Engineering and Technology Journal 42 (01) (2024) 51- 64

Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

Solar photovoltaic thermal cells performance improvement using jet, phase change material and nanoparticles cooling technology: a review

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Mays N. Shaeli[a]*, **Monier Baccar**[a], **Jalal M. Jalil**[b]
[a] Mechanical Engineering Dept., Ecole National Ingenious, Route Soukra Km 3.5 B.P 1173-3038 Sfax, Tunis.
[b] Electromechanical Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
*Corresponding author Email: mays-nasir-nima.shaaeli@enis.tn

HIGHLIGHTS

- Jet impingement cooling and PCM are effective methods to enhance solar (PV) cell performance.
- PCM as storage energy with Nanoparticles to enhance the thermal con ductive of PCM.
- The integration of jet impingement cooling with PCM and Nanoparticles shows improving PV system efficiency

ARTICLE INFO

Handling editor: Sattar Aljabair

Keywords:
Photovoltaic
Nanoparticles
Pcm
Jet Impingement
Thermal

ABSTRACT

The cooling of solar photovoltaic (PV) cells is reviewed in this study. The critical analysis aims to increase PV cell life span and electrical efficiency. To improve the caliber of future studies, this paper examines the implications of earlier studies as well as technical specifics for optimization. Additionally, some of the benefits and drawbacks of various cooling methods are explored. The PV cells cool rate and the PV system's jet impingement cooling technology in PV systems are more effective than any conventional PV cooling systems. Phase change material (PCM) is one of the effective methods used to cool PV cells, as it supporting PV cell cooling in both hot and cold environmental circumstances is beneficial. PCM is appropriate for the cooling application of PV cells due to the requirement of local temperature variation. Many researches and experiences on a different ways of cooling PV collector had been studied to analyze the behavior of PVT systems. Jet and Nanoparticles with PCM are the main ways of cooling and will be discussed in this paper. Lastly, future recommendations based on identified research gaps were suggested. In future work, it is recommended to use jet impingement cooling with PCM together for the PVT system. The proposed system integrates two types of the cooling system with a PV system, the advantage of using jet impingement cooling can result in low average cell temperature for PV cells, and PCM as storage energy with Nanoparticles to enhance the thermal conductive of PCM.

1. Introduction

Solar power development and usage have expanded as a result of great concerns about depletion of the natural resources and future energy supplies. Photovoltaic, a solar power system that utilizes semiconductors to convert solar radiation directly into electricity, has made the most significant leap in the development of solar technology. One way to reduce the cost of solar energy is by concentrating sunlight onto photovoltaic cells and replacing the pricey photovoltaic areas with less expensive concentrating mirrors or lenses. The use of more expensive but more efficient PV cells is possible due to the reduction in solar absorber area. However, only a small portion of the sunlight that strikes the cell is turned into electrical energy (a concentrator cell's normal efficiency is 25%). The remaining absorbed energy will be transformed into thermal energy in the cell and may cause the junction temperature to increase if this heat is not effectively dispersed to the environment [1]. Alternative methods of PVT integration exist a few options include choosing between PVT types as follows:

1) Type of solar cells (polycrystalline/monocrystalline/amorphous silicon (c-Si/pc-Si/a-Si) or thin-film).
2) Type of fluid in collector (air, water, or evaporative).
3) Type of collector (flat-plate or concentrator types, glazed or unglazed panels).
4) Type of fluid flow (naturally occurring or forced fluid flow).

http://doi.org/10.30684/etj.2023.137599.1379
Received 07 April 2023; Received in revised form 09 April 2023; Accepted 09 April 2023; Available online 28 August 2023
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2. Standalone or building- integrated features, etc.

There are three key benefits of PV/T collectors as compared to standalone Photovoltaic panels or thermal collectors: the possibility of higher energy production per area as compared to separate thermal and photovoltaic production for the same total area; Architectural standardization; comparison of separate photovoltaic and thermal systems; and potential cost savings compared to installing photovoltaic panels and thermal collectors separately [2]. Accordingly, there are varieties used of PVT as follows:

1) PVT air or water pre-heating systems.
2) Integrated PV heat pumps for hot water.
3) Actively-cooled PV concentrators that use affordable reflectors.

To maximize the overall benefits, design choices must be made about the type of collector, the thermal- to- electrical yield ratio, and the solar portion. Each of them influences the operating mode of the system, working temperature, and effectiveness [3].

The ability of the PV system to generate solar power was controlled by several factors. One of them was the temperature. The PV module conversion rate would then fall by up to 0.5% for every degree Celsius greater than the ambient temperature (25℃) at which it operates. PV systems like solar panels could absorb most of the solar energy and create the most electricity or heat during the summer, which was the highest solar radiation season. However, a summer day's temperature often ranges from (40 – 70)℃, which was (2-3) times the temperature at which solar panels perform at their best. It poses risks to the PV system's overall performance, with a potential 7.5% –22.5% decline in conversion rate. In other words, radiation loss that occurs as the liquid temperature becomes greater than normothermia has a detrimental impact on the efficiency of PV modules [4].

Every year, photovoltaic technology advances, and in 2021, it was predicted that almost 160 GW of new PV capacities would be added globally. Around 30 GW of installed PV capabilities were in the EU market in 2021. This set a record, whereas Asia is the region with the largest PV market China, which presently has the most PV capacity installed globally, added over 53 GW of additional PV capacity in 2021. When taking into account the objectives of the global energy transition and the imperative decarburization of power systems, the general significance of PV technologies is crucial. Based on IRENA's forecasts, about 8500 GW of installed PVcapabilities will be needed by 2050, to accomplish low-carbon energy transformations. There are other applications for PVs besides the usage of PV technology in residential or large-scale systems, such as photovoltaic-thermal systems (PVT). The PVT system's main drawback is its comparatively high unit cost, which has an impact on the dynamic of installed capacities. Specifically, while examining 2018 data, based on actual PVT systems that have been deployed in the EU, the least cost was approximately €330 per square meter of collection area, with the majority of investments falling between €600 and €900. Even though PVT systems have a relatively high unit cost, they do have a place in the ongoing energy revolution. The PVT system's key benefit is the potential for effective integration into more intricate energy systems, especially when taking into account the installation and integration of heat pumps or even cogeneration systems. However, it should be emphasized that only a small number of studies have examined the economic and environmental implications of the various PVT designs; as a result, the primary focus of subsequent investigations should be centered on the comprehensive assessment of the suggested PVT collector designs [5].

Solar radiation was necessary for photovoltaic modules to produce electricity, however a sizable percentage of solar energy was transformed to thermal heat, reducing its conversion efficiency, open-circuit voltage would decrease as the cell temperature rises. The photoelectric cell's temperature raise increase the circuit resistance to electrons' speed. From the aforementioned, it was evident that solar cell performance degrades as temperature increases. The voltage produced by solar cells decreases with increasing cell temperature. Solar cells' cooling was therefore extremely important and effective. The nature of cooling technology depends on the cooling fluid used to cool solar cells. According to the cooling medium, the cooling techniques were divided into four categories: cooling water, cooling with impinging air jets, cooling with PCM as thermal storage, and cooling with Nanofluid [6].

Solar energy was abundantly present in nature; however, this energy source was uncertain with lower efficiency. To store the energy for later use, new thermal energy storage (TES) system must be developed. The storage medium, energy transfer mechanism, and containment system are the three basic components of a thermal energy storage system. Sensible heat, latent heat of fusion (solid-liquid phase change), or latent heat of vaporization are all forms of heat that the storage medium can hold (liquid-gas phase change). While the containment system holds the other components and also insulates them from the environment to avoid heat losses, the energy transfer mechanism's goal is to extract or deliver heat to the storage medium [7].

When a new solar air collector with corrugated packing was investigated for its thermal performance using mathematical models, it performed better than other corrugated absorbers [6]. By accelerating airflow during the charging process, PCM melting can be delayed and its melting temperature can be lowered. Additionally, there is an inverse relationship between the freezing duration and airflow speed [8].

In recent years, Phase change materials (PCMs), which might absorb significant amounts of latent heat during phase transition processes with little temperature rise, caught the interest of certain researchers. Such a PV-PCM module was anticipated to maintain a lower temperature of PV cells and achieve improved conversion efficiency by attaching the PCM at the rear of the PV panel. The PV-PCM system required less maintenance than most traditional PV/T systems because it used passive cooling and didn't require any additional electricity or running fluid. A lot of research had been done to examine PCMs' use in solar energy and building energy conservation since they were also seen as a practical way to use thermal energy from renewable energy sources. It gave the PV-PCM systems a strong platform for solar energy cogeneration [8]. The main drawback of this approach is delayed response time during charging and discharging; this is caused by the thermal characteristics of phase change materials (PCM), which are frequently utilized to store heat as latent heat [9].

In this research provides a thorough analysis of previous works that explores several strategies to maximize output power by lowering PV collector surface temperatures through the application of various cooling techniques. Although each cooling strategy has been shown to benefit PV panels in the literature, there hasn't been a thorough investigation into how much performance may be improved by combining several cooling techniques. Many additional methods for cooling solar panels PVTS (Photovoltaic Thermal-based Systems) air as PCM (work in night as thermal storage when no solar flux), jet impingement (enhancement heat transfer), Nanoparticles (improve the thermal and heat transfer characteristics of the PCM). and hybrid (PCM, Nanoparticles, Jet) are presented.

