Al-Rafidain Journal of Engineering Sciences

Journal homepage https://rjes.iq/index.php/rjes

ISSN 3005-3153 (Online)

Involving the Phase Change Materials for Passive Cooling Applications in Photovoltaic: Review

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ARTICLE INFO

Article history:

Received	22 October 2024
Revised	23 October 2024,
Accepted	04 November 2024,
Available online	08 November 2024

Keywords:
Phase change materials
Photovoltaic
Passive cooling
Heat storage
Review

ABSTRACT

Heat storage is one of the most important energy saving methods. It finds a solution for the applications that consumes a huge amount of energy, especially in cooling. Phase change materials (PCMs) consider the main objects utilized in heat storage purposes, and they also deal with decreasing the pollution effects. Photovoltaic cells suffer from a main issue, which is the temperature rise, and this problem leads to degrade the cell efficiency. Therefore, a system of cooling is required to mitigate the overheating of the componential materials. There are several ways to reach a suitable usage of PCMs in the photovoltaic cells cooling. A lot of solutions depend on utilizing certain types of PCMs with reasonable amount of addition. Common methods serve a suitable thickness of cooling medium, or by using different shapes for the photovoltaic panel. Recent methods implement nanoparticles to enhance the storing heat capacity. This work introduces a review for the solution that the researcher uses to improve the efficiency and power of the panel, and to reduce the temperature of the cell. Beside paraffin and salt hydrates, recent studies utilize hybrid materials and those combined with metallic or composite panels. Note that the environmental impact is an important factor in evaluating the different methods of enhancement.

1. Introduction

Solar photovoltaic (PV) is commonly used to meet the current energy challenges as an alternative to conventional power sources, which has less environmental impacts. The progressing in PV panel makes it an important source of electrical power supporting energy demand and supplanting the corresponding shortages in electricity for certain areas. Researchers put in their mind the developing of materials to satisfy higher efficiency while focusing on safety and economic aspects [1].

The first solar panels were made of silicon photovoltaic cells that could convert enough sunlight to produce useful electricity. It only converted 5% of sunlight into electricity. However, it laid the foundation for renewable energy technology and became the foundation of the world's renewable energy system. Over the next few years, solar panels have changed dramatically. This great success can be attributed to the use of new materials and technologies. Thin-film silicon solar cells are cheaper and more flexible than traditional solar cells. A dye-sensitized solar cell (DSSC) is a low-cost solar cell belonging to the 3rd generation thin film solar cells. It is based on a combination of semiconductors and organic fillers to form a photo-sensitized cell. A modern DSSC is composed of a porous layer of titanium dioxide nanoparticles, covered with a molecular dye taken from green leaves to absorb the sunlight. The titanium dioxide is immersed into an electrolyte solution, above which is a platinum-based catalyst. Perovskite

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https://doi.org/10.61268/

solar cells are the photovoltaic device kind in which the perovskite structured compounds of Lead/Tin halide materials acts as a light harvesting active layer with the other components. On the other hand, bifacial solar cells, which can use sunlight from both sides, have played a significant role in gathering more power. In addition, the track system of solar panel towards the sun can maximize the energy production. Today, solar panels are a reliable and sustainable solution for homes and businesses of all sizes and backgrounds [2-6]. Figure 1 depicts the best research PV cells efficiencies from NREL [7].

