled panel has an average power output of 12.19 W, representing an increase of 11.33%. On the other hand, the electrical efficiencies for the cooled panel and the referenced modules are respectively 14.30% and 13.60%, showing an increase in electrical efficiency of 5.15%. A computational and experimental investigation on the backside convective cooling of PV modules was carried out by Nizetic *et al.,* [14]. The study's findings showed that the unique convective profiles of the modules significantly affect the rate of electrical efficiency deterioration of the panel, which is estimated to be between 2.5% and 4.5%. Agyekum *et al.*, [15] cooled a photovoltaic module using a combination of active and passive cooling approaches. For the purpose of cooling the PV module, they made use of both aluminium fins and an ultrasonic humidifier. According to the findings of their investigation, the strategy that they have recommended has the potential to bring the average temperature of the panel down by 14.61 °C. Chen *et al.*, [16] conducted an experiment to investigate the effect that U- and L-shaped fins have on the electrical performance of a PV system when it is exposed to natural airflow. According to the findings of their research, the cooled PV module achieved an electrical efficiency that was between 0.3 and 1.8% greater than that of the PV module that was used as a reference. Additionally, Nada *et al.,* [17] investigated the idea of using PCM to manage the PV modules in order to improve the efficiency of the system. They evaluated four distinct modules: building integrated, free standing, Al nanoparticles-enhanced PCM integrated, and PCM integrated experimentally. The building integrated module was shown to be the most effective. According to the findings of their research, the incorporation of the nanoparticles into the PCM resulted in a temperature drop of the PV module to 59 °C. Hudisteanu *et al.*, [18] conducted a numerical study to investigate the viability of non-perforated and perforated six-fin types as passive heat sinks when positioned horizontally and vertically on the back of the PV module. The numerical CFD study has taken into account the speed of the wind, the average temperature of the surrounding air, the amount of solar radiation, and the convective heat transfer coefficient on both the front and the back of the PV module. According to the findings, there was a significant heat sink impact when the air velocity was 1 m/s, the solar radiation was 1000 W/m^2, and the ambient temperature was 35 °C. In this scenario, an increase in power output of 6.49% was reached in the best-case scenario. Hasan [19] conducted an experiment to study how the temperature of a PV module dropped as a result of heat dissipation, and he did it by observing what happened when rectangular fins with varying cross-sections were attached to the back of the panel. When compared to a different PV that did not have fins, the experimentally adjusted model of the PV was analysed using a thermal model so that the temperature fluctuation could be predicted. The results demonstrated a significant reduction in average PV temperature of 5.7 °C by the use of fins, which resulted in an increase in PV power production of around 15.3%. Experiments conducted by Adibpour *et al.,* [20] in Melbourne, Australia, compared the performance of a tracking photovoltaic (PV) module equipped with a power conditioning module (PCM) to the performance of a stationary PV module serving as a reference. According to the findings, the PCM was successful in lowering the temperature of the tracking PV module by an average of 9.1 °C. This resulted in a maximum temperature differential of 16.3 °C between the modified and reference modules. In addition, in comparison to the reference module, the efficiency of the tracking PV module equipped with PCM attained a maximum of 6.8% of its potential efficiency. A modified photovoltaic (PV) panel with a phase change material (PCM) chamber and a natural water-cooling system was tested by Sudhakar *et al.*, [21] under four different scenarios of water flow (bottom to top and vice versa) to improve temperature management while taking into consideration a number of electrical and thermal indicators. The results of the experiments showed that the suggested method was successful in improving the performance of the PV system. The scenario known as "top to bottom continuous water flow" achieved the greatest average amount of power production by 11.92%. In addition, the electrical efficiency increased by 12.4%, the power increased by 13.54%, the average temperature decreased by 5.4 °C, the highest total exergy output increased by 26.07%, and the exergy efficiency increased by 8.08% in comparison with the PV module that was used as the reference. Al Hariri *et al.*, [22] investigated the electrical and thermal performance of a photovoltaic thermal collector using forced convective cooling using a phase change material (paraffin) plus steel foam combination and two distinct angularly positioned finned heat sink attachments. The fins are arranged in a flat and inclined configuration, and a fan was used to push air to flow between them. The findings indicate that the incline and flat finned heat sink connected collectors dissipated a considerably greater amount of heat than the solar module. When compared to the electrical efficiency of the solar module, which is 4.38%, the electrical efficiency of the incline finned and flat finned heat sink application achieved around 5.09% and 6.18% improvement, respectively. The total efficiencies came in at 41.4% and 59.53% respectively. Maghrabie *et al.*, [23] conducted an experiment in which they cooled a photovoltaic (PV) panel by attaching a phase change material (PCM) consisting of paraffin wax RT-42 to the rear surface of the PV panel. Two identical PV panels with a maximum electrical produced power of 40 W are used for outdoor experiments: a reference PV panel (PV_r) and one integrated with PCM (PV-PCM). PCM thicknesses of 1, 2, and 3 cm are used to tilt PV panels at 15°, 20°, 25°, and 30° in the present implementation. Findings show that at a 15° tilt, the top side of the panel is 17.1%, 15.7%, and 13.2% hotter than the bottom side for PCM thicknesses of 1, 2, and 3 cm, respectively. In a same vein, increasing the tilt angle of the PV-PCM from 15° to 30° results in a 7.4% increase in the electrical efficiency of the system when the PCM layer is 3 cm thick. At a tilt angle of 30°, utilizing PCM with a thickness of 3 cm results in an increase in the electrical efficiency of the PV-PCM panel that is 14.4% higher than the efficiency of the PV_r panel. Ekiz *et al.*, [24] studied the influence of the fin surface on the electrical performance of passively cooled photovoltaic (PV) modules equipped with flat (PV_f) and tread (PV_t) surface finned heat sinks. Mean values for the experiment's environment (ambient temperature), solar radiation, and solar power were around 13 °C, 864 W/m^2, and 247 W. Both the PV_f and PV_t modules produced 10.84% and 17.2% more electricity than the PV module, while the average temperature dropped by 11.78% and 16.5%, respectively. In terms of cooling efficiency, the PV_t module was 5.37% better than the PV_f module, and the electrical power it generated was 5.74% greater. Power conversion efficiency for PV modules was 11.35%, with PV_f modules increasing at a rate of 1.21% and PV_t modules increasing at a rate of 1.95% due to cooling. Alktranee *et al.,* [25] contrasted passive cooling with active cooling using cotton wicks integrated with rectangular aluminium fins (CWIRAFs) immersed in water. Evaporative cooling and wet cotton bristles combined with CWIRAFs improve PV module performance over active cooling. CWIRAFs with the PV module lowered temperature by 31.4%, boosted power by 66.6%, and enhanced electrical efficiency from 3.12 to 8.6%. Active cooling has decreased PV temperature by 20.8%, boosted power by 56.7%, and improved electrical efficiency by 7.9%. Circulating water removes surplus heat from the PV module's backside, increasing the PVT system's thermal efficiency by 26.3 and 34.2%.

