Global Scientific Review
A Peer Reviewed, Open Access, International Journal
www.scienticreview.com
Volume 43 September 2025
ISSN (E): 2795-4951

Performance Analysis Of Passive Air-Cooling System Pvt Utilizing Phase Change Material

Atheer S. Hassoon[1*], Ghaidaa M. Ahmed[2], Shaymaa A. Hameed[1]
[1] Power Mechanics Techniques Engineering Department, Al-Musaib Technical College, Al-Furat Al-Awsat Technical University (ATU), Kufa 54001, Iraq.
2 Middle Technical University Engineering Technical College-Baghdad, Baghdad 10074, Iraq
*Corresponding author: atheer.hassoon@atu.edu.iq

Abstract
Phase Change Materials (Paraffin wax-RT42) were included into Photovoltaic Thermal (PVT) systems to examine their thermal performance and the generation of electricity. The experimental setup is made up of two polycrystalline (PVT) panels, each of which has a power rating of 10 watts and measures 360 millimeters by 240 millimeters by 5 millimeters. All of the experimental tests were carried out in the city of Babel for February and March 2024 months, which is located in Iraq, with passive cooling method.

The outcomes of the study displayed that the operating temperature of PV cells is significantly reduced when PCM integration is implemented, resulting in better thermal stability and electrical conversion efficiency. In comparison to PVT, PVT-PCM augmentation achieves an overall effectiveness of as high as 12%. Additionally, the incorporation of PCM improves the cooling of PVT, which leads to a 14.5% reduction in the temperature of the PV panel as well as a 16% increase in PVT power output. In addition, the use of a 30-degree tilt angle results in the best possible performance for both PVT and PVT-PCM systems.

Keywords: Photovoltaic Thermal (PVT), PCM (Paraffin Wax RT42), Sustainability of Solar Energy, Overall Efficiency, Passive Cooling Method.

1. Introduction

Renewable energy sources may be renewed quickly. Solar, wind, water, geothermal, wave energies and others are sustainable. Sunlight is one of the greatest common renewable energy sources because of its many advantages, such as providing a constant supply of clean electricity and reducing pollution. Most of solar energy conversion processes involve very little money. PV modules last over 30 years and require little maintenance [1].
This method enables the production of photovoltaic modules in a wide range of sizes, from modest residential systems to massive solar arrays. Photovoltaic modules exhibit sensitivity to operating temperature, resulting in a reduction in electrical efficiency of between 0.4 to 0.65% for every degree of temperature increase [2,3]. This phenomenon is thoroughly explained by Mahdavi et al. (2022) [4]. Consequently, the design of a cooling system for a solar cell is essential. The subsequent paragraph examines and contrasts several sun cooling methodologies. Photovoltaic cooling systems may be classified into three categories: Passive cooling (which requires no more energy), Active cooling (which necessitates supplemental energy), and a hybrid

of active and passive cooling. Active cooling solutions are exceptionally effective in environments where hot air or water is necessary for the procedure of photovoltaic thermal (PVT) systems [5]. In these instances, the cooling system enhances electrical efficiency while also supplying thermal energy, resulting in improved total efficiency [6]. The passive cooling method is an efficient strategy for cooling photovoltaic modules without additional energy consumption. This strategy involves the transmission of a photovoltaic module's stored heat to the environment via radiation, natural convection, evaporation, and spectral splitting, minimizing environmental effect [7].

One technique to enhance cooling efficiency is to use phase-changing materials (PCMs) as a cooling medium, which may regulate temperature within a specified range [8]. A large latent heat of fusion through melting optimizes thermal energy storage. Thus, phase change materials in solar modules may enable passive operation. The latest comprehensive assessment by **Dwivedi et al., (2020)** [9] concludes "PCM-cooling is the greatest effective method". The benefits of phase change materials (PCMs) would reduce two major shortcomings of photovoltaic (PV) systems when combined with solar modules/panels by **Klemm et al., (2017)** [10]. Rapid temperature changes between day and night can induce thermal stresses and generate a thick crust on solar modules from water vapor condensation. Several studies have used phase change materials and solar modules/panels due to their benefits. PVT-PCM is active, whereas some research is passive.

Koundinya et al., (2017) [11] carried out a numerical analysis of the effectiveness of PV/PCM with a metal fiber construction. There are three distinct phase change materials that have been assessed: RT 44, RT 50, and RT 54. The maximum PV temperature during its day-to-day life cycle decreased by 20 K, as indicated by the data. They have indicated that the selection of PCM is dependent on the latent heat of fusion; a greater latent heat of fusion correlates with improved system performance. Moreover, reducing the porosity from 90% to 80% or 70% does not contribute to the improvement of heat transport. **V. Sun et al., (2020)** [12] conducted a summer experimental and numerical study in Chiang Mai, Thailand. The city of Chiang Mai is hot; thus, the solar module was mounted at a 10° angle. They investigated RT 35, 42, 47, and 55 phase change materials (PCMs) to establish their ideal thickness. These PCMs were best at 50 mm, 40 mm, 30 mm, and 20 mm thick. **M. Rajvikram et al., (2019)** [13] The (OM 29) PCM was selected for the organic phase transition in the PV/PCM system cooling that was tested in Chennai, an Indian city. They discovered that the solar array with a phase change material and aluminum support had a 24.4% higher conversion efficiency instead of the location module with no cooling equipment. **Akshayveer et al., (2020b)** [14] conducted a numerical analysis of the geometry of the PCM tank and its impact on the melting speed of (RT-27) PCM. In comparison to the conventional rectangular container, three distinctive unconventional configurations were devised and evaluated. Compared to conventional regular designs, the linear, parabolic, and cubic configurations exhibited superior performance in dissolving the PCM, which led to a reduction in the PV temperature and an improvement in electrical efficiency. In comparison to the three PCM enclosures, the cubic design exhibits superior performance.