3. Cooling Method for Solar Collector

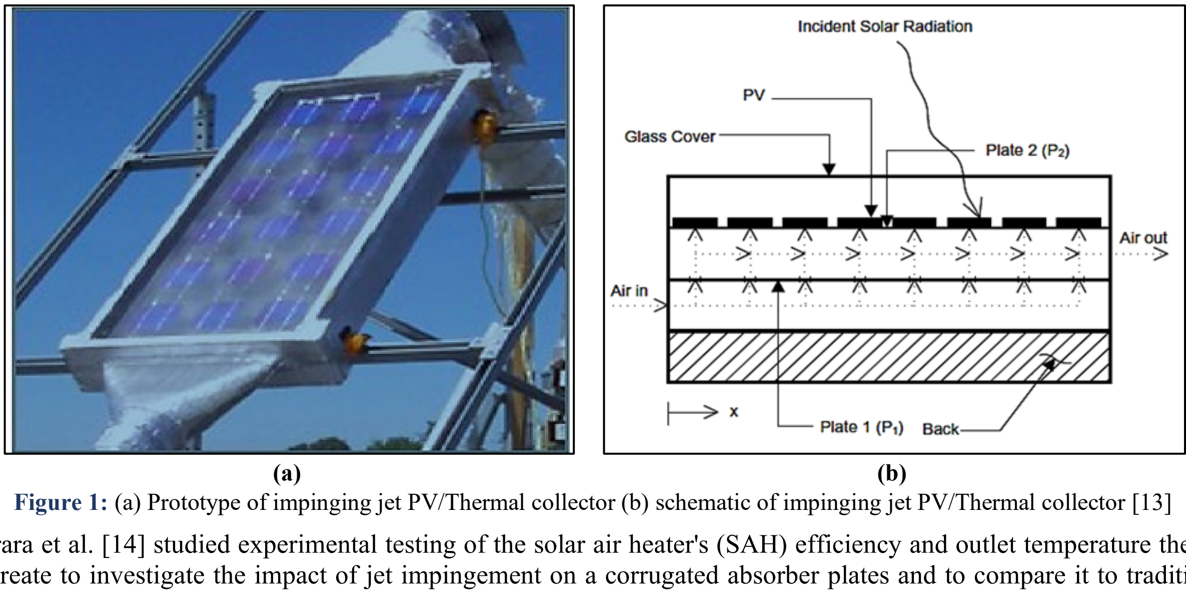
3.1 Jet Impingement

Due to their capabilities for large-scale localized heat and mass transfer, glass tempering, cooling of gas turbines, drying of paper and textiles, and food processing, impinging jets have drawn a lot of interest. Heat transmission between air and a heated surface could be enhanced via jet impingement.

Belusko et al. [10] identified the performance features of jet impingement by a theoretical and experimental analysis. The collector's thermal efficiency was improved by 21 through jet impingement. The pressure loss did increase, but it did so merely little. The efficiency rose by 37%, from (46 - 63)%, with the flow distribution of jets along the collector being the most important component. For tightly packed PV cells under high concentration, some research presented new hybrid jet impingement/micro-channel cooling system. For a combination of slot jet impingement with non-uniform distribution of micro-channels. The hybrid cooling method, as researched by Barrau et al. [11], had a thermal resistance coefficient of $(2.18*10)^{-5}$ km^2/W with lower pressure drop than that of micro-channel devices. This property was related to the fact that the PV receiver 's Net PV output was greater if cooled using a hybrid design than that of micro-channel, with Net PV output at the PV receiver area of 576 cm^2 for hybrid and the Micro-channels = 7905.6 W and 7900.8 W, respectively. By properly distributing local heat removal capacity, it was possible to improve the temperature uniformity of the PV receiver by internal geometry during the design phase.

Researchers that used impinging jets in a solar air heater duct, for example, Chauhan et al. [12] conducted an experimental examination to study the characteristics of heat transmission and friction factor. The experiments covered flows with Reynolds numbers between 3800 and 16,000. The ranges for jet diameter, stream-wise pitch, and span-wise pitch, when normalized by the duct's hydraulic diameter, are 0.043-0.109, 0.435-1.739, and 0.435- 0.869, respectively. Normal air impingement occurs between the jets and the absorber surface, which has been heated with a uniform heat flux of 1000 W/m^2 The findings demonstrate 2.67 and 3.5 times improvement in heat transfer and friction factor, respectively.

To test and validate the model's capabilities, Brideau et al. [13], created a predictive PV/T collector model utilizing impinging jets. A prototype is built and operates at an outdoor facility, see Figure 1 (a,b). The model was discovered to provide findings that were generally fairly accurate. The 6.35 mm diameter holes had a 76.2 mm gap between them when they were bored. With a flow rate of 0.0434 kg/s, the three cells' average efficiency at 25.33°C was 11.88%. For 8 testing days, the worst total daily energy model forecasts for thermal and electrical output, respectively, were within 10% and 11% of the observed value.



(a) **(b)**

Figure 1: (a) Prototype of impinging jet PV/Thermal collector (b) schematic of impinging jet PV/Thermal collector [13]

Aboghrara et al. [14] studied experimental testing of the solar air heater's (SAH) efficiency and outlet temperature the test setup was create to investigate the impact of jet impingement on a corrugated absorber plates and to compare it to traditional solar air heaters that use flat plate absorbers. Results indicate that a key factor in improving heat transmission is flow jet impingement on the corrugated plate absorber. The sun intensity of I=500 W/m^2 and the mass flow rate of 0.028 kg/s result in a maximum efficiency of 68.2% for the solar air heater with jet impingement and corrugated plate. And for I=1000 W/m^2 and a mass flow rate of 0.01 kg/s, the minimum value of 27%. The thermal efficiency of the proposed design duct is observed almost 14% more as compared to the smooth duct.

For inline holes installed between the absorber and the back plate, certain studies examine heat and flow transmission in solar air heaters. It has been investigated how geometrical features, particularly jet and hydraulic diameters, affect flow. Soni and Singh [15] adjusted the experimental mass flow rate for the inquiry based on the Reynolds number (4600-12,000). The normalized hydraulic diameter values for the jet diameter, stream-wise pitch, and span-wise pitch, or Dj/Dh, X/Dh, and Y/D_h, are (0.053-0.084), (0.53-0.63) and (0.53-0.63) respectively. The Temperature Rise Parameter (TRP), collector effectiveness, and Nusselt number were evaluated about performance. It had also been demonstrated that sun intensity varied hourly. For all geometrical configurations, an increase in mass flow rate resulted in an increased in collector efficiency and a drop in the Temperature Rise Parameter. At a jet diameter to hydraulic diameter ratio of 0.07, it is discovered that all the performance metrics given above are at their maximum.

In his study, Matheswaran et al. [16], used the jet impingement of Single Pass Double Duct Jet Plate Solar Air Heater (SPDDJPSAH), which was analyzed systematically for energy efficiency. Several rates of mass flow of (0.002-0.023) kg/s, the ratio of stream wise-pitch (X/Dh) of (0.435-1.739), ratio of span-wise pitch (Y/Dh) of (0.435-0.869), and the ratio of jet diameter (Dj/Dh) of (0.043-0.109) are used in the analysis. Results reveal that when compared to a control, SPDDJPSAH has improved both effective efficiency and exergy efficiency by 21.2% and 22.4%, respectively (SPSDJPSAH). Hai et al. [17] looked at how inclined impinging jets on the surface of a solar air heater could improve performance. The parallel and crossing orientation of nozzles in successive rows were two basic sets of arrangements that were taken into consideration for the jet nozzles Figure 2 (a-c). When contrasting the parallel and crossing orientations, it has been demonstrated that the velocity ratio amount plays a significant role. Results also showed that increasing the streamwise and spanwise pitch increased the Nu number while only slightly affecting the friction factor.

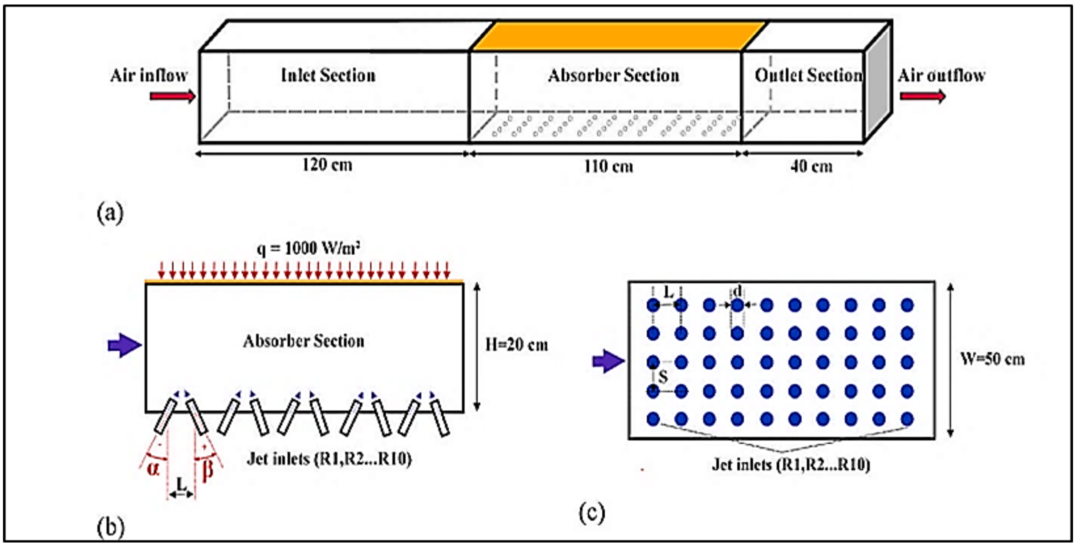


Figure 2: Schematic of jet SAH (a) isometric view (b) side view of absorber section (c) bottom view of absorber section [17]