The analysis of battery thermal management by WafirulHadi *et al.,* [26] was looked at by employing PCM and a heat pipe. The PCM that was utilized in this experiment was soy wax, and its melting point was 38.49 °C. It is anticipated that the soy wax will take in and retain the heat that is produced, and the heat pipe may assist in speeding up the process of heat transmission that takes place inside the battery. The straightforward experimental setup is created, and a series of tests are carried out with four distinct iterations: the battery without a cooling system; cooling with just PCM; cooling with only a heat pipe; and cooling with a combination of PCM and heat pipes. The findings demonstrated that the thermal management system consisting just of heat pipes was successful in bringing the temperature down from 108.2 °C to 97.2 °C. When the PCM is placed in the heatsink box that surrounds the battery, it can result in a temperature drop of up to 40 °C, from 108.2 degrees Celsius to 68.2 °C. Additionally, when the PCM is placed in the heatsink box that surrounds the battery and heat pipe, it gives a temperature drop of up to more than 50 °C, from 108.2 °C to 58.3 °C. During the discharge process and cycle tests, the thermal properties of PCM play an important role in increasing natural convection and heat conduction in the PCM structure. This improves the efficiency of heat dissipation and lowers the risk of failure in a passive thermal management system that uses PCM. Azmi *et al.,* [27] performed numerical tests to assess PCM phase change performance in the unique bricks designed for energy-efficient construction. These bricks were developed for use in energy-efficient building. The performance of organic PCM phase change materials is all that has been tested. The enthalpy-porosity technique and the lattice Boltzmann method were the approaches that were used in the computational research. The majority of the investigations came to the conclusion that the natural convection that occurs in the domain has the greatest impact on how well the PCM phase change material performs. It has been shown that PCM-filled bricks have the ability to modulate heat in structures that are designed to be energy efficient. By using the TRNSYS software, Abdalla *et al.,* [28] conducted research that resulted in a numerical investigation of the influence that the magnitude of the hot water demand had on the overall performance of a grid-integrated hybrid energy system. It was discovered that the volume of the module's hot water demand has a major role in determining both the temperature at which it operates and the amount of energy that it generates. When compared to the high-emittance collector, the low-emittance collector is about 200% more sensitive to shifts in the scale that measures the demand for hot water. The low emissivity collector, in general, generates more energy than the high emissivity collector, and the disparity between their respective levels of performance becomes more evident as the total need for thermal energy increases. As a result, the low-emissivity collector is strongly suggested for use in building applications where the objective is to satisfy a significant demand for both electricity and a volume of hot water. On the other hand, if the main objective is to increase the amount of electricity that can be generated, the collector with a high emissivity would be the best option. Jowsey *et al.,* [29] carried out an investigation on the heat and flow profile of nanofluid flow inside of a multilayer microchannel heat sink. Comparative analysis of water and an aluminium oxide solution based on water is performed here. The temperature of the heated surface of the heat sink is maintained at a constant heat flux of 200 W/cm^2, and the mass flow rate is changed to be 20, 40, 60, and 80 kg/hr. Based on the findings, it can be deduced that the utilization of Al_2O_3 nanofluid is superior to that of water in terms of heat transfer. This is evidenced by the fact that the percentage of increment of Nusselt number is higher (83%) when compared to the percentage of increment of friction factor (23.5%). Therefore, Al_2O_3 nanofluid is superior than water in terms of heat transmission, but it still has a disadvantage in terms of pressure drop since it is more than water's level.