R. Kumar et al., (2020c) [15] tested a cooling photovoltaic module for high heat. The horizontally aligned photovoltaic modules received constant sunlight. Three systems were studied: Individual PV, Photovoltaic/PCM, and Photovoltaic/PCM plus fins. Their passive cooling method differed slightly but significantly from the previous

trials. External fins on the PCM container increased heat dissipation from stored PCM. Since PCM charges and discharges simultaneously (SCD), this approach is justified. The front PV module absorbs heat and transfers it to the PCM, which distributes it to the environment on the bottom. The PCM is in SCD, therefore heat promoter selection must be careful **Mahdavi et al., (2021b)** [16]. **Kumar et al., (2020c)** [17] found that example 3 with exterior fins performed better in all dimensions. They reported a 22.3 °C and 12 °C temperature reduction for PV modules in cases three and two, respectively, compared to the scenario without cooling. **M. J. Mahdi et al., (2021)** [18] By incorporating a metallic foam sheet into a solar power and PCM system, the heat transfer surface area was increased under SCD conditions. According to their computer simulation, the incorporation of a metal foam layer could accelerate the melting process by 32%. Melting time increases by 18% when the incline angle is reduced from 90° to 30°. **L. Siahkamari et al., (2019)** [19] conducted an experimental study of the PVT/PCM system's performance during controlled laboratory circumstances (23 °C surrounding temperature and continuous radiation is equal 1000 $W.m^{-2}$). The graphic representation of their experimental work. Sheep fat and paraffin wax were utilized as two distinct phase change materials for their experimental study. The results indicate that sheep fat was more efficient in cooling the PV module than paraffin. The suitability of a PCM for photovoltaic cooling is significantly dependent on geographical and climatic conditions **Chandel and Agarwal, (2017)** [20], as demonstrated by the experimental setting in reference **Sandro et al., (2021)** [21]. The simplified representation of the experimental study by **Siahkamari et al., (2019)** [19] is advised for regions with elevated sunlight and high ambient temperatures. Previous studies conclude that the utilization of a PV/PCM system is economically viable under specific environmental conditions.
The current study investigates the influence of inclination angle on the application of phase change materials (PCM) as a cooling medium in photovoltaic systems.

2. Electrical and Energy Analysis

The PV electrical circuits consist of three types: an individual diode design with three variables, a series resistant design with four variables, and a series resistant and shunt resistant design with five variables. The PV current, resistance in series, and the shunt resistance properties of photovoltaic panels are contingent upon the temperature of the semiconductors and the quantity of solar radiation.
The greatest amount of power (P_{max}) generated by a photovoltaic cell may be represented as originating from the highest power point [22].

$$P_{max} = V_{max}\ I_{max} \quad (1)$$

Where: the V_{max} is the PV-voltage (Volt) and I_{max} is the PV-current (Amp).
The PV electric efficiency (η_{el}) It can be described as the ratio of the maximum potential electrical generated by the photovoltaic panel to the quantity of solar radiation absorbed by the solar cells, and it can be calculated as [22]:

$$\eta_{el} = \frac{P_{max}}{G_{PV}\ A_{PV}} \quad (2)$$

Where: the G_{PV} is the PV-solar radiation (W/m^2) and A_{PV} is the PV-area (m^2).
Alongside evaluating the efficacy of PCM in reducing the temperature of PV cells, the subsequent PV efficiency formula was employed [23]:

$$\eta_{el} = \eta_{ref}[1 - \beta_{ref}(T_c - T_{ref})] \quad (3)$$

where, η_{el} is the PV module electrical efficiency, η_{ref} is the standard efficiency (0.14), β_{ref} is the temperature coefficient (0.00392/ °C), and T_c is the PV temperature (°C).
The thermal efficiency (η_{el}) of a PV panel is defined as

$\eta_{th} = \frac{Q_{air}}{G_{PV}\,A_{PV}}$ (4)

The usable air heat collected which is further calculated:

$Q_{air} = \dot{m}\,cp(T_o - T_i) = \dot{m}\,(h_o - h_i)$ (5)

Where the $\dot{m}$ refers to the air mass rate of flow kg/sec, cp refers to specifical air heat (1005 J/KgK). T_i represents the intake air Temp and T_o signifies the outlet air Temp. The overall efficiency (η_{ov}) of a PV panel is defined as

$\eta_{ov} = \eta_{th} + \eta_{el}$ (6)

The enthalpy concept incorporates all energy in systems that employ phase change materials (PCMs), which includes both sensible and latent energy through changes in phase. The overall enthalpy can be represented as follows [24,25]:

$h = C_p(T - T_{ref}) + \Delta H_f \times f_L$ (7)

where, T_{ref} is the standard temperature (25°C), ΔH_f is the latent heat of fusion (J/kg), and f is the liquid fraction (0 to 1).

Heat conduction in photovoltaic systems and phase change materials according to Fourier's law [26]:

$q_{cond} = -k \times \Delta T$ (8)

where, q_{cond} is the heat flux (W/m^2).

To assess the heating capacity of the collector device, a thermal efficiency formula was employed, predicated on the increase in PCM temperature. [27,28]:

$q_{conv} = h_{conv} \times A_{PV} \times (T_{sur} - T_\infty)$ (9)

where, h_{conv} is the coefficient of convective heat transfer (W/m$^2\cdot$ K), T_{sur} is the PV-surface temperature (°C), and T_∞ is the environment temperature (°C).

3. Experimental Work

3.1 Experimental Setup

Figure 1 depicts that the experimental test rig involves a wooden frame on its backside, which supports two separate polycrystalline photovoltaic (PV) systems of the EU-M10W type arranged in series. The solar panels, consisting of layered glass, silicon, and aluminum, are detailed in **Table 1**, which describes their dimensions and specifications. The first photovoltaic panel employs passive air cooling techniques, whereas the second photovoltaic panel also utilizes passive air cooling techniques, augmented by the addition of PCM (RT42) at the rear of the panel, the PCM propeties are detailed in **Table 2**.

Fig. 1. Schematic diagram and the apparatus of the experimental work.

Table 1 The properties of the polycrystalline photovoltaic (PV) panels

Model Type	EU-M10W
Electrical Characteristics	
Related Max. Power (Pmax)	10W
The Limit of Power Allowance	±3%
Open Circuit Voltage (Voc)	21.7V
Peak Voltage (Vmp)	18V
Short Loop Current (Isc)	0.61V
Peak Loop Current (Imp)	0.56A
Highest System Voltage	1000V
Highest Series Fuse Rating	15A
Weight	0.98KG
Module Application	Class A
Dimension	360*240*15mm
All technical data at standard test condition, Am1,5 E = 100W/m², Tc = 25° C	

Table 2 Thermal Characteristics of utilized paraffin wax.