Solar air heater with an impinging jet and an absorber plate heat transfer behavior computational analysis created by Yadav et al. [18]. Under various flow situations, with Reynolds numbers of (3500 -17,500), jet impingement solar air heater performance was examined. When operating under the same conditions, it has been discovered that jet impinging solar air heaters produce a far higher heat transfer rate than smooth solar air heaters. The highest heat transfer enhancement of 7.58 is attained with a friction factor penalty of 9.01 times at jet diameter to height ratios of 0.0650 and 0.216 at Reynolds number 17,500. The higher thermal-hydraulic performance parameter value of 3.66 was attained for Reynolds number 15,500, which is equivalent to 0.216 jet height ratio and 0.065 jet diameter ratio. Kumar et al. [19] examined into the combined effect of artificial roughness and jet impingement on the performance of the solar air heater (SAH) depicted. The impingement jet (SAH) was roughened using discrete multi-arc-shaped ribs. By changing the Reynolds number (Re) from 3,000 to 19,000, the experiment was conducted. During experimentation, the various multi-arc rib roughness characteristics changed. In comparison to a smooth channel, the roughened solar thermal collector's Nusselt number (Nu) and friction factor (f) were determined to be 7.61 and 6.48 times greater, respectively. For the variety of intended parameters, a thermal-hydraulic performance of 4.1 was found. Therefore, it was discovered that the roughness element used in SAH coupled with jet impingement had a significant impact on its thermo-hydraulic performance. Jalil et al. [20] studied numerically the thermo hydraulic performance of a solar air heater with straight-shaped baffles is computationally and experimentally evaluated to determine the best value. According to the findings, the 3.75 cm duct height and 0.05 kg/s air mass flow rate produce the maximum effective efficiencies. Matheswaran et al.[21] improved the performance of the jet plate solar air heater using the multi-hole jet impingement technique as Figure 3. The findings indicate that the optimal design parameters are an airflow velocity of 0.01386 kg/s, a length of 1.5108 m, a jet diameter of 0.0046 m, and a stream-wise pitch distance of 0.05108 m with a span-wise pitch distance of 0 0.03414 m. Table 1 shows some of the research results of jet impingement.

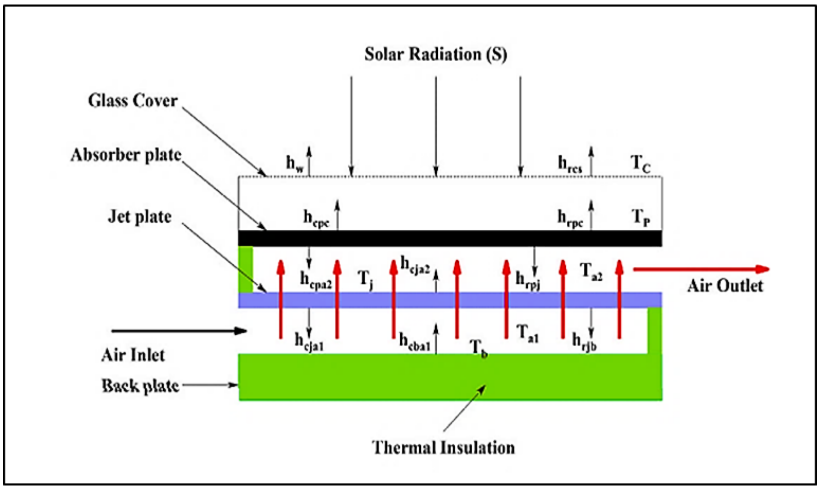


Figure 3: Schematic layout of JPSAH [21]

Table 1: Some results of PV with jet studies

Jet hole diameter (mm)	Florates (kg/s)	Tambient (°C)	Distance between jet holes (mm)	Efficiency of PV	Ref.
4.5	0.046	13	50	63%	[10]
6.35	0.0434	25.33	76.2	Average	[13]
3	0.028	25	80	68.2%	[14]
5	0.0602	25.4	75	35%	[19]

3.2 PV- PCM System

PVT hybrid systems can simultaneously generate heat and power. These systems' overall effectiveness, which accounts for both their entire thermal and electrical performance, is greater than that of PV as well as thermal collectors used separately, and it could be increased by integrating (PCM). PCMs first capture the latent heat from the PV panel's waste heat, which lowers the panel's surface temperature and improves electrical efficiency. To increase freshwater productivity, Kabeel et al. [22] investigated experimentally a double pass solar air collector-coupled modified solar still using Phase Change Material (PCM), to enhance the freshwater productivity. To assess the improvement in freshwater productivity, comparisons were done between the traditional still and a modified still with PCM and hot air injection. It was made of 17.5 kg of paraffin wax. According to the experimental findings, the traditional still's freshwater production was 4.5 (L/m^2 day), whereas the double passes solar air collector-coupled modified solar still's productivity was around 9.36 (L/m^2 day). The two passes solar air collector-coupled modified solar still with PCM had an average freshwater production that was 108% higher than that of the traditional still.

Rajvikram et al. [23] concentrated on a unique method for improving solar PV panel efficiency using PCM and aluminum sheet as Thermal Conductivity Enhancers (TCE). The PV panel's back side has a 0.0361 m^2 area made of PCM and aluminum. An aluminum sheet with a surface area of 0.036 m^2 is immediately attached to the back of the PV panel to develop the PCM thermal conductivity and heat dissipation. Two 5 W panels were employed in the experiment, and the PV-PCM embedded with an aluminum panel's performance was compared to that of a naturally ventilated panel devoid of PCM and the aluminum. The PV-PCM with aluminum sheet on the panel back boosted the panel's conversion efficiency by an average of 24.4%, according to experimental verification. The panel's electrical efficiency went up 2% for a 10.35°C average decrease in temperature. According to the FLIR thermal imaging camera's findings, the temperature dropped by a high of 13°C on Day 1 and 7.7°C on Day 2.

To simulate the convective impact without solving N-S equations, Zhao et al. [24] used an improved conductivity technique. With a good mix between simplicity and accuracy, the model was created based on a 1-D thermal resistance model and validated using experimental data. The results indicate that systems function differently under various weather conditions within five simulated systems. For instance, a PV-PCM system of high melting temperature typically does well during summer but may inhibit heat transfer during winter, as it is difficult to melt PCM on cold days. The biggest year-round power production improvement was 2.46% compared to the reference PV system, which is less than the figure recorded in the majority of research that was only conducted in a lab or on bright days over a short period time. Additionally, the economic analysis shows that the PV-PCM system is not practical at this time without major improvement in PCM performance or by utilizing electricity-and-heat cogeneration. After adding a layer of PCM inside the panel, some studies assessed the behavior of various photovoltaic-thermal panels (PVT) and their energy performance. Simón-Allué et al. [25] exposed PVT panels to the sun during maximum irradiance hours and exposed to various working conditions to correctly assess their thermal performance. In terms of the heat absorber, aluminum was shown to have better thermal performance than polymeric cases, but electrical generation was produced at a similar rate in both cases. After eliminating sun exposure, PCM produced up to 30% of its maximum thermal power, which is not a major improvement but does indicate the improved output of heat distribution.

Salih et al. [26] used several rectangular capsules filled with paraffin wax-based phase change material PCM. A novel solar air heater was merged with a mathematical model to analyze three-dimensional forced convection turbulent flow. The data results show that there was a significant relationship between airflow speed and useable energy rate and thermal storage efficiency and, Abed [27] used PCM as thermal storage to improve thermal storage behavior and efficiency for a system that integrates cylindrical capsules with solar air heaters. Results indicate that, when compared to conventional sensible heat energy storage systems, the performance of combined sensible and latent heat storage systems is most suitable for a variety of applications. Abdulmunem et al. [28] regulated the temperature of PV cells to improve performance by harnessing the latent heat of fusion provided by paraffin wax (PCM) and calculating the impact of coupling aluminum fins with PCM. In comparison to using PV cells without PCM, the performance of the employed PV cells improved with a decrease in temperature by approximately 9.84% and 5.1% for maximum power and fill factor, respectively. Bayrak et al. [29] investigated experimentally photovoltaic (PV) panels by using different cooling methods. Thermoelectric (TE), aluminum fins, and phase change material (PCM) were chosen as the cooling methods. One PCM that was frequently used for cooling PVs was $CaCl_26H_2O$, and the other PCM has a melting temperature that is higher than the surface temperature of the PV panel. The PV with fin system provided the maximum power output of 47.88 W when the most effective cooling techniques were evaluated in the same environmental conditions, while the PV with PCM and TEM produced the lowest power generation of 44.26 W. Zohra et al. [30] has been presented to improve electrical energy in the photovoltaic (PV) system by absorbing heat. In order to extend thermal stability duration, minimize temperature variance, and maximize thermal production efficiency, the suggested system incorporates two types of PCM see Figure 4. Electrical efficiency has increased by around 34% compared to PV without PCM and can reach 42.5% with two PCM, and electrical power output has increased dramatically, reaching 54.5% at the start of the day.