The researches presented in the aforementioned literature has shown that a PCM is an efficient thermal absorber and storage medium that is able to bring the temperature of a PV module down to an acceptable level. One of these PCMs is paraffin wax, which is often placed in a single block directly below the photovoltaic module in order to facilitate cooling. However, one important drawback that is connected to the use of a single block is the difficulty in avoiding leakage of melted paraffin wax. This is a problem that is related with this method. The natural consequence of this is the loss of the paraffin wax, which necessitates its regular replacement. At addition, the sloped shape of PV modules makes it challenging to maintain the molten PCM in its intended location. As a consequence of this, the research suggested a system that would make use of separate containers to hold the PCM, which would then be fastened behind the PV module. Aluminium fins, which will similarly depend on natural airflow (free convection) to cool the PV module, are joined with PCM container to create the system. One advantage of this cooling mechanism is that, in contrast to the conventional single block application mechanism of cooling PV modules using PCM as demonstrated in the majority of the reviewed literature, it allows for sections of the backside of the PV module to be cooled by ambient air. This is a significant improvement over the previous mechanism. This is due to the fact that the back of the module is not completely covered, which leaves space for the cooling effects of natural air circulation. Therefore, our work contributes to the expanding body of knowledge that is already available in regard to the passive cooling of PV modules.

The present research intends to increase the performance of a photovoltaic (PV) module experimentally under extreme weather conditions in southern Iraq by combining passive cooling technologies such as aluminium fins and PCM. Solar PV OREX-170W modules were placed at Basra Engineering Technical College, Basra, Iraq. The installed design of the PV modules was 30° angle tilted to the south to receive a higher heat flux for the Basra condition (30.5°N Lat., 47.78°E Long.) [30]. During working hours, paraffin wax (PCM) was used as a thermal energy storage medium in order to remove excess heat generated by the PV module. In addition, aluminium fins were used alone as a finned wall for the first case in order to remove heat from the PV module through a convection heat transfer. In the second case, aluminium fins were accompanied internally and externally by a PCM aluminium container in order to improve the performance of PCM during heat charging and discharging.

In summary, many tests of the experiment were performed to employ the cooling technique and absorb more heat from two PV modules simultaneously under the same conditions. The current work represents a qualitative transition in the cooling of solar panels both the aluminium finned wall and a combination of the longitude aluminium fins were placed internally and externally in the aluminium PCM-cooling container adhered at the back of the PV module were used to study the effect of passive cooling and improve the electrical efficiency of the PV modules.

2. Materials and Methods

2.1 Experimental Setup

In the experimental work, it was proposed to use two solar PV modules with a passive cooling strategy for comparison with an uncooled PV module and for studying many parameters of the three PV modules that were simultaneously tested under the same conditions. The proposed cooling technique uses an aluminium finned wall and phase-changing material as a cooling fluid. The PV-Aluminium Finned Wall was implemented and assembly by using an aluminium plate with dimensions of (112 x 64 x 0.5) cm was first directly adhered to the PV module by making use of heavy-duty epoxy, and then nine aluminium fins with dimensions of (60 x 2 x 0.7) cm was directly fixed to the aluminium plate by making use of epoxy and the distance of 10 cm between each pair of fins was maintained throughout as shown in Figure 1. On the other hand, The PV-Aluminium Finned Wall-PCM was configured by utilizing aluminium fins with an aluminium container of dimensions (115 x 64 x 3 cm). Heavy-duty epoxy and anti-leak material were also used in the container's fabrication in order to prevent drainage of the PCM during the melting process. The PCM container contains 18 aluminium fins distributed inside and on its backside with the same dimensions as the first module.

Fig. 1. PV-Aluminium Finned Wall module structure

Figure 2 shows the complete combination of the cooling system connected to the three solar modules which were installed on an iron stand at a tilt angle of 30° facing south.

Fig. 2. Experimental structure of the PV modules

The thermocouples of K-type with accuracy (±0.4%) were used in order to get temperature measurements from a variety of positions on the PV modules the used sensor length was 3m. The positions of the thermocouple's distribution for the two situations (PV-Aluminium Finned Wall) and (PV-Aluminium Finned Wall-PCM) were depicted in Figure 3. The total number of thermocouples used was about 48 distributed in different locations in order to get a better understanding of temperature distribution.