Melting temperature Range (K)	319-321
Specific heat (J/kg·K)	2000
Heat of fusion (J/kg)	114540
Viscosity coefficient (kg/(m·s))	0.033
Conductivity (W/m·K)	0.14
Thermal expansion coefficient (1/K)	$6*10^{-4}$
Density (kg/m³)	820

3.2 Test Procedure

The studies testing two solar panels took place in Babylon, Iraq. The subsequent stages describe the method for this task:

1. Positioning the two photovoltaic panels at a 30° angle and including all required sensors, including thermocouples and a solar meter, while filling the second photovoltaic panel with one kilogram of paraffin wax (RT 42).
2. Recording the measurements of temperature, solar radiation, voltage, and current for each photovoltaic panel on an hourly schedule.
3. Reiterate point two for two photovoltaic panels positioned at a 180° inclination angle and record the readings.

3.3 Uncertainty of Measurement

In order to guarantee that the sensors utilized in the testing are precise, each sensor undergoes validation. The precise and approximate precision metrics that were derived from the instrument specifications are presented in Table 3. The majority of arithmetic errors are undoubtedly the result of errors in the measured quantities. As a result, the precision of the data acquired is assessed using the Kline and McClintock technique [29].

Let the final result R depend on a collection of variables ($v_1, v_2 \ldots v_n$)..

$R=R^*(v1, v2 \ldots v_n)$ (10)

This relationship may be expressed as a linear equation when the variations in the variables are minimal:

$$\delta R = \frac{\partial R}{\partial v_1}\delta v_1 + \frac{\partial R}{\partial v_2}\delta v_2 + \cdots + \frac{\partial R}{\partial v_n}\delta v_n \quad (11)$$

The resulting interval of uncertainty (w) can be expressed as

$$w_R = \left[\left(\frac{\partial R}{\partial v_1} W_1\right)^2 + \left(\frac{\partial R}{\partial v_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial v_n} w_n\right)^2\right]^{1/2} \quad (12)$$

Division by R

$$\left(\frac{w_R}{R}\right)^2 = \left(\frac{\partial R}{\partial v_1}\frac{w_1}{R}\right)^2 + \left(\frac{\partial R}{\partial v_2}\frac{w_2}{R}\right)^2 + \cdots + \left(\frac{\partial R}{\partial v_n}\frac{w_n}{R}\right) \quad (13)$$

Consequently, Table (3) delineates the possible experimental errors induced by the application of the variables.

Table 3: Absolute Accuracy

Instruments	Error
data-logger	± 0.5 °C

thermocouple (K-type)	± 0.75 °C
Solar meter (EY800 W)	± 0.1 %

4. Results and Discussions

4.1 Effect of temperature

Figure 2 displays the variation of temperature over time at a 180° tilt angle. It can be seen the highest temperate occur around twelve o'clock, when the maximum value for temperature reach to 37 °C for PVT and 29.8°C for PVT-PCM consequently. The use of paraffin wax as a cooling medium lowers the temperature by up to 7.2 degrees and enhances the PV-cooling system's efficiency by 23%. This behavior occurred due to the integration of PCM, which enhances the capacity to absorb heat from the base of the PV panel.

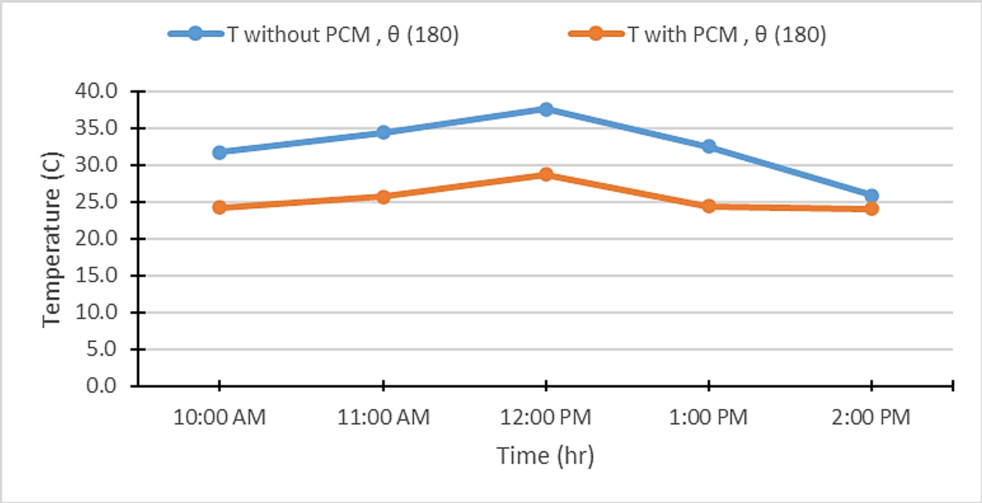

Figure 2: Temperature against Time at a 180-degree tilt angle.

Conversely, in Figure 3, a similar result is observed when the tilt angle is adjusted to 30°, where it is noticed that the base temperature of the PVT decreases to 10 degrees when employing PCM as a cooling medium. The utilization of PCM at a tilt angle of 30 degrees yields optimal performance.