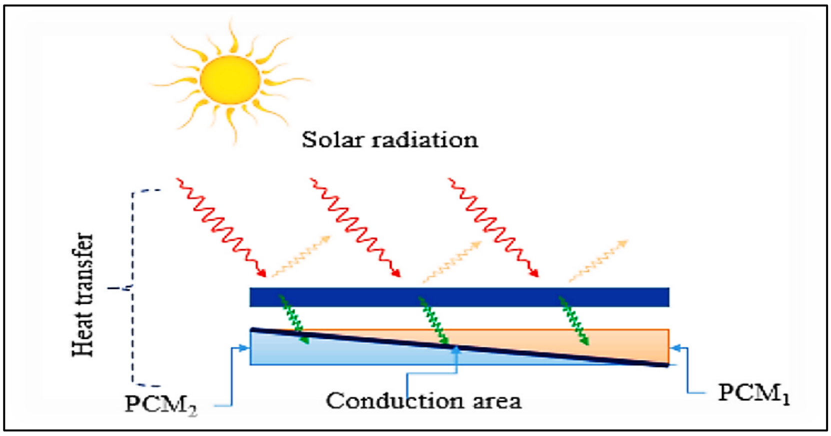


Figure 4: Description of the solar radiation effect on PV/PCM system [30]

To improve cooling and thermal control in hybrid systems and eliminate the elevated PV-temperature levels caused by PCMs, Abdelrazik et al. [31], used many arrangements of various PCMs and various forms of a Nanomaterial at various loadings. At big loadings (10, 20, 30) wt% four different PCM types and four different Nanoparticles materials were utilized. Although the temperature increase along the panel lowers from 41% to 12% as paraffin wax RT35 was utilized as PCM, PV temperatures rise when compared to a normal PV/T system (65℃ with RT35 against 47.5℃ without a PCM) 50 mm PCM thickness. Better cooling and enhanced overall performance were provided by increasing Nanoparticles loading in PCM. The best nanomaterial for best cooling (52℃ for RT35/MWCNT at loading of nanoparticles of 10 wt.%) and superior overall performance was a multi-walled carbon nanotube. Additionally, when there is a larger sunlight concentration, the addition of nanoparticles is more operative. While RT35 offers improved thermal management of PV panels, while at relatively higher temperatures, the $CaCl_2.6H_2O$ (PCM) offers superior performance at reasonably lower temperatures.

To forecast PV temperature (Tpv) which was in contact with PCM with the roughly same precision as CFD modeling but with two or three orders of magnitude less computational time, Elsheniti et al. [32] suggested a revolutionary simplified-one-dimensional mathematical model during the melting and solidification processes, as well as at various inclination angles for a PV panel, the novel "1D Boosted Conduction Model ECM" approach is based on calculating the equivalent thermal conductivity that is boosted by the convection currents within PCM. The biggest differences between the two models in determining average Tpv, for all angles of inclination and during the peak melting period of (10:00 - 15:000, are 1.78% for the highest, while it was 0.74% for lowest aspect ratios, whereas it almost zero during the solidification. The melting of PCM inside a rectangular enclosure-probably finned and inclined-was explored statistically by Groulx et al. [33]. The investigated scheme is modeled as a 2D rectangular enclosure packed between two aluminum plates and filled with PCM (RT25), with the front exposed to a steady heat flux of 1000 W/m^2 of two hours. Non-finned (PCM) enclosure, (PCM) enclosure with one half-width fin attached to the front plate, (PCM) enclosure with one centered full-width fin, and (PCM) enclosure with one half-width fin attached to the back plate were all taken into consideration. Results have demonstrated that a full-width fin that is concurrently mounted to front and the back plates of the PCM enclosure allows for the most effective thermal control of PV- PCM panel. With this type of PV panel design, natural convection heat transport from both sides of the PCM enclosure dominates PCM melting early on, with additional heat losses from the back plate to surrounding environment. Therefore, as tilt angle was changed between 0° and 75° from vertical, temperature values of the front and back plates may be maintained low over a stabilization duration of 80 min. The high total coefficient of heat transfer acquired throughout the entire melting process was primarily responsible for the effective temperature control provided by the full-width fin design. To extract heat from the PV panel, Singh et al. [34] described research on merging natural convection phenomena with (PCM). To compare the electrical and thermal properties of PV, PV/PCM, and air-integrated PV-T/PCM systems with an incidence solar radiation of 800 W/m^2, numerical analysis has been done. In comparison to the base PV system, the temperatures of the PV cells in the PV/PCM system and the air PV-T/PCM, respectively, have decreased by 25% and 35%. This drop in temperature has increased PV cells' electrical efficiency by 14.12% for the PV/PCM system and 19.75% for the air PV-T/PCM, respectively. Using SILICON CARBIDE (Sic), COPPER (Cu), and PARAFFIN WAX (Petroleum wax).

Kumar et al. [35] conducted an experimental study on the impact of thermal behavior and electrical performance of PV panels. Three prototypes were developed and tested before an appropriate experimental setup is created. Platform, photovoltaic panel, and electrical circuit with predetermined charge make up Prototype 1. In Prototype 2, a container holding a combined PCM has been added to the back of each PV panel. It was determined that whereas using standard increased electrical output by an average of 2.8%, using combined PCM increased it by an average of 4.3%.

Performance of PVTs (photovoltaic thermal systems) with and without glazing combined with a PCM layer (PVT/PCM) which was examined in some research employing a mixture of ethylene glycol (EG) and pure water, for instance, Kazemian et al. [36]. Pure water, 100% pure EG, and a mixture of pure water and 100% pure EG with a mass ratio of 50% (EG 50%) are three cooling fluids that were studied. According to the findings, mixing EG with pure water reduces thermal energy efficiency of PVTs but increases their thermal energy efficiency. Additionally, if EG was added as an impurity to pure water, PVT/PCM system's total energy and exergy efficiency decrease. The findings also show that, compared to the unglazed systems, the percentage of energy losses lowers in the glazed cases of water-based PVT/water, PVT/EG (50%), and PVT/EG (100%) by (9.28%, 23.33%, and 48.58%), respectively. Environmental research also shows that employing a PVT system greatly improves CO2 mitigation from both thermodynamic methods when compared to PV unit. The water/EG blend, which has a lesser freezing point and more total energy and exergy than pure EG which was recommended for cold climate conditions, is finally introduced as a suitable coolant fluid.

When applied to a thorough examination of a PV/T-PCM (photovoltaic/thermal/phase change material) solar system. The PV was cooled using a solar collector filled with PCM that include rectangular metal fins to improve heat transmission. According to findings, the PV panel s ' temperature fluctuation could be greatly reduced and photoelectric efficiency increased by using PCM in the solar collector. Even with the inclusion of metal copper fins, the solar collector temperature stratification was still significant due to limit thermal conductivity of fatty acids. The overall efficiencies of Cases 1 and 3 were able to attain about 91% thanks to the thermal regulation technique of setting the temperature at 45°C. With the temperature set at 50°C for the thermal regulation technique, Cases 3 and 4's total efficiency was around 85%. It used the thermal regulation strategy's relatively low-temperature setting; more heat might be evacuated from PCM in the solar collector. It determined that a decent thermal management method can increase the PV/T-PCM system's total energy consumption ratio [37]. By utilizing heated sinks instead of flexible blades below the panel as Figure 5 and Figure 6 (a,b), Gholami and Gorji [38] improved the thermal conductivity of PV by using sodium sulfate decahydrate ($Na_2SO_4.10H_2O$) with varying masses as a PCM. The findings indicate that fixed blades and heatsinks have a favorable impact on temperature parameters and panel efficiency. The test was conducted at a 35-degree angle to the horizon in the radiation range of 800 W/m^2.

Docosane $C_{22}H_{46}$ paraffin wax PCM is utilized in some cases to reduce thec- Si PV modules operating temperature running in hot climates. According to Amalu and Fabunmi [39] results, the temperature differential between the ambient environment and the solar cell peaked at noon (23.7°C) and then monotonically fell to zero at 6 a.m. and 8 p.m. When PCM is used, a PV-PCM module is produced that has a conversion efficiency of 10.88% higher than a typical c-Si PV module. Further research revealed that the PV-PCM module's increased efficiency led to a drop in cell temperature of 78.4% at peak heat flow and 31.1% overall. Compared to the standard c-Si PV module, the PV- PCM module daily produced 6.1% more voltage, 2.1% more electric power, and 8.1% greater maximum power. Additionally, it was discovered more efficient by 1.05% and had a 34.0% longer fatigue life. Table 2 shows some of the research results of PCM.