Fig. 3. Thermocouples distribution

Schematic diagrams of the experimental unit with measurement devices (data logger, current-voltage device, wind speed, solar radiation) and thermocouples are shown in Figure 4. The PV module's basic features are outlined in Table 1. The tested PV modules were installed all faced south at a tilted angle of 30°.

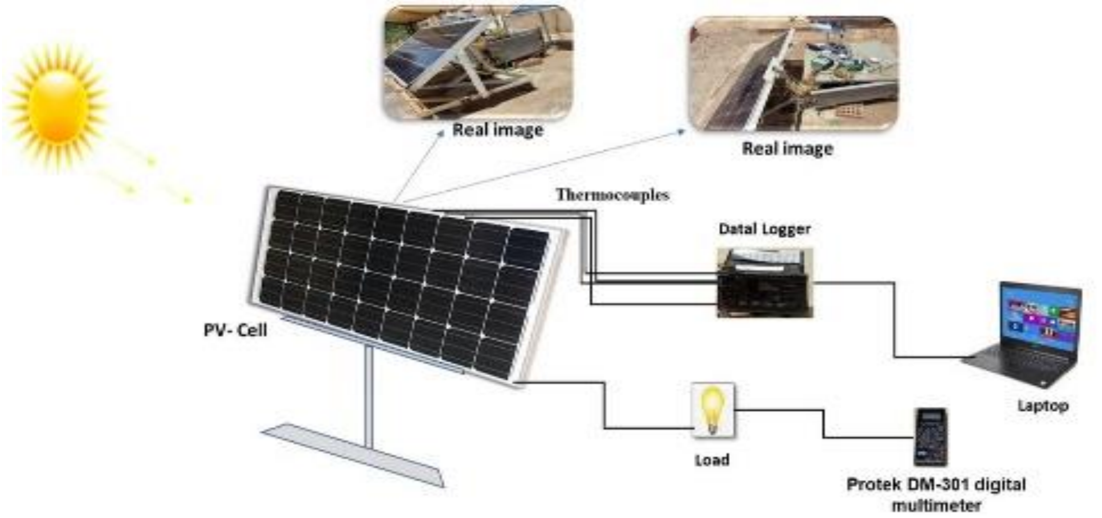

Fig. 4. Schematic of experimental setup

Table 1
PV module characteristics

Model	OREX-170W Monocrystalline Silicon
Maximum Power (P_{max})	170 W
Maximum Power Voltage (V_m)	18.8 V
Maximum Power Current (I_m)	9.04 A
Short Circuit Current (I_{sc})	9.49 A
Open Circuit Voltage (V_{oc})	22.7 V
Module Efficiency	17.1 %
Operating Temperature	25 ℃
Total number of cells	36
Module dimensions	(148 x 67 x 3) cm

2.2 Phase Change Material

A phase change material (PCM) is a kind of substance that is capable of storing energy in the form of latent heat. The phase shift of a substance is the focus of the phenomenon known as latent heat storage. In this process, energy may be either released or retained depending on how the enthalpy of the phase change varies. Because of the contribution of the phase transitions, thermal energy storage acts almost isothermally at the temperature at which the material undergoes phase change [31]. In terms of energy density, the capacity of latent heat thermal energy storage is superior to that of sensible heat thermal energy storage. Because of this, the melting temperature of a PCM has to be as low as it can possibly be in order to provide the greatest potential gain in electrical performance [32]. In this work, paraffin wax was utilised as a phase change material (PCM) to cool the PV module. Table 2 illustrates the features of the PCM that was employed.

Table 2
PCM Properties (The College of Science Advisory Office - Basra University)

Parameters	Value	Unit
Density ($\boldsymbol{\rho}$)	0.894	g/cm^3
Thermal Conductivity (k)	0.2	W/m. K
Specific heat capacity (Cp) Solid Phase	2.9	kJ/kg. K
Specific heat capacity (Cp) Liquid Phase	2.2	kJ/kg. K
Melting Point	338	K
Dynamic Viscosity ($\boldsymbol{\mu}$)	0.006	kg/m. s
Kinematic Viscosity ($\boldsymbol{v}$)	6.713	mm^2/s
Melting Heat (H)	70.006	kJ/kg
Dropping Point	359.5	K

Figure 5 illustrates the melting process of the phase change material and the transition of the material from its solid phase to its liquid phase. On the other hand, Figure 6 demonstrates the process of injecting molten PCM into the aluminium container using a little funnel. Approximately 15kg worth of injected phase change material was employed throughout the whole of this passive cooling system's design procedure in its entirety.