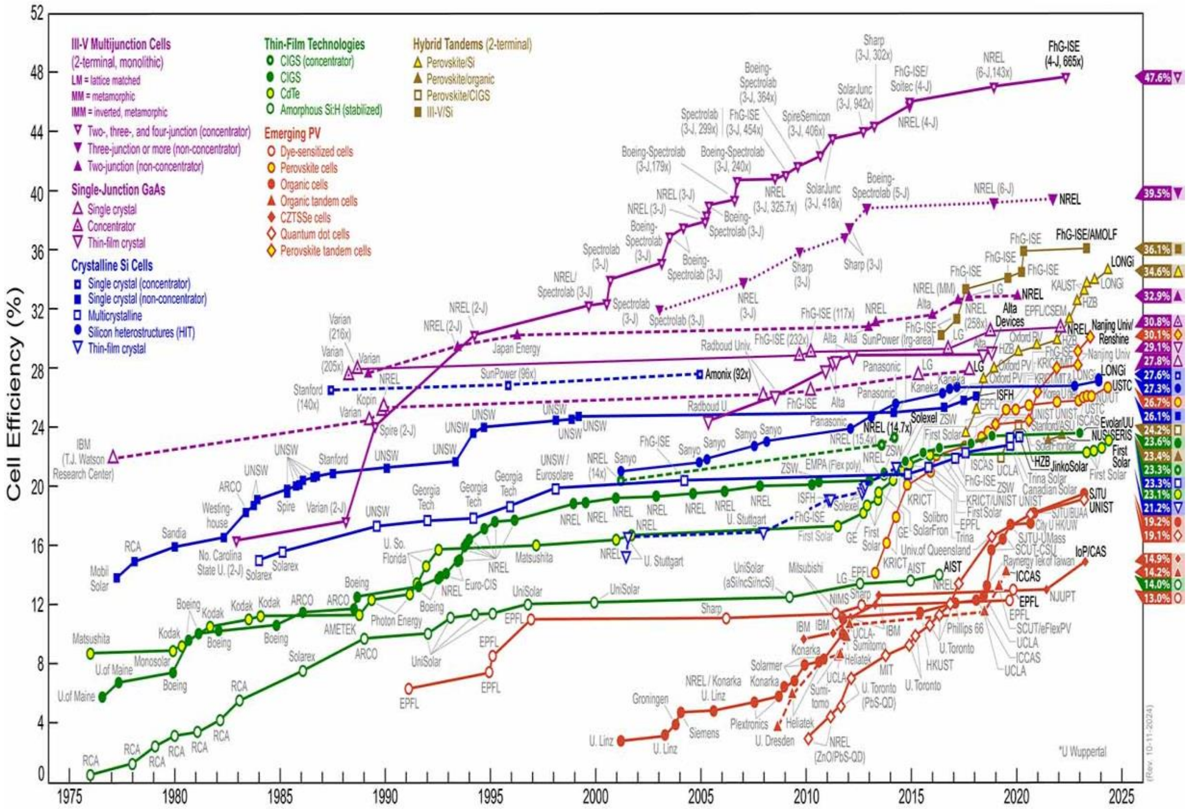

Figure 1. Best research PV cells efficiencies from NREL [7]

The operation of solar cells and related components is often affected by the increase in photovoltaic temperature. This problem appears because the solar radiation subjected to the film is not completely converted into electrical energy but is absorbed in the form of large amounts of heat, causing the temperature of the film to rise, which leads to a reduction in efficiency. And, as the PV panel temperature rises higher than (25°C), its efficacy has a tendency to reduce owing to the coefficient of temperature. It is found that for every degree Celsius above the optimal temperature, the efficiency of a typical crystalline silicon PV cell can decrease by approximately 0.5%. The higher temperatures reason the semi-conductor substances in the photovoltaic cells to be further conductive. Also, it raises the charge carriers flow and subsequently decreases the created voltage. The performance of solar cell reduces with raising the temperature, basically due to the augmented rates of interior carrier recombination, resulted in via the augmented carrier concentrations. In addition, the working temperature plays a crucial part in the photovoltaic transformation procedure. The photovoltaic (PV) module's electrical efficacy as well as the power output depends linearly upon the working temperature. A typical PV module converts up to (20%) of the incident solar radiation into electricity, relying on the solar cells kind and the climatic circumstances.

Furthermore, the rest of incident solar radiation is transformed into heat, which considerably raises the PV module temperature and decreases the module PV efficacy. The heat can be removed from the inner layers by cooling techniques. One of these methods is by passing water or air flows [8-11]. Figure 2 evinces the current-voltage relationship of a PV cell under different temperatures [11].

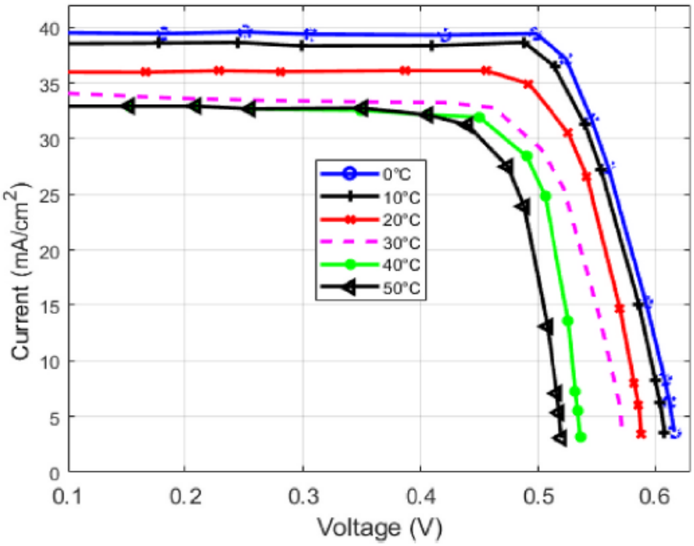

Figure 2. The current-voltage relationship of a PV cell under different temperatures [11]