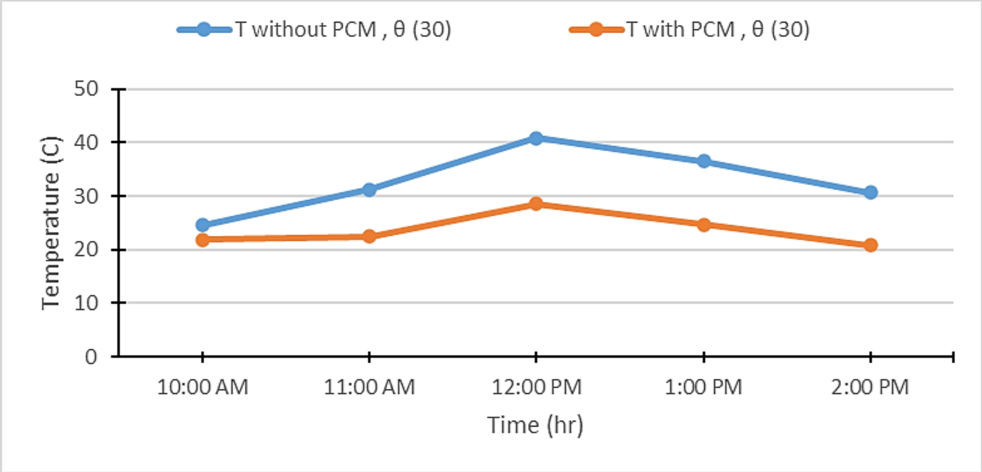

Figure 3: Temperature against Time at a 30-degree tilt angle.

4.2 Effect of Heat transfer

Figure 4 illustrates the variation of theoretical heat transfer across time for February and March 2024. The largest theoretical heat transfer occurs around twelve o'clock, reaching values of 6.4 W/m²·K and 5.6 W/m²·K at a tilt angle of 180 degrees for photovoltaic systems with and without PCM, respectively. The use of paraffin wax as a cooling medium enhanced the potential heat transfer by 14%. This behavior occurred due to the use of PCM, which enhances the capacity to absorb heat from the base of the PV panel.

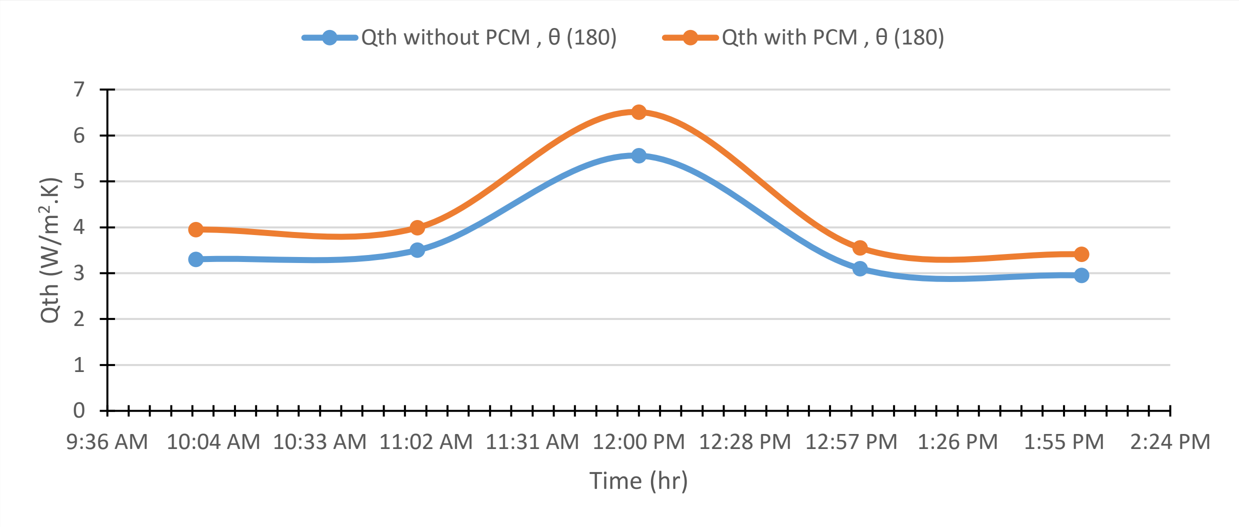

Figure 4: Theoretical Heat against Time at a 180-degree tilt angle.

At a tilt angle of 30 degrees, as seen in Figure 5, the heat transmission increases to 7.1 W/m²·K for photovoltaic systems with phase change material (PCM) and 6.14 W/m²·K for those without PCM. Where added paraffin wax as cooling medium increased the theoretical heat transfer by 16%.

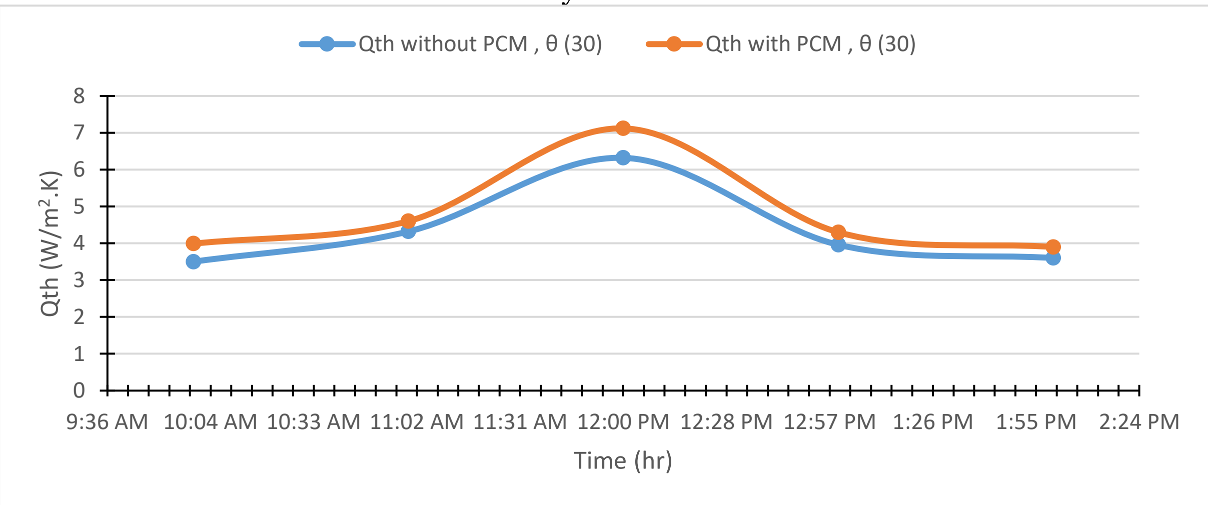

Figure 5: Theoretical Heat against Time at a 30-degree tilt angle.