Fig. 5. Melting process of the paraffin wax

Fig. 6. Pouring paraffin wax into the aluminum container

2.3 Efficiency Calculations

The cooling of the solar photovoltaic module was studied to identify the influence that it had on the module efficiency. The module's performance may be anticipated based on its electrical efficiency, which is the ratio of the actual amount of electrical production to the amount of solar irradiation that is incident on the PV module surface. The following equation are used to calculate electrical efficiency of the PV module [33]

$$\mathrm{P_{out}} = \mathrm{V} \, . \, \mathrm{I} \tag{1}$$

$$\mathrm{P_{in}} = \mathrm{G} \, . \, \mathrm{A_{PV}} \tag{2}$$

$$\eta_e = \left(\frac{\mathrm{P_{out}}}{\mathrm{P_{in}}}\right) \mathrm{x}\ 100\% \tag{3}$$

where η_e is the electrical efficiency, A_{PV} (m^2) is the front area of the PV module, G (W/m^2) is the solar radiation, (P_{in} and P_{out}) are the input and output power (W), (V and I) are voltage and current output from the PV module.

2.4 Measurement Devices

The experimental setups were built in order to investigate the cooling influence on the performance of the solar panel by employing a variety of methods that lead to a reduction in the temperature that is produced and an increase in the efficiency of the panel. This was accomplished by employing a variety of methods that lead to a reduction in the temperature that is produced. The experimental endeavour made use of a broad range of instruments covering a number of categories. The primary instruments that are used in the carrying out of this research are outlined in Table 3, which provides an illustration of these instruments.

Table 3
Measurement devices

No.	Device	Specification
1	TES-1333 solar power meter with accuracy ±0.5%	measures the total solar radiation that was received by PV modules while being tested at a 30° angle with longitude.
2	MPD-580 multi-channel data logger (48 channels) with accuracy ±0.2%	utilizes to record instantaneous temperatures by employing thermocouple sensors of the type-K that were dispersed in various positions on the designed modules.
3	GM-550 Infrared Thermometer with accuracy ±1.5°C	reads the levels of thermal radiation which is emitted by the PV panel surface.
4	Protek DM-301 digital multimeter with accuracy ± 0.2 & 0.5%	uses for current voltage measurement.
5	Ragova Weather station RG- 0189 with accuracy ±0.03 m/s	Measures airspeed while the air flew under operational circumstances

2.5 Uncertainty Analysis

The measurements, the design specifics of the test equipment, and the amount of human error all play a role in determining how accurate the experimental findings are. The experimental errors that might possibly occur in the variables that were employed are outlined in Table 4, which was derived from the measurement tools.

Table 4
Uncertainties of measurement devices

Parameters	Accuracy (%)
Solar Radiation (W/m^2)	0.5
Current (A)	0.5
Voltage (V)	0.2

The following formula may be used to calculate the percentage error in the electrical efficiency of a PV module, given that the electrical efficiency of solar PV modules is a function of the following [34]

$$w_R = \left[\left(\frac{\partial R}{\partial x_1}.w_1\right)^2 + \left(\frac{\partial R}{\partial x_2}.w_2\right)^2 + \left(\frac{\partial R}{\partial x_n}.w_n\right)^2\right]^{\frac{1}{2}} \tag{4}$$

$$\eta_e = \eta_e(G, I, V) \tag{5}$$

$$\frac{w_{\eta_e}}{\eta_e} = \left[\left(\frac{w_G}{G}\right)^2 + \left(\frac{w_I}{I}\right)^2 + \left(\frac{w_V}{V}\right)^2\right]^{\frac{1}{2}} \tag{6}$$

where w_{η_e} is the uncertainty in the result and (w_G, w_I and w_V) are the uncertainty in solar radiation, current, and respectively. In this experiment, the overall amount of uncertainty for the PV system is equivalent to 0.734%, which is acceptable for this kind of study.

3. Results and Discussions

In order to explore the impact of alternative cooling methods on the thermal performance of PV/T modules, experimental investigates were carried out on three days during the month of July 2022. In conjunction with the Technical Engineering College in Basra, Iraq, we conducted field testing on three different modules.

3.1 Weather Characteristics

Solar radiation, the angle of an inclination, the speed of the wind, and the temperature of the surrounding environment all have an effect on the efficiency of a solar PV module. In this study, the angle of inclination was kept constant at 30° toward the southern direction. Therefore, the primary parameters that had an effect were the amount of solar radiation, the wind speed, and the overall ambient temperature. During the testing, TES-1333 solar power meter with accuracy (±0.5%) was used to measure the amount of radiation received from the sun. Irradiance's impact on temperature increase was another factor that researchers looked at. When there is a greater amount of irradiance, the temperature will continue to rise.

In the experiments that were carried out for this work, the fluctuation of solar radiation with time is shown in Figure 7. The findings indicate that the intensity of solar radiation steadily rises over the course of the day; the greatest level of solar radiation intensity, which was about 1400 W/m^2 (the solar power meter measures total radiation which is a combination of diffuse, direct, and reflector radiation.), was recorded between 11:00 AM and 12:00 PM. The average temperatures recorded during the day are shown in Figure 8. The temperature reached its peak of around 45 °C at 12 o'clock in the afternoon. As a result, the rise in solar irradiation, the average ambient temperature climbed. Figure 9 depicts the fluctuations in wind speed as a function of time during the course of the recording period, which lasted from nine in the morning until twelve in the afternoon. The range between the lowest and highest readings was (0.8 to 1.3) m/s.