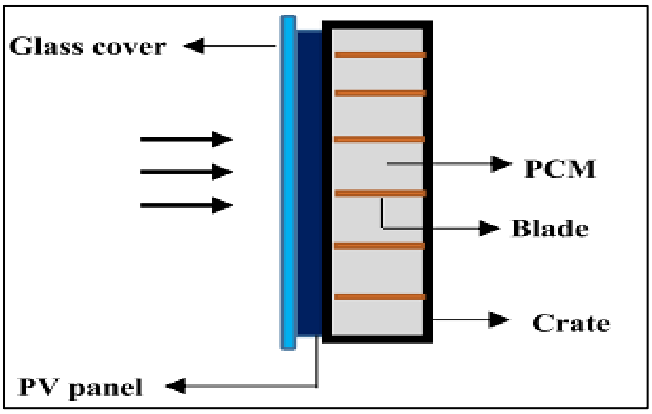


Figure 5: Schematic of PV and compartment containing PCM from side view [38]

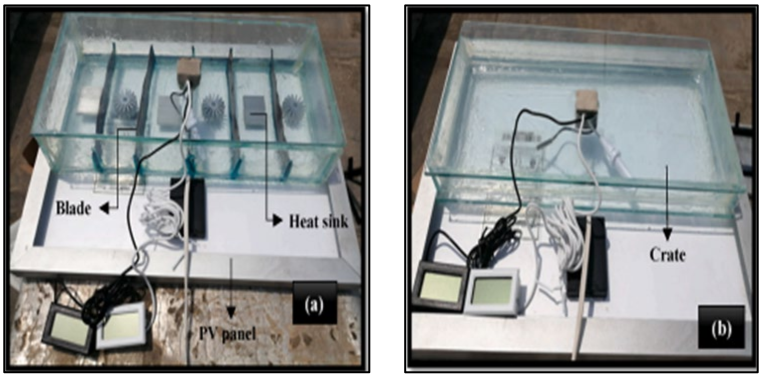


Figure 6: Panel (a) with blade and heatsink (b) normal [38]

Table 2: Results of PV with PCM studies

PCM type	PCM thickness (mm)	Melting temp (˚C)	Efficiency of PV	Ref.
OM-29	30	29.0	24.4%	[23]
Paraffin wax	50	42	improving the electricity production by 2.46% yearly	[24]
organic RT50, RT-LINE	10 and 15	45 and 50	13–15%	[25]
paraffin wax RT35	50	25	17.8%	[31]
paraffin wax	40	25	18%	[32]
paraffin wax/copper/silicon carbide	50	50	12.9%.	[3]
Paraffin wax (Merck, 107151)	256	46-48	14.17%	[3]

3.3 Nanoparticles as cooling system

To enhance PCM's thermal and heat transfer properties, nanotechnology developed a new technique called Nanoparticles, which combines solid Nanoparticles and melted PCM as composite materials. Metal and metal oxide Nanoparticles, grapheme, and carbon Nanotubes typically selected for improving heat conductivity. The improvement of Nano fluids thermal conductivity significantly influenced by the size and shape of the particle [40].

Saadoon et al. [41] used Nanofluids (Al_2O_3) for the enhancement Performance of PV Several researchers have examined the potential use of PCM to increase PV/T system thermal performance while lowering system heat loss and energy destruction. The majority of researchers have found that adding Nanoparticles to the PCM bulk improves its thermal properties [42,43]. This increases the material's thermal conductivity and thermal storage capacity. For instance, Kazanci et al. [44] analyzed PCM's performance in PV/T systems they discovered that PCM can increase PV panels 'electricity output by 15.5%. SiC Nanoparticles with mass fractions of (0 –4)% in paraffin-PCM were used by Al-Waeli et al. [45] to investigate the electrical and thermal performance of hybrid PV/T panels. Results cleared that, when PCM was incorporated into the system, the PV/T panel heat dissipation become more uniform. As compared to standard PV systems, the system's efficiency increased from 7.1% to 13.7% with the addition of PCM. Sardarabadi et al. [46] conducted an experimental study on the impact of ZnO/water Nanofluids and paraffin wax PCM in a PV/T system. They observed a 13% increase in electrical efficiency using Nanofluids at concentrations of 0 weight percent, 0.1 weight percent, 0.2 weight percent, and 0.4 weight percent. Compared to PV/T systems cooled with pure water, the efficiency of systems using Nanofluids were 5% higher. A PCM also increased PV panel's efficiency by 9%. In a different study, Al-Waeli et al. [47] experimentally examined the functionality of a hybrid PV/T system and numerically assessed the system's economic functionality. They used paraffin wax as a PCM material and SiC/water Nanofluids of 0 to 4 wt. percent. Al_2O_3-water was employed by Teamah et al. [48], as their working fluid. The findings demonstrated that, in comparison to pure water, the convective heat transfer coefficient increases as the percentage of Nanoparticles increases. The heat transfer coefficient rises by 62% in comparison to pure water at =10.0% and Re=24000. It has been shown that CuO Nanofluids improve heat transmission by 8.9% and 12%, respectively, when compared to titanium and aluminum Nanofluids. Hasan et al. [49] examined the impact of water-based nanoparticles (SiC, TiO_2, and SiO_2) on the electrical and thermal performance of a jet impingement-equipped photovoltaic thermal (PVT) collector. With predetermined solar irradiation levels and mass flow rates, had tested the PVT collector indoors 36 nozzles and four parallel tubes made up the system, which directly injected fluid into the PVT collector's rear. Comparing the PVT with SiC Nanofluids to the conventional PV module, the Pmax rose by 62.5%.

The electrical and thermal performance of the multi-walled carbon nanotube- water/ethylene glycol (50:50) Nano-suspension (MWCNT/WEG50)- based photovoltaic solar panel cooling system was examined. The experimental was created by Sarafraz et al. [50]. Using an ultrasonic homogenizer and nonylphenol ethoxylates at a concentration of 0.1vol%, the produced Nanofluids were stabilized at a PH of 8.9. A cooling jacket was created and affixed to the solar panels to decrease heat loss and increase the rate of heat transfer between the coolant and the panel. Additionally, it was filled with multi-walled carbon nanotube-paraffin PCM, through which cooling pipes were run. While Nano-PCM was in the cooling jacket, MWCNT/WEG50 Nanofluids is put inside pipes. At various local periods and with varied MWCNT mass fractions, the system's electrical and thermal power as well as equivalent electrical-thermal power was evaluated. Results reveal that there was the increase in coolant mass concentration increased power output and electricity generation, while an increase in Nanofluids mass concentration increased pumping power and decreased thermal-electrical equivalent power. An MWCNT/WEG50 Nano-suspension was found to have maximum electrical and thermal performance, with a 292.1 W/m^2 rating. It’s discovered also that, between 1:30 and 3:30 pm, a photovoltaic (PV) panel can generate 45% of electricity as well as 44% of thermal power at 0.2wt%. Abdelrahman et al. [51] enhanced the photovoltaic cells performance. The effect of changing configurations and using PCM mixed with Nanoparticles were experimentally investigated. PCM (RT35HC) was mixed with various volume fractions of AL_2O_3 from 0.11% to 0.77%. Also, cylindrical fins were used as heat sink and thermal conductivity enhancers (TCE) for a heat aluminum plate to simulate PV solar cell. The results showed that the cylindrical fins with RT35HC achieved enhancement in a temperature reduction of 20–46.3% in the front surface temperature and increases to 52.3% by adding the nanoparticles.

When some studies employed hybrid PVT/PCM system to explore experimentally effects of organic paraffin wax PCM as a passive cooling medium and water/glycol-based Nanofluids as active cooling media, for instance, Naghdbishi et al. [52], built a (2 kg of paraffin wax) the charging process takes place between 21.41 and 70.32°C, and the discharging process takes place between 74.75 and 30.88°C.Based on their high thermal conductivity, which enables employing lower concentration of these nanoparticles while lowering the flow pressure drop and pumping power consumption, multi-wall carbon Nanotubes (MWCNT) were regarded as nanoparticles. MWCNT/water Nanofluids exhibit the best PVT/PCM panel performance in terms of the relative improvement of electrical energy and exegetic efficiency. In comparison to pure water as a cooling fluid, the dispersion of MWCNT nanoparticles in the water base fluid boosts the thermal and electrical energy efficiency up to 23.58% and 4.21%, respectively. Heat dissipation from the PVT panels to the surroundings and the difference in surface temperatures of the sun and PVT are discovered to be the main influencing variables for external energy losses and exergy destructions of the system, respectively.

In order to cool a photovoltaic (PV) panel experimentally, Maghrabie et al. [53] used a phase change material (PCM) of paraffin wax RT-42 connected to the panel's back surface as shown in Figure 7. For the outdoor testing, two identical PV panels with a combined maximum electrical generated power of 40 W were used: a reference PV panel (PVr) and a PV panel with PCM integration (PV-PCM). The electrical power output of the PV-PCM panel with a 3 cm PCM thickness over the reference panel (PVr) at a tilt angle of 30 also increased by 15.8%. Table 3 shows some of the research results of Nanoparticles.