4.3 Effect of Current

Figure 6 illustrates the variation of current over time for tilt angles of 180 degrees and 30 degrees. At 180 degrees, the maximum current for PV is 0.27A without PCM and 0.33A with PCM. At 30 degrees, the maximum current for PV reaches 0.34A without PCM and 0.4A with PCM, as seen in Figure 7. The practice of PCM as a cooling intermediate enhances the photovoltaic system's capacity to generate electrical current.

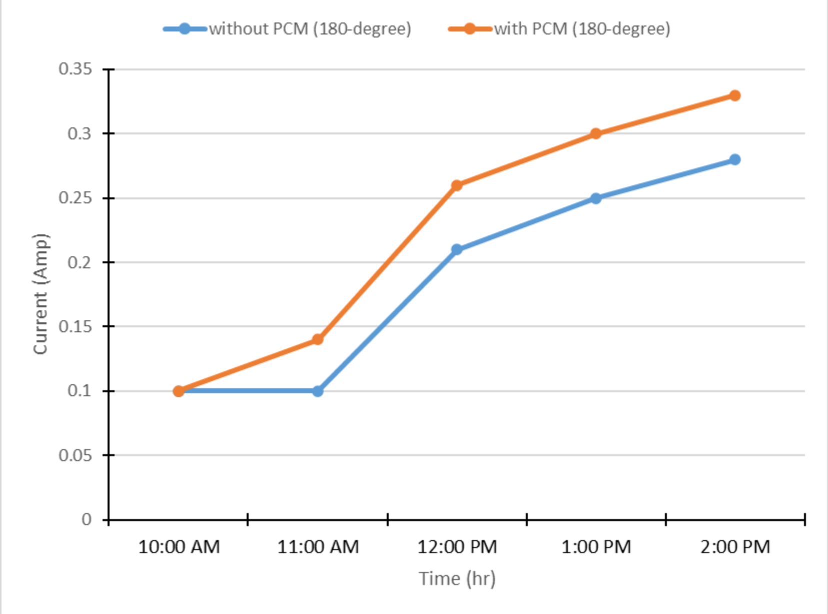

Figure 6: Current against Time at a 180-degree tilt angle.

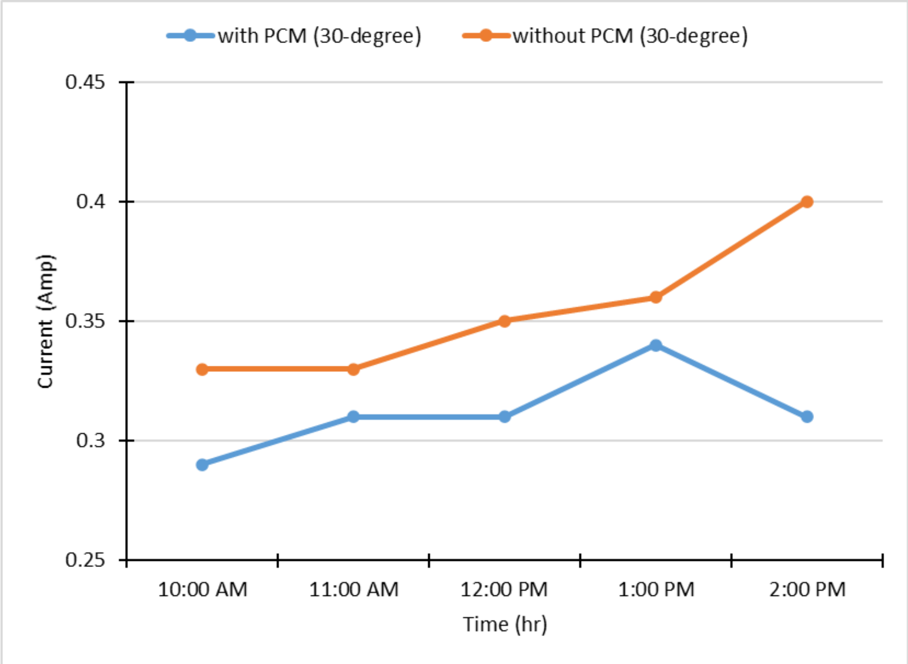

Figure 7: Current against Time at a 30-degree tilt angle.

4.4 Effect of Power output

Figures 8 and 9 illustrate the variation of power production vs time for tilt angles of 180 degrees and 30 degrees. The highest power production occurs at twelve o'clock, when a tilt angle of 180 degrees yields a peak power output of 5.1 W for the photovoltaic system with phase change material (PCM) and 4.5 W for the system without PCM. The highest power production reaches 6.7 W and 5.4 W at a 30-degree tilt angle for photovoltaic systems with and without phase change material, respectively. This behavior occurred due to the use of PCM, which enhances the capacity to absorb heat from the base of the PV panel.

Global Scientific Review
A Peer Reviewed, Open Access, International Journal
www.scienticreview.com
Volume 43 September 2025
ISSN (E): 2795-4951

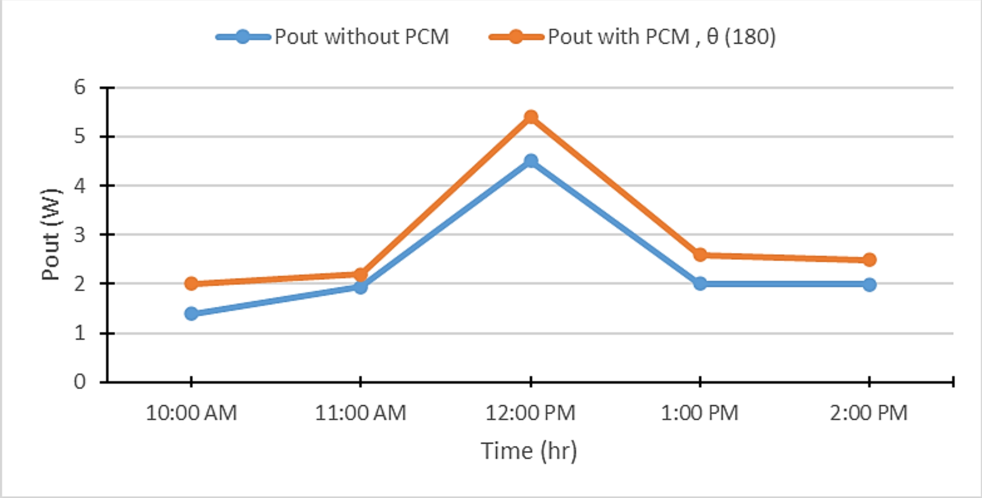

Figure 8: Power output against Time at a 180-degree tilt angle.