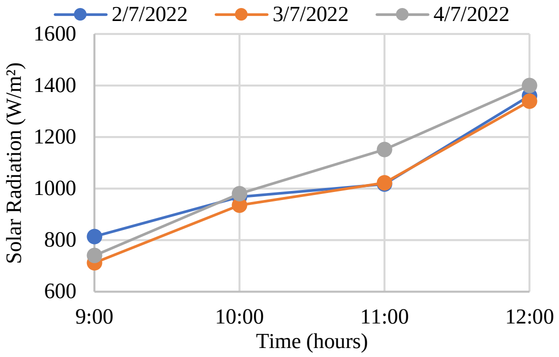

Fig. 7. Solar radiation variation in July 2022

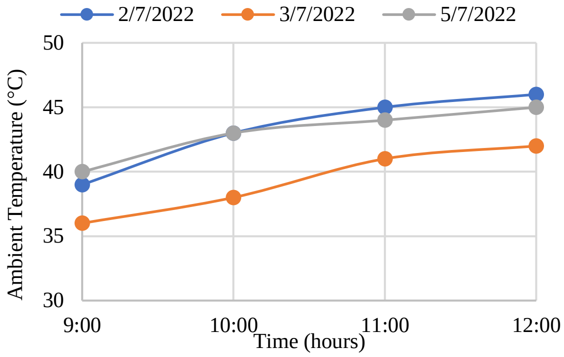

Fig. 8. Ambient temperature variation in July 2022

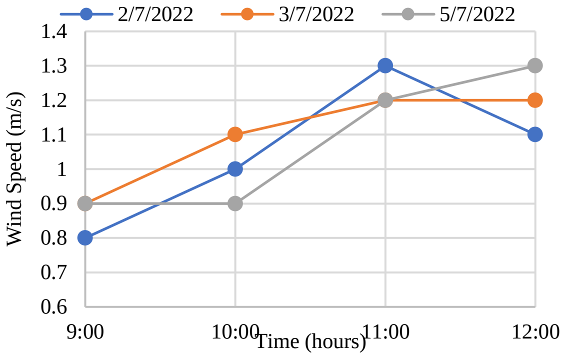

Fig. 9. Average wind speed variation in July 2022

3.2 Cooling Process Effect on the PV Module Temperature

The variability in the average temperature of the back surface of all photovoltaic modules over time from 09:00 Am to 12:00 PM is shown in Figure 10, and this variation is shown for both un-cooled and cooled PV modules. In general, temperatures rise around the middle of the day as a result of an increase in solar radiation and an increase in air temperature, both of which produce an increase in the amount of heat transfer that occurs inside cells. The underlying module's (PV Reference) average temperature was around 67.85 °C in July 2022 the recorded value was the highest because there is no cooling system. On the other hand, the recorded values of the average temperature of the module PV-Aluminium Finned Wall-PCM and PV-Aluminium Finned Wall were around 48.25 °C and 59.5 °C respectively in July 2022 these values were the lowest when compared with the PV reference. Additionally, the implementation of the back-cooling strategy in the PV-Aluminium Finned Wall-PCM and PV-Aluminium Finned Wall scenarios in July 2022 helped bring the average temperature of the PV down from 72 °C to 52.4 °C and 65.1°C respectively at 12:00 PM which characterizes an average reduction in the temperature of about 27.2% and 9.6% correspondingly as shown in Figure 11. According to these results, the PV-Aluminium Finned Wall-PCM has a greater reduction temperature, which contributes to an increase in the efficiency with which the PV module generates electricity.