Table 3: Photovoltaic /thermal (PV/T) systems research with Nanofluids

Type of Nanofluids	Concentration of Nanoparticles	Efficiency	Ref.
SiC, TiO_2, and SiO_2	1 wt.%	SiC= 16.5%, TiO_2=15.5% SiO_2= 14.4%	[49]
Water/ethylene glycol/multi-walled carbon nanotubes (50:50) Nano-suspension	0.2wt.%	~45%	[50]

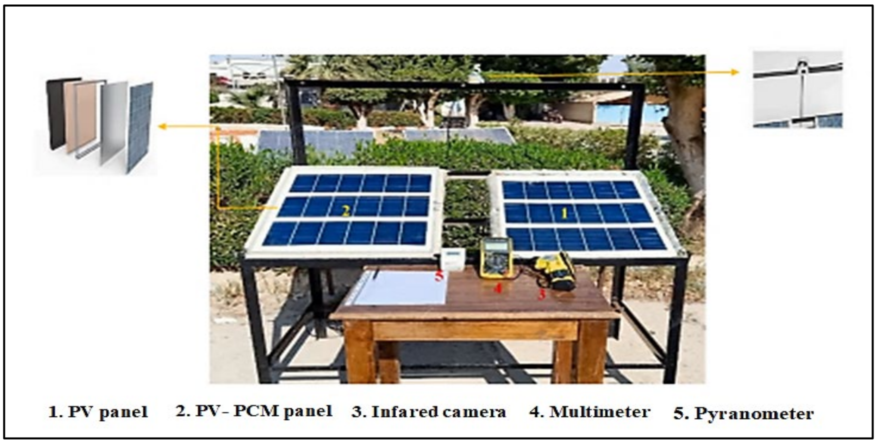


Figure 7: Experimental set-up of PV and PV-PCM panels [53]

3.4 PCM with jet impingement system

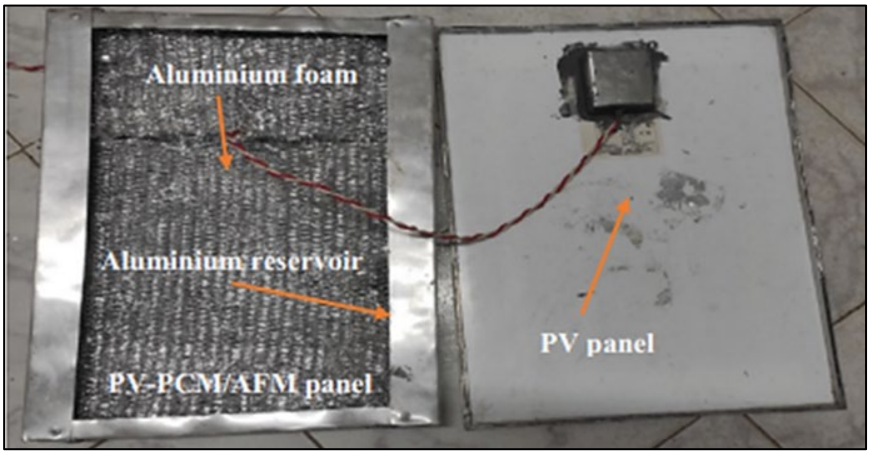
PCM can release or absorb thermal energy if there is a phase change from liquid to solid and vice versa. This slurry could be utilized to minimize coolant loop total pumping power due to the increment of carrying fluid heat capacity. Jet impingement shows an enhancement of the heat transfer of the PCM slurry, and provides a higher average heat transfer coefficient. To improve the heat transfer performance of jet impingement and spray cooling, Wu et al. [54] introduced Polymer encapsulated Nano phase change materials (paraffin) in particle form (Nano PCM) to water. When paraffin transforms from its solid state into a liquid, the Nano PCM particles absorb heat. Paraffin aggregation and leakage are both prevented by encapsulation. Heat transfer and pressure decrease are significantly influenced by the Nanoparticles volume fraction. In comparison to a base solution, slurry with a 28% particle volume percent improves the heat transfer coefficient for jet impingement and spray cooling by 50% and 70%, respectively. A closed loop of repeated use has proven the shell encapsulation's structural integrity.

Nada et al. [55] explored the temperature regulation and efficiency improvement of PV-building integrated systems utilizing PCM and Al_2O_3 nanoparticles. The study's technique entails testing three distinct integrated PV units into building walls, pure PCM, and a combination of PCM and Al_2O_3 nanoparticles all at once. The results show that:

1) Adding a PCM to the back of a PV module improves efficiency and controls module temperature.

2) Adding Al_2O_3 Nanoparticles to the PCM increases the likelihood of temperature management and thermal efficiency of interconnected modules.
3) By combining pure PCM and improved PCM with PV, the temperature of modules can be lowered by (8.1 and 10.6)°C and their efficiency could be raised by (5.7 and 13.2)%, respectively.

Utilizing an experimental investigation and a compound enhancement method, Salem et al. [56] investigated the cooling impact of PV modules; they employed water and/or an Al_2O_3/PCM combination with varying nanoparticle mass concentrations. Through the use of water and an Al_2O_3/PCM mixture with various nanoparticle mass concentrations ranging from (0 – 1)% and mass fluxes of cooling water ranging from (0 - 5.31) kg/s.m^2 over flat aluminum channels underneath the PV panel. The findings show that the compound approach (Al_2O_3/PCM mixture + water) is superior to cooling with 100% water when the Al_2O_3 nanoparticle concentration is less than 1%. The compound approach, consisting of Al_2O_3 (=1%)/PCM combination (PCM = 25%) + 75% water (5.31 kg/s.m^2), produces the maximum PV performance when compared to all analyzed cooling technique parameters. For the purpose of controlling the temperature of a PV system, Sharaf et al. [57] used a passive cooling technology combining aluminum metal foam (AMF) with PCM as Figure 8. The findings showed that the PV-PCM/AFM system's PV surface temperature was 4%, 7.4%, and 13.2% lower than that of conventional PV in December, January, and February, respectively, and that the system's power output was 1.85%, 3.38%, and 4.14% higher. The previous studies showed that the researchers attempted to increase electrical and thermal efficiencies by different methods as shown in Table 4.



(a) (b)

Figure 8: A photograph of the modified module PV-PCM/AFM [57]

Table 4: Summary of various studies of integrated PV panel and methods cooling systems

Theoretical/Experimental Description	Results	Ref.
Experimental investigation to study heat transfer utilizing impinging jets inside solar air heater duct	Results show that, there is significant improvement by 2.67 times in heat transfer while there 3.5 times in friction factor	[12]
Experimentally and numerically the effect of jet geometry	The elliptic jet layouts produced the best heat transfer results.	[31]
The experimental investigate of SAH with jet impingement	Results indicate that a key factor in improving heat transmission is flow jet impingement on the corrugated plate absorber. In comparison to a smooth duct, the proposed design's thermal efficiency is found to be around 14% higher.	[14]
Investigated analytically (SPDDJPSAH) exergy efficiency	findings show that SPDDJPSAH improving both effective and exergy efficiencies by 21.2% and 22.4% respectively as compared with (SPSDJPSAH)	[16]
Computational investigation of solar air heater's impinging jet absorber plate's heat transfer behavior.	A maximum increase of 7.58 in heat transfer was attained with friction factor penalty of 9.01 times at a jet diameter to height ratio of 0.0650 and a jet height to ratio of 0.216 for a Reynolds number of 17,500.	[18]
Experimented with the effects of artificial roughness and jet impingement mixed on effectiveness of SAH.	In comparison to a smooth channel, the roughened solar thermal collector's Nusselt number (Nu) and friction factor (f) were determined to be 7.61 and 6.48 times greater, respectively.	[19]

Table 4: Continued

Investigate experimentally effect of (SiC, TiO_2, SiO_2) Nanoparticles with water as its base fluid on photovoltaic thermal (PVT) collector equipped with jet impingement.	Comparing the PVT with SiC nanofluid to the conventional PV module, the Pmax rose by 62.5%.	[49]
Nano-suspension of multi-walled Carbon nanotubes in water and ethylene glycol (50:50) were studied for an experiment on cooling PV solar panels.	A Nano-suspension at 0.2 weight percent was found to have the maximum electrical and thermal performance of about 292.1 W/m^2 Additionally, it is determined that at 0.2wt%, 44% of the thermal power and 45% of electricity.	[50]
PCM and Al_2O_3 nanoparticles were used in experimental studies to investigate the heat management and efficiency improvement of PV-building integrated systems.	By combining PV with pure PCM and improved PCM by nanoparticles, the temperature of units may be lowered by 8.1 and 10.6°C, and their efficiency can be raised by 5.7 and 13.2%, respectively.	[55]
Experimentally investigated the of a PV module cooling water and/or Al_2O_3/PCM mixture with different nanoparticles mass Concentrations.	It is observed that the compound technique; Al_2O_3 (ø =1%) /PCM mixture (λPCM = 25%) + 75% water (5.31 $kg/s.m^2$) achieves the highest PV performance.	[56]
A closed-cycle experimental system has been set up to explore the properties of jet impingement heat transfer using slurry of microencapsulated phase change material (MEPCM).	Results indicate that due to the PCM Core's ability to absorb latent heat, a 10% mass fraction of MEPCM slurry may improve jet heat transfer by 32.8% when compared to water.	[58]

4. Conclusion

In this study, a review of various solar photovoltaic cell cooling techniques has been provided. The review's main goal is to identify the best configurations for design and operation that will minimize PV cell temperature rise and boost electrical efficiency. From the previous work, rich information was given on jet, PCM as a cooling system for PVT collector, and the main parameters that influence its performance.

A summary of the results is as follows:

1) As mentioned above, the PCM core's latent heat absorption during the melting process may raise the PCM's apparent heat capacity and improve the convective heat transfer efficiency even further.
2) As compared to a straight forward PV system, the performance of PV cells that use the jet impingement cooling approach will be better for energy generation.
3) The use of Nanoparticles which would improve the thermal and heat transfer characteristics of the PCM.
4) There is a shortage of studies focusing on combined jet impingement with PCM with Nanoparticles as a cooling system for PVT collectors.