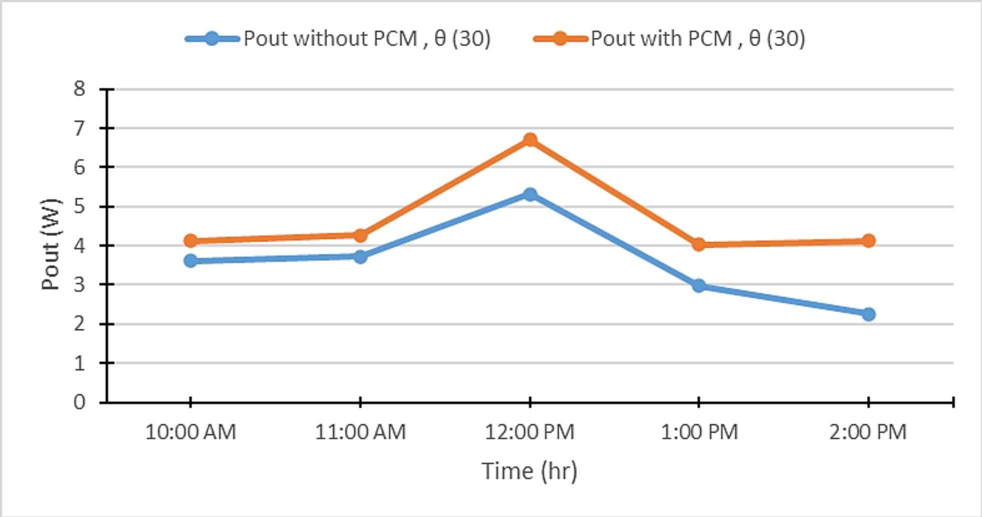

Figure 9: Power output against Time at a 30-degree tilt angle.

4.5 Effect of Efficiency

Figures 10 and 11 depict the efficiency variations over time for tilt angles of 180 degrees and 30 degrees. The optimal photovoltaic efficiency is achieved at a tilt angle of 180 degrees, yielding 63% for the photovoltaic system incorporating phase change material (PCM) and 57% for the system devoid of PCM. Furthermore, with a 30-degree tilt angle, optimal efficiency is achieved around twelve o'clock, reaching up to 65% for photovoltaic systems without phase change material and 70% for those with phase change material. This behavior occurred due to the use of PCM, which enhances the capacity to absorb heat from the base of the PV panel.

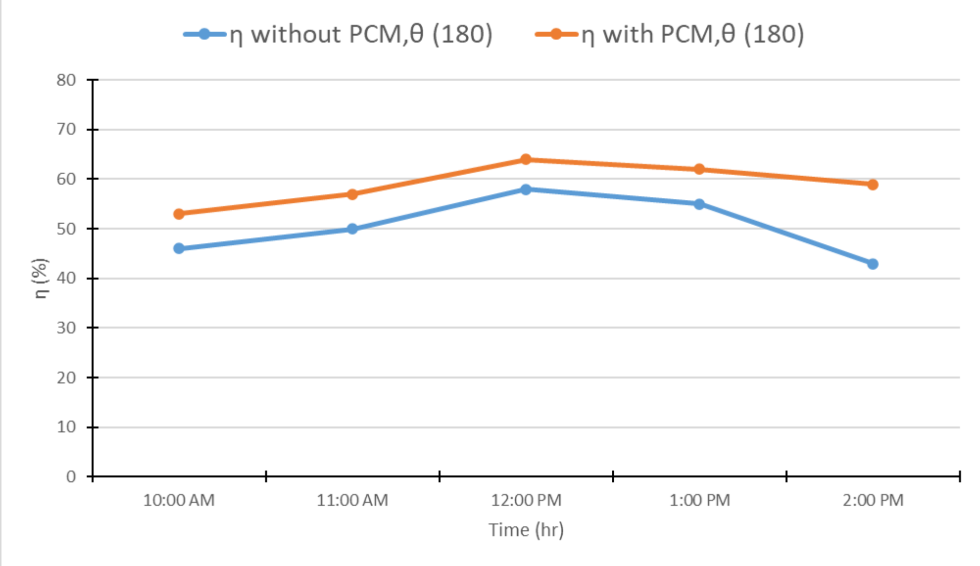

Figure 10: Overall efficiency of system against Time at a 180-degree tilt angle.

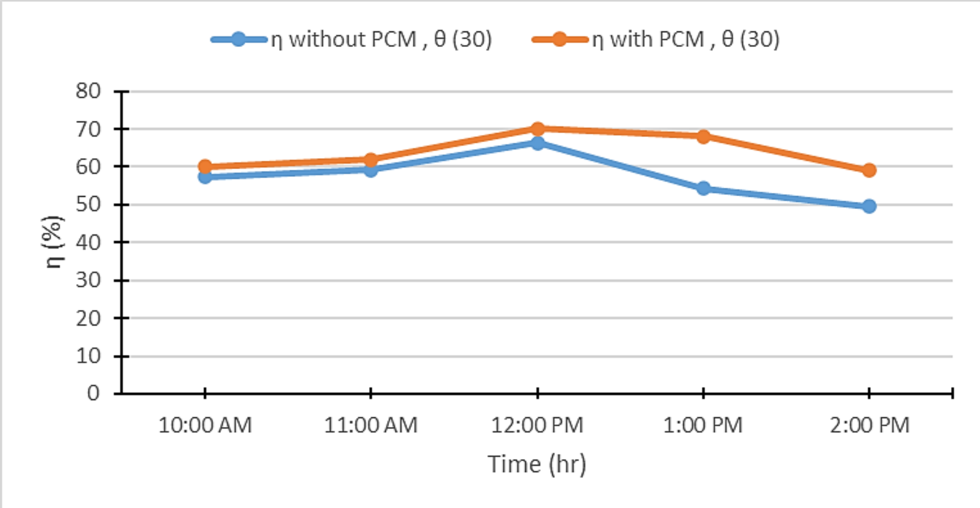

Figure 11: Overall efficiency of system against Time at a 30-degree tilt angle.