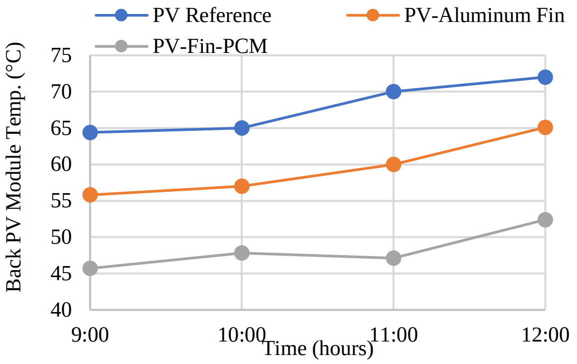

Fig. 10. Average back temperature in July 2022

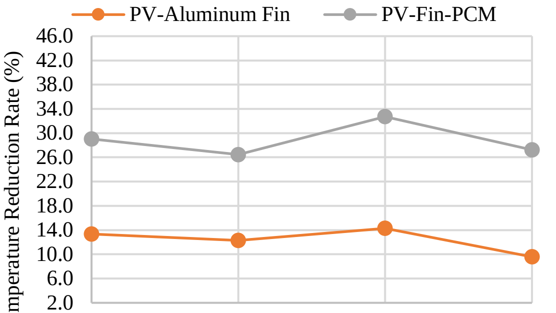

Fig. 11. Average temperature reduction in July 2022

3.3 Power Output Analysis

Figure 12 compares the output power of three PV modules throughout testing time from 09:00 AM to 12:00 PM in July 2022, the average power output of the PV-Aluminium Finned Wall- PCM module was around 147.4 W, compared to 141.8 W for the PV-Aluminium Fin scenario and 128.3 W for the PV reference case. The lower output power for the underlay module owing to the absence of a cooling approach, while the output power of modified modules is increasing due to their usage of passive cooling strategies through aluminium fins and phase change material.

Figure 13 illustrates the output power increase with respect to time during daytime from 09:00 AM to 12:00 PM in July 2022 for three different modules with and without cooling effect. Comparing the PV-Aluminium Finned Wall-PCM and the PV-Aluminium Finned Wall modules cooling strategies to the baseline model, the PV-Aluminium Finned Wall-PCM module's peak power increase was around 23.1% in July 2022 from 09:00 AM to 12:00 PM, while the PV-Aluminium Finned Wall cooling strategy increased power by 16.8 %.

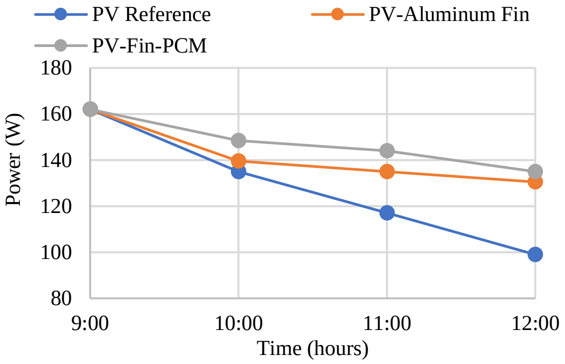

Fig. 12. Power output of PV modules in July 2022

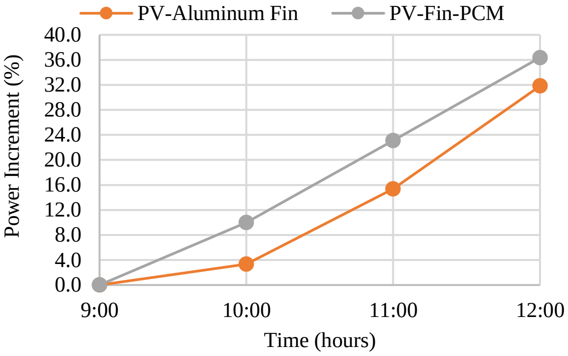

Fig. 13. Power output incremental of PV modules in July 2022

3.4 Electrical Efficiency Analysis

The fluctuation in the electrical efficiency with time for the various PV modules that were tested is shown in Figure 14. Owing to an increase in solar radiation throughout the day, the temperature of the PV modules increased, which resulted in a drop in the voltage that was acquired from the PV modules this caused the electrical efficiency to decline. According to the findings, the average electrical efficiency achieved by using cooling strategies provided by PV-Aluminium Finned Wall and

PV-Aluminium Finned Wall-PCM was approximately (14.7 %) and (15.2 %) in July 2022 respectively from 9:00 AM to 12:00 PM. On the other hand, the average electrical efficiency of the basic module (PV without cooling) was roughly (13.6 %) for the same period of time. The results demonstrate that the cooling methods, particularly those using PV-Aluminium Finned Wall-PCM, have a greater impact on reducing the temperature and improving electrical efficiency.

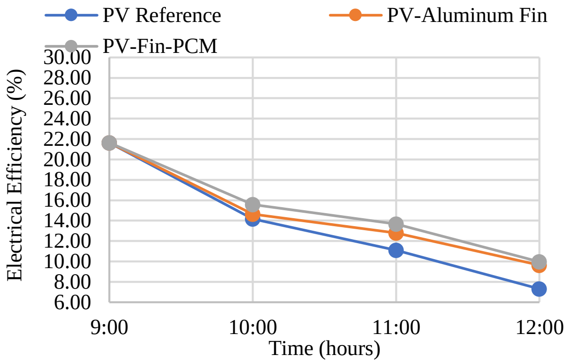

Fig. 14. Electrical Efficiency of the PV modules in July 2022

3.5 PV Modules Characteristics

The impact that lowering the temperature of the cell has on the photovoltaic characteristics of voltage, power, and electrical efficiency is subdivided and discussed in this section by demonstrating the link between power-voltage. The variability in power and voltage at the open circuit voltage at the standard condition, which was 22.7V for all three PV modules, is shown in the Figure 15. The data that was recorded indicate that the highest level of solar radiation was measured at 12:00 PM in July 2022, and on the basis of these findings, the figures that were shown were based on that time.