In future work, it is recommended to use of jet impingement cooling with PCM together for the PVT system. The proposed system integrates two types of cooling systems with a PV system, the advantage of using jet impingement cooling can result in low average cell temperature for PV cells, and PCM as storage energy with Nanoparticles to enhance the thermal con ductive of PCM.

list of abbreviations

I	Sun intensity
D_j	Jet diameter
D_h	Hydraulic diameter
X	Streamwise pitch
Y	Spanwise pitch
TRP	Temperature Rise Parameter
SAH	Solar air heater
Re	Reynolds number
Nu	Nusselt number
F	Friction factor
T_{amb}	Temperature of ambient
TCE	Thermal Conductivity Enhancers
Tpv	PV temperature
STC	Standard Testing Conditions
SPDDJP	Single Pass Double Duct Jet Plate Solar Air Heater
SPDDJP	Single Pass Single Duct Jet Plate Solar Air Heater

Author contributions

Conceptualization M. Shaeli. M. Baccar and J. Jalil; methodology, J. Jalil; formal analysis, J. Jalil; investigation, M. Shaeli; writing original draft preparation, M. Shaeli; writing review and editing, M. Shaeli; visualization, M. Baccar; supervision, M. Baccar and J. Jalil; project administration, M. Baccar and J. Jalil. All authors have read and agreed to the published version of the manuscript.

Funding

No specific grant was given to this research by any funding organization in the public, private, or nonprofit sectors.

Data availability statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

[1] A. Royne, C J. Dey and D. R. Mills, Cooling of photovoltaic cells under concentrated illumination: a critical review, Sol. Energy Mater. Sol. Cells, 86 (2005) 451-483. https://doi.org/10.1016/j.solmat.2004.09.003

[2] S. A. Brideau, and M. R. Collins, Development and validation of a hybrid PV/Thermal air based collector model with impinging jets, Sol. Energy, 104 (2014) 234-246. https://doi.org/10.1016/j.solener.2014.01.022

[3] T. T. Chow, A review on photovoltaic/thermal hybrid solar technology, Appl. Energy, (2010) 365-379. https://doi.org/10.1016/j.apenergy.2009.06.037

[4] Y. M. Choo, and W. Wei, Salt hydrates as phase change materials for photovoltaics thermal management, Energy Sci. Eng., 10 (2022) 1630-1642. https://doi.org/10.1002/ese3.1007

[5] M. Jurčević, S. Nižetić, D. Čoko, M. Arıcı, A. T. Hoang, E. Giama, and A. Papadopoulos, Techno-economic and environmental evaluation of photo voltaic-thermal collector design with porkfatas phase change material, Energy, 254 (2022) 124284. https://doi.org/10.1016/j.energy.2022.124284

[6] A. E. Kabeel, M. Abdelgaied, R. Sathyamurthy, and A. Kabeel, A comprehensive review of technologies used to improve the performance of PV systems in a view of cooling mediums, reflectors design, spectrum splitting, and economic analysis, Environ. Sci. Pollut. Res., 86 (2021) 7955-7980. https://doi.org/10.1007/s11356-020-11008-3

[7] S. L. Tariq, H. M. Ali, M. A. Akram, M. M. Janjua, and M. Ahmadlouydarab, Nanoparticles enhanced phase change materials (NePCMs)-A recent review, Appl. Therm. Eng., 176 (2020) 115305. https://doi.org/10.1016/j.applthermaleng.2020.115305

[8] T. Ma, Z Li, and J. Zhao, Photovoltaic panel integrated with phase change materials (PV-PCM): technology overview and materials selection, Renewable Sustainable Energy Rev., 116 (2019) 109406. https://doi.org/10.1016/j.rser.2019.109406

[9] A. K. Khudhair, F. Hatem; D. M. Ridha, Enhancement of Thermal Storage Properties of Phase Change Material by Using Metallic Swarf, Eng. Technol. J., 36, A (2018) 586-595. https://doi.org/10.30684/etj.36.5A.15.

[10] M. Belusko, W. Saman, W., & Bruno, F, Performance of jet impingement in unglazed air collectors, Sol. Energy, 82 (2008) 389-398. https://doi.org/10.1016/j.solener.2007.10.005

[11] J. Barrau, J. Rosell, D. Chemisana, L. Tadrist, and M. Ibáñez, Effect of a hybrid jet impingement/micro-channel cooling device on the performance of densely packed PV cells under high concentration, Sol. Energy 85 (2011) 2655-2665. https://doi.org/10.1016/j.solener.2011.08.004

[12] R. Chauhan and N. S. Thakur, Heat transfer and friction factor correlations for impinging jet solar air heater, Exp. Therm Fluid Sci., 44 (2013) 760-767. https://doi.org/10.1016/j.expthermflusci.2012.09.019

[13] S. A. Brideau, and Collins, M.R. Experimental model validation of a hybrid PV/thermal air based collector with impinging jets. Energy Procedia., 30 (2012) 44-54. https://doi.org/10.1016/j.egypro.2012.11.007

[14] A. M. Aboghrara, B. T. H. T. Baharudin, M. A. Alghoul, Nor Mariah Adam, A. A. Hairuddin, and Husam A. Hasan, Performance analysis of solar air heater with jet impingement on corrugated absorber plate, Case Stud. Therm. Eng., 10 (2017) 111- 120. https://doi.org/10.1016/j.csite.2017.04.002

[15] A. Soni and S.N. Singh, Experimental analysis of geometrical parameters on the performance of an inline jet plate solar air heater, Sol. Energy, 148 (2017) 149-156. https://doi.org/10.1016/j.solener.2017.03.081

[16] M. M. Matheswaran, T. V. Arjunan, and D. Somasundaram, Analytical investigation of solar air heater with jet impingement using energy and exergy analysis, Sol. Energy 141 (2018) 25-37. https://doi.org/10.1016/j.solener.2017.12.036

[17] T. Hai, Mansir, I.B., Alshuraiaan, B., Abed, A.M., Ali, H.E., Dahari, M. and Albalawi, H. Numerical investigation on the performance of a solar air heater (SAH) using inclined impinging jets on absorber plate with parallel and crossing orientation of nozzles, Case Stud. Therm. Eng., 45 (2023) 102913. https://doi.org/10.1016/j.csite.2023.102913

[18] S. Yadav and R. P. Saini, Numerical investigation on the performance of a solar air heater using jet impingement with absorber plate a solar air heater using jet impingement with absorber plate , Sol. Energy, 208 (2020) 236-248. https://doi.org/10.1016/j.solener.2020.07.088

[19] R. Kumar, S. Kumar, R. Nadda, K. Kumar, and V. Goel,Thermo-hydraulic efficiency and correlation development of an indoor designed jet impingement solar thermal collector roughened with discrete multi-arc ribs, Renewable Energy, 189 (2022) 1259-1277. https://doi.org/10.1016/j.renene.2022.03.037

[20] J. M. Jalil, M. K. Ahmed, and H. A. Idan, Experimental and Numerical Study of a New Corrugated and Packing Solar Collector, In IOP Conf. Ser.: Mat. Sci. Eng., 765 (2020) 012026. IOP Publishing.

[21] M. M. Matheswaran, Arjunan, T.V., Muthusamy, S., Natrayan, L., Panchal, H., Subramaniam, S., Khedkar, N.K., El-Shafay, A.S. and Sonawane, C. A case study on thermo-hydraulic performance of jet plate solar air heater (JPSAH) using response surface methodology, Case Stud. Therm. Eng., 34 (2022) 101983. https://doi.org/10.1016/j.csite.2022.101983

[22] A. E. Kabeel, M. Abdelgaied, and M. Mahgoub, The performance of a modified solar still using hot air injection and PCM, Desalination, 379 (2016) 102-107. https://doi.org/10.1016/j.desal.2015.11.007

[23] M. Rajvikram, Leoponraj, S., Ramkumar, S., Akshaya, H. and Dheeraj, A., Experimental investigation on the abasement of operating temperature in solar photovoltaic panel using PCM and aluminium, Sol. Energy, 188 (2019) 327-338. https://doi.org/10.1016/j.solener.2019.05.067

[24] J. Zhao, Tao M., Z. Li, and A. Song, Year- round performance analysis of a photovoltaic panel coupled with phase change material, Appl. Energy, 245 (2019) 51-64. https://doi.org/10.1016/j.apenergy.2019.04.004

[25] R. Simón-Allué, I. Guedea, R. Villén, and G. Brun, Experimental study of Phase Change Material influence on different models of Photovoltaic-Thermal collectors, Sol. Energy, 190 (2019) 1-9. https://doi.org/10.1016/j.solener.2019.08.005

[26] S. M. Salih., Jalil, J. M. and S. Najim, Artificial Solar Simulator of an (Air-PCM) Double-Pass Solar Collector,4 th Sci. Int. Conf. -Najaf, 1570530075, 2019.

[27] H. A. Akram, Thermal Storage Efficiency Enhancement for Solar Air Heater Using a Combined SHSm and PCM Cylindrical Capsules System: Experimental Investigation, Eng. Technol. J., 34, A (2016) 999-1011.