5. Conclusion

Based on the quantitative and experimental findings, the following conclusions were chosen:

1. When PV is cooled using paraffin wax, the average base temperature can be reduced to 4 degrees at a 180° tilt and 6 degrees at a 30° tilt.
2. Using paraffin wax as a cooling medium enhanced the potential heat transfer by 14% for PVT-PCM at a tilt angle of 180 degrees, while 16% at a tilt angle of 30°.
3. At a tilt angle of 180°, the maximum current increased from 0.27A without PCM to 0.33A with PCM degrees, while, at 30°, increased from 0.34A without PCM to 0.4A with PCM.
4. The highest power production when a tilt angle of 180° yields a peak power output of 5.1 W for the photovoltaic system with PCM and 4.5 W for the system without PCM. Also, reaches to 6.7 W and 5.4 W at a 30° tilt angle for photovoltaic systems with and without PCM.

5. At 180° tilt angle, the photovoltaic system with PCM has 63% overall efficiency and 57% for system without PCM. A 30° tilt angle overall efficiency reaching 65% without PCM and 70% with PCM.
6. The efficiency of PVT-PCM with tidal angle 30° best then the tidal angle 180°.

Funding: This study was not supported by any specific funding.
Availability of information assertion: Upon written request, the author can make available the data used to support the results of this work.
Declarations
Ethical approval: It is not applicable.
Competing interests: The authors affirm that they do not have competing interests.

References
[1]. S. Dixit, "Solar technologies and their implementations: A review," *Materials Today Proceedings*, vol. 28, pp. 2137–2148, Jan. 2020, doi: 10.1016/j.matpr.2020.04.134. Available: https://doi.org/10.1016/j.matpr.2020.04.134
[2]. D. Su, Y. Jia, G. Alva, L. Liu, and G. Fang, "Comparative analyses on dynamic performances of photovoltaic–thermal solar collectors integrated with phase change materials," *Energy Conversion and Management*, vol. 131, pp. 79–89, Nov. 2016, doi: 10.1016/j.enconman.2016.11.002.Available:https://doi.org/10.1016/j.enconman.2016.11.002
[3]. M. M. Rahman, M. Hasanuzzaman, and N. A. Rahim, "Effects of various parameters on PV-module power and efficiency," *Energy Conversion and Management*, vol. 103, pp. 348–358, Jul. 2015, doi: 10.1016/j.enconman.2015.06.067. Available: https://doi.org/10.1016/j.enconman.2015.06.067
[4]. A. Mahdavi, M. Farhadi, M. Gorji-Bandpy, and A. Mahmoudi, "A review of passive cooling of photovoltaic devices," *Cleaner Engineering and Technology*, vol. 11, p. 100579, Nov. 2022, doi: 10.1016/j.clet.2022.100579. Available: https://doi.org/10.1016/j.clet.2022.100579
[5]. W. Pang, Y. Cui, Q. Zhang, Gregory. J. Wilson, and H. Yan, "A comparative analysis on performances of flat plate photovoltaic/thermal collectors in view of operating media, structural designs, and climate conditions," *Renewable and Sustainable Energy Reviews*, vol. 119, p. 109599, Nov. 2019, doi: 10.1016/j.rser.2019.109599. Available: https://doi.org/10.1016/j.rser.2019.109599
[6]. S. M. Parsa *et al.*, "A critical analysis on the energy and exergy performance of photovoltaic/thermal (PV/T) system: The role of nanofluids stability and synthesizing method," *Sustainable Energy Technologies and Assessments*, vol. 51, p. 101887, Jan. 2022, doi: 10.1016/j.seta.2021.101887. Available: https://doi.org/10.1016/j.seta.2021.10188

[7]. R. B, S. Ck, and K. Sudhakar, "Sustainable passive cooling strategy for PV module: A comparative analysis," *Case Studies in Thermal Engineering*, vol. 27, p. 101317, Aug. 2021, doi: 10.1016/j.csite.2021.101317. Available: https://doi.org/10.1016/j.csite.2021.101317

[8]. A. Mahdavi, M. A. E. Moghaddam, and D. D. Ganji, "Hierarchical implementation of hybrid heat promoters fixated on operational conditions to accelerate the melting phenomenon of a triplex tube heat exchanger," *Thermal Science and Engineering Progress*, vol. 25, p. 101008, Jul. 2021, doi: 10.1016/j.tsep.2021.101008. Available: https://doi.org/10.1016/j.tsep.2021.101008

[9]. P. Dwivedi, K. Sudhakar, A. Soni, E. Solomin, and I. Kirpichnikova, "Advanced cooling techniques of P.V. modules: A state of art," *Case Studies in Thermal Engineering*, vol. 21, p. 100674, Jun. 2020, doi: 10.1016/j.csite.2020.100674. Available: https://doi.org/10.1016/j.csite.2020.100674

[10]. Klemm, T., Hassabou, A., Abdallah, A., & Andersen, O. (2017). Thermal energy storage with phase change materials to increase the efficiency of solar photovoltaic modules. Energy Procedia, 135, 193–202. https://doi.org/10.1016/j.egypro.2017.09.502

[11]. S. Koundinya, N. Vigneshkumar, and A. S. Krishnan, "Experimental Study and Comparison with the Computational Study on Cooling of PV Solar Panel Using Finned Heat Pipe Technology," Materials Today Proceedings, vol. 4, no. 2, pp. 2693–2700, Jan. 2017, doi: 10.1016/j.matpr.2017.02.145. Available: https://doi.org/10.1016/j.matpr.2017.02.145

[12]. V. Sun, A. Asanakham, T. Deethayat, and T. Kiatsiriroat, "Study on phase change material and its appropriate thickness for controlling solar cell module temperature," International Journal of Ambient Energy, vol. 41, no. 1, pp. 64–73, Feb. 2018, doi: 10.1080/01430750.2018.1443500. Available: https://doi.org/10.1080/01430750.2018.1443500