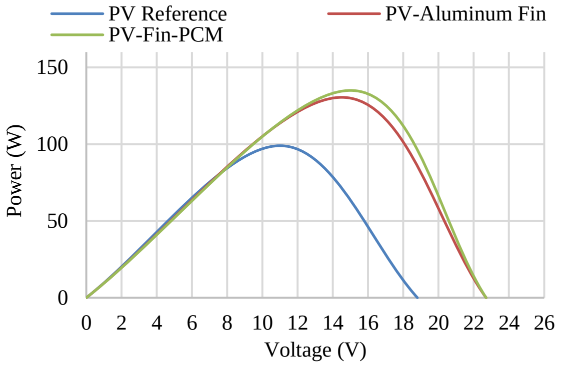

Fig. 15. Power-Voltage curve of the PV modules in July 2022

Throughout the duration of the study, the findings revealed significant variations in the amount of temperature decrease, amount of output power produced, and electrical efficiency of the changed PV modules. The results demonstrate a significant advancement given that the suggested passive cooling method is able to maintain the PV module's cool temperature even under extreme hot weather circumstances. In addition, the mechanism that was employed in this research is persuasive in comparison to others that were done in the literature, such as conventional cooling systems that adopted PCM and linked it to the back of the panel. The findings of the current investigation are shown in Table 5, along with comparisons to the findings of previous research that deal with PCM, PCM/fins, and several alternative cooling methods.

Table 5
Comparison of past work with the present study

Reference	Cooling Mechanism	Power Output (%)	Electrical Efficiency (%)
[35]	PCM panel fixed on the backside of a PV module (RT28HC, 28 °C melting temperature)	9.2	1.1 - 2.8
[36]	combined PCM (white petroleum jelly, copper, and graphite (36 °C - 60 °C melting temperature)	7.4	5.8
[13]	PCM (28 °C melting temperature paraffin wax) filled aluminum cylinders with fins	11.33	5.15
[37]	PCM panel of 52 °C melting temperature palm wax in a finned stainless-steel container	3.6	5.3
[38]	PCM (RT27, 27 °C melting temperature) panel with aluminum fins	3.44	5.39
[39]	Nanofluid (SWNTs/75% water/25% glycol ethylene) circulation on the back of the PV module	11.7	25.2
[40]	Paraffin wax (40 °C - 44 °C) filled galvanized steel panel with internal smooth wavy fins	36.1 - 38.4	34 - 37.2
[41]	evaporating cooling by using cotton wicks immersed in the water (CWIWs) attached to the backside photovoltaic module	12.9	7.25
Current Study	Aluminum finned wall (200 W/m^2. K thermal conductivity)	16.8	14.7
	PCM (65 °C melting point) with internally and externally longitude aluminum fins	23.1	15.2

4. Conclusions

In the current work, experimental analysis was carried out in Basra, Iraq, to study the effect of cooling techniques on the thermal and electrical behaviour of PV OREX-170W modules installed at a 30° tilt angle facing south. The aim of the research was to determine how the different passive cooling techniques affect the behaviour of the modules. A photovoltaics module was used for comparison with two different kinds of passive cooling which is namely PV-Aluminium Finned Wall and PV-Aluminium Fin-PCM. The findings illustrate how the passive cooling method influences the overall performance of the photovoltaics modules that were constructed. Once compared to the underlying module, which had an average efficiency of around 13.6% in July 2022, the PV-Aluminium Finned Wall-PCM and PV-Aluminium Finned Wall boosted the average PV module's electrical efficiency by 15.2% and 14.7%, respectively. Furthermore, the deployment of the back-cooling technique in the PV-Aluminium Finned Wall-PCM and PV-Aluminium Finned Wall scenarios in July 2022 contributed to an average temperature drop of roughly 27.2% and 9.6%, respectively. In addition, the power output rose by 23.1% for the PV-Aluminium Finned Wall-PCM and by 16.8% for the PV-Aluminium Finned Wall, respectively. As a result, the cooling method is the most effective strategy for increasing the amount of electricity produced. This is accomplished by bringing the operating temperature of the PV module down to its lowest possible level. This allows the module to be utilized more effectively in the warm climate of Iraq.

5. Future Work

The following are some recommendations that might be made for potential future research

i. Examining the design and construction of the suggested hybrid modules with bigger PV module dimensions.
ii. Carrying out experimental and computational research on the topic of cooling photovoltaic cells with fins by modifying the size, shape, number of fins, and the distance between each individual fin.
iii. Investigate the impact that using a range of tilted angles has on the performance of the PV module, and then evaluate the newly obtained result in light of the one previously obtained for this project.
iv. Using phase-changing material that is different from the material that was studied in our research and carrying out an experimental and theoretical study to compare it with the paraffin wax that was utilized, and to decide which one is the best in terms of removing heat and improving efficiency.

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