[28] A. R. Abdulmunem and J. M. Jalil, Indoor investigation and numerical analysis of PV cells temperature regulation using coupled PCM/Fins, Int. J. Heat Technol., 36 (2018) 1212-1222. https://doi.org/10.18280/ijht.360408.

[29] F. Bayrak, H. F. Oztop, and F.Selimefendigil, Experimental study for the application of different cooling techniques in photovoltaic (PV) panels, Energy Convers. Manag., 212 (2020) 112789. https://doi.org/10.1016/j.enconman.2020.112789

[30] M. B. Zohra, Riad, A. and Alhamany, A. Optimizing the conception of hybrid PV/PCM by optimizing the heat transfer at the contact interface and by integrating two types of PCM, Results Eng., 16 (2022) 100614. https://doi.org/10.1016/j.rineng.2022.100614

[31] A. S. Abdelrazik, R. Saidur, and F. A. Al-Sulaiman, Thermal regulation and performance assessment of a hybrid photovoltaic/thermal system using different combinations of Nano- enhanced phase change materials, Sol. Energy Mat. Sol. Cells, 210 (2020) 110645. https://doi.org/10.1016/j.solmat.2020.110645

[32] M. B. Elsheniti, M. A. Hemedah, M. M. Sorour, and W.M. El-Maghlany, Novel enhanced conduction model for predicting performance of a PV panel cooled by PCM, Energy Convers. Manag., 205 (2020) 112456. https://doi.org/10.1016/j.enconman.2019.112456

[33] D. Groulx, P. H. Biwole, and M. Bhouri, Phase change heat transfer in a rectangular enclosure as a function of inclination and fin placement, Int. J. Therm. Sci. 151 (2020) 106260.https://doi.org/10.1016/j.ijthermalsci.2020.106260

[34] A. P. Singh, A. Kumar, and O. P. Singh, systems, Effect of natural convection and thermal storage system on the electrical and thermal performance of a hybrid PV-T/PCM, Mat. Today: Proc., 39 (2020) 1899-1904. https://doi.org/10.1016/j.matpr.2020.08.010

[35] K. S. Kumar, S. Revanth, D. S., P. S. Kumar, and P. Surya, Experimental investigation of improving the energy conversion efficiency of PV cell by integrating with PCM, Mat. Today: Proc., 37 (2021) 712-716. https://doi.org/10.1016/j.matpr.2020.05.723

[36] A. Kazemian, A. Taheri, A. Sardarabadi, T. Ma, M. Passandideh-Fard, and J. Peng, Energy, exergy and environmental analysis of glazed and unglazed PVT system integrated with phase change material: An experimental approach, Sol. Energy, 201 (2020) 178-189. https://doi.org/10.1016/j.solener.2020.02.096

[37] K. A. Ahmed, M. Kh. Kadhim, Numerical Investigation of Energy Storage in Packed Bed of Cylindrical Capsules of PCM, Eng. Technol. J., 32 (2014) 494-510.

[38] A. Gholami and Gorji, M. Experimental study for the use of Na2SO4. 10H2O as a PCM with fixed blades for temperature and efficiency parameters of photovoltaic panel, Case Stud. Therm., (2023) 1032. https://doi.org/10.1016/j.csite.2023.103219

[39] E. H. Amalu and O. A. Fabunmi, Thermal control of crystalline silicon photovoltaic (c-Si PV) module using Docosane phase change material (PCM) for improved performance, Sol. Energy, 232 (2022) 203-221. https://doi.org/10.1016/j.solener.2022.02.001

[40] M.R. Safaei, H.R. Goshayeshi, and I. Chaer, Solar still efficiency enhancement by using graphene oxide/paraffin nano-pcm, Energies, 12 (2002). https://doi.org/10.3390/en12102002

[41] M. Saadoon, I. A. Hasan, M. J. Mohammed, Preparing Nanofluids (Al2O3) for Enhancement Performance of Photovoltaic, Eng. Technol. J., 39 (2021) 1445-1453. https://doi.org/10.30684/etj.v39i9.2110.

[42] T. K. Murtadha; H. M. Salih; A. D.Salman, Experimental and Numerical Study of Closed Loop Solar Chimney Assisted with PCM and CFM as Thermal Energy Storage Collector, Eng. Technol. J., 34 (2016) 2450-2463. https://doi.org/10.30684/etj.34.13A.8

[43] H. Xu, C. Zhang, N. Wang, Z. Qu, and S. Zhang, Experimental study on the performance of a solar photovoltaic/thermal system combined with phase change material, Sol. Energy, 198 (2020) 202-211. https://doi.org/10.1016/j.solener.2020.01.064

[44] O. B. Kazanci, M. Skrupskelis, P. Sevela, G.K. Pavlov, B.W Olesen, Sustainable heating, cooling and ventilation of a plus-energy house via photovoltaic/thermal panels, Energy Build, 83 (2014) 122–129. https://doi.org/10.1016/j.enbuild.2013.12.064

[45] A. H. Al-Waeli, K. Sopian, H.A. Kazem, and M.T. Chaichan, Photovoltaic solar thermal (PV/T) collectors past, present and future, Appl. Eng. Res., (2017) 10757–10765.

[46] M. Sardarabadi, M. Passandideh-Fard, M.-J. Maghrebi, and M Ghazikhani, Experimental study of using both zno/water nanofluid and phase change material (pcm) in photovoltaic thermal systems, Energy Mater. Sol. Cell, (2016) 62–69. https://doi.org/10.1016/j.solmat.2016.11.032

[47] A. H. Al-Waeli, H.A. Kazem, M.T. Chaichan, and K Sopian, Experimental investigation of using nano-pcm/nanofluid on a photovoltaic thermal system (PVT): Technical and economic study, Therm. Sci. Eng. Prog., (2019) 213–230. https://doi.org/10.1016/j.tsep.2019.04.002

[48] M. A.Teamah, Mohamed M. K. Dawood, and A. Shehata, Numerical and experimental investigation of flow structure and behavior of nanofluids flow impingement on horizontalflat plate, Exp. Therm. Fluid Sci., 74 (2015) 235-246. https://doi.org/10.1016/j.expthermflusci.2015.12.012

[49] A. Hasan, H. Alnoman, and A Shah, Energy efficiency enhancement of photovoltaics by phase change materials through thermal energy recovery, Energies, 782 (2017). https://doi.org/10.3390/en9100782

[50] M. M. Sarafraz, M. R. Safaei, A. S. Leon, I. Tlili, T. A. Alkanhal, Z. Tian, M. Goodarzi, and M. Arjomandi, Experimental investigation on thermal performance of a PV/T-PCM (photovoltaic/thermal) system cooling with a PCM and nanofluid, Energies, 12 (2019) 2572. https://doi.org/10.3390/en12132572.

[51] H. E. Abdelrahman, Wahba MH, Refaey HA, Moawad M, Berbish NS, Jan Performance enhancement of photovoltaic cells by changing configuration and using PCM (RT35HC) with nanoparticles Al_2O_3, Sol. Energy, 177 (2019) 665-71. https://doi.org/10.1016/j.solener.2018.11.022

[52] A. Naghdbishi, M. E. Yazdi and G. Akbari, Experimental investigation of the effect of multi-wall carbon nanotube–Water/glycol based nanofluids on a PVT system integrated with PCM-covered collector, Appl. Therm. Eng., 178 (2020) 115556. https://doi.org/10.1016/j.applthermaleng.2020.115556

[53] Maghrabie, H.M., Mohamed, A.S.A., Fahmy, A.M. and Samee, A.A.A., 2023. Performance enhancement of PV panels using phase change material (PCM): An experimental implementation. Case Studies in Thermal Engineering, 42, p.102741. https://doi.org/10.1016/j.csite.2023.102741

[54] W. Wu, H. Bostanci, L. C. Chow, S. J. Ding, Y. Hong, M. Su, J. P. Kizito, L. Gschwender, and C. E.Snyder, Jet impingement and spray cooling using slurry of Nanoencapsulated phase change materials, Int. J. Heat Mass Transfer, 54 (2011) 2715-2723. https://doi.org/10.1016/j.ijheatmasstransfer.2011.03.022

[55] S. A. Nada, D. H. El-Nagar and H. M. S. Hussein, Improving the thermal regulation and efficiency enhancement of PCM-Integrated PV modules using nano particles, Energy Convers. Manag., 166 (2018) 735-743. https://doi.org/10.1016/j.enconman.2018.04.035

[56] M. R. Salem, M. M. Elsayed, A. A. Abd-Elaziz, and K. M. Elshazly, Performance enhancement of the photovoltaic cells using Al_2O_3/PCM mixture and/or water cooling-techniques, Renewable Energy, 138 (2019) 876-890. https://doi.org/10.1016/j.renene.2019.02.032

[57] M. Sharaf, Huzayyin, A.S. and Yousef, M.S., Performance enhancement of photovoltaic cells using phase change material (PCM) in winter, Alexandria Eng. J., 61 (2022) 4229-4239. https://doi.org/10.1016/j.aej.2021.09.044

[58] J. J. Zhang, Yang, C.H., Jin, Z.G., Ma, S.X., Zhang, J.S. and Pang, X.M., 2021. Experimental study of jet impingement heat transfer with microencapsulated phase change material slurry, Appl. Therm. Eng., 188 (2021) 116588. https://doi.org/10.1016/j.applthermaleng.2021.11658