[13]. R. M, L. S, R. S, A. H, and D. A, "Experimental investigation on the abasement of operating temperature in solar photovoltaic panel using PCM and aluminium," Solar Energy, vol. 188, pp. 327–338, Jun. 2019, doi: 10.1016/j.solener.2019.05.067. Available: https://doi.org/10.1016/j.solener.2019.05.067

[14]. N. Akshayveer, A. Kumar, A. P. Singh, and O. P. Singh, "Effect of novel PCM encapsulation designs on electrical and thermal performance of a hybrid photovoltaic solar panel," Solar Energy, vol. 205, pp. 320–333, May 2020, doi: 10.1016/j.solener.2020.05.062. Available: https://doi.org/10.1016/j.solener.2020.05.062

[15]. R. Kumar, P. Praveen, S. Gupta, J. Saikiran, and R. S. Bharj, "Performance evaluation of photovoltaic module integrated with phase change material-filled container with external fins for extremely hot climates," Journal of Energy Storage, vol. 32, p. 101876, Sep. 2020, doi: 10.1016/j.est.2020.101876. Available: https://doi.org/10.1016/j.est.2020.101876

[16]. A. Mahdavi, M. A. E. Moghaddam, and A. Mahmoudi, "Simultaneous charging and discharging of multi-tube heat storage systems using copper fins and Cu nanoparticles," Case Studies in Thermal Engineering, vol. 27, p. 101343, Aug. 2021, doi: 10.1016/j.csite.2021.101343. Available: https://doi.org/10.1016/j.csite.2021.101343

[17]. R. Kumar, P. Praveen, S. Gupta, J. Saikiran, and R. S. Bharj, "Performance evaluation of photovoltaic module integrated with phase change material-filled container with external fins for extremely hot climates," Journal of Energy Storage, vol. 32, p. 101876, Sep. 2020, doi: 10.1016/j.est.2020.101876. Available: https://doi.org/10.1016/j.est.2020.101876
[18]. A. Mahdavi, M. A. E. Moghaddam, and D. D. Ganji, "Hierarchical implementation of hybrid heat promoters fixated on operational conditions to accelerate the melting phenomenon of a triplex tube heat exchanger," Thermal Science and Engineering Progress, vol. 25, p. 101008, Jul. 2021, doi: 10.1016/j.tsep.2021.101008. Available: https://doi.org/10.1016/j.tsep.2021.101008
[19]. L. Siahkamari, M. Rahimi, N. Azimi, and M. Banibayat, "Experimental investigation on using a novel phase change material (PCM) in micro structure photovoltaic cooling system," International Communications in Heat and Mass Transfer, vol. 100, pp. 60–66, Jan. 2019, doi: 10.1016/j.icheatmasstransfer.2018.12.020. Available: https://doi.org/10.1016/j.icheatmasstransfer.2018.12.020
[20]. S. S. Chandel and T. Agarwal, "Review of cooling techniques using phase change materials for enhancing efficiency of photovoltaic power systems," Renewable and Sustainable Energy Reviews, vol. 73, pp. 1342–1351, Mar. 2017, doi: 10.1016/j.rser.2017.02.001. Available: https://doi.org/10.1016/j.rser.2017.02.001
[21]. S. Nižetić, M. Jurčević, D. Čoko, and M. Arıcı, "A novel and effective passive cooling strategy for photovoltaic panel," Renewable and Sustainable Energy Reviews, vol. 145, p. 111164, Apr. 2021, doi: 10.1016/j.rser.2021.111164. Available: https://doi.org/10.1016/j.rser.2021.111164
[22]. S. A. Kalogirou, Solar Energy Engineering: Processes and Systems: Second Edition. 2014.
[23]. H. Ebrahimi, H. S. Akhijahani, and P. Salami, "Improving the thermal efficiency of a solar dryer using phase change materials at different position in the collector," Solar Energy, vol. 220, pp. 535–551, Apr. 2021, doi: 10.1016/j.solener.2021.03.054. Available: https://doi.org/10.1016/j.solener.2021.03.054
[24]. S. Aneli, R. Arena, and A. Gagliano, "Numerical simulations of a PV module with phase change material (PV-PCM) under variable weather conditions," Int. J. Heat Technol., vol. 39, no. 2, pp. 643–652, 2021. https://doi.org/10.18280/ijht.390236
[25]. H. A. Maarof, V. M. Avargani, I. E. Maree, and A. H. Yaseen, "CFD modeling of a tubular three-pass solar air heater with phase change material: Investigating heat transfer enhancement and energy efficiency," J. Energy Storage, vol. 87, p. 111522, 2024. https://doi.org/10.1016/j.est.2024.111522
[26]. N. Azimi, E. Sharifzadeh, M. Rahimi, and M. Nouira, "Improving the performance of photovoltaic panels integrated with ultrasound and phase change materials: Experimental study and CFD modeling," J. Therm. Anal. Calorim., vol. 149, no. 15, pp. 8193–8213, 2024. https://doi.org/10.1007/s10973-024-13295-1
[27]. S. D. Prasetyo, A. R. Prabowo, and Z. Arifin, "The use of a hybrid photovoltaic/thermal (PV/T) collector system as a sustainable energy-harvest instrument in urban technology," Heliyon, vol. 9, no. 2, p. e13390, 2023. https://doi.org/10.1016/j.heliyon.2023.e13390

[28]. N. Azimi, E. Sharifzadeh, M. Rahimi, and M. Nouira, “Improving the performance of photovoltaic panels integrated with ultrasound and phase change materials: Experimental study and CFD modeling,” J. Therm. Anal. Calorim., vol. 149, no. 15, pp. 8193–8213, 2024. https://doi.org/10.1007/s10973-024-13295-1

[29]. F. M. Hussien, A. S. Hassoon, and J. J. Faraj, “Performance Analysis of a Triple Pipe Heat Exchanger with Phase Change Materials for Thermal Storage,” International Journal of Heat and Technology, vol. 41, no. 3, pp. 619–628, Jun. 2023, doi: 10.18280/ijht.410314. Available: https://doi.org/10.18280/ijht.410314