2. Traditional techniques of PV cooling

Cooling of PV panels is commonly related to the coolant underuse. Usually, there are two methods; air cooling and water cooling. The technique of air cooling is divided into natural cooling and forced cooling. The natural cooling depends on the convection with the ambient or still air.

The performance of this method can be improved by using extended surfaces like the fins. In forced cooling, electrical power is consumed to operate a fan or a source of moving air for cooling. This method satisfies faster cooling and higher performance [12]. In case of utilizing water, there are two methods for cooling: Active and passive cooling. The principle work of active cooling is using a pump that gives faster cooling, especially when the water is the cooling medium. Utilizing the pump improves the velocity of water flow, so the efficiency increases by approximately 10%. However, the increasing in water flow means increasing the mass flow rate that causes more consumption of electrical power.

Passive cooling by water is not common, where the water is used without pump by spraying it on the PV panel as an evaporation cooling. Other methods of cooling include the thermo-electrical cooling and the use of phase change materials (PCMs). Recently, nanoparticles played a role for extra cooling [13, 14]. However, Figure 3 manifests the methods of cooling for PV panel.

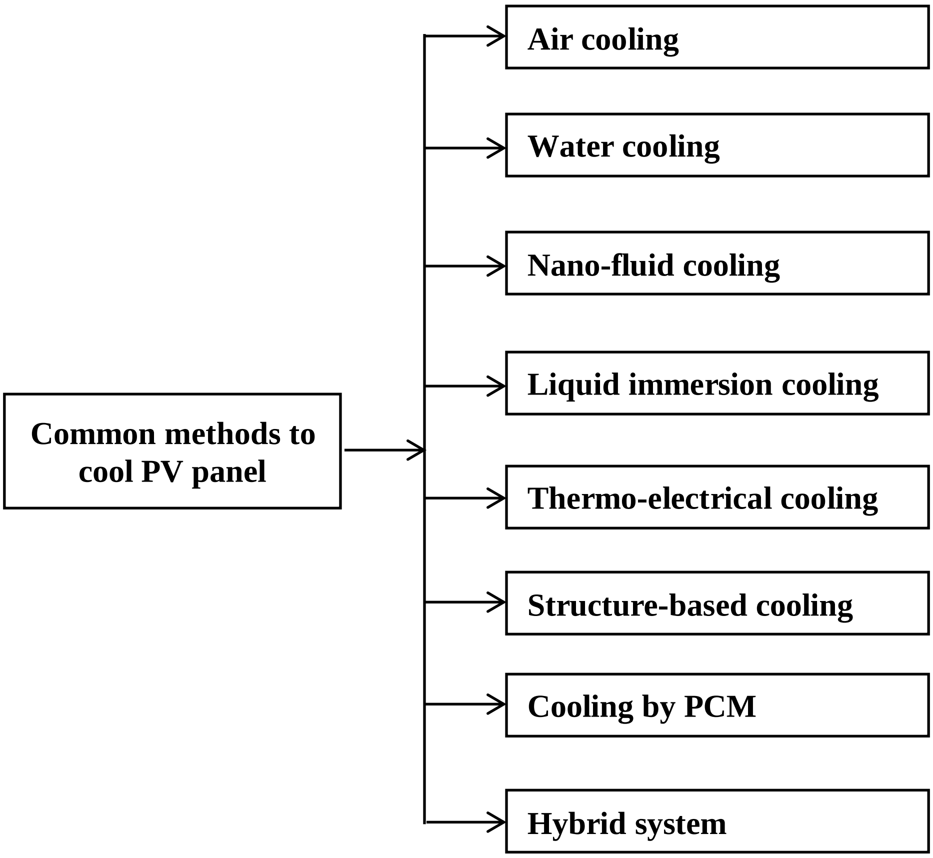

Figure 3. Common methods to cool the PV panel

3. Methods of cooling PV panel by PCMs

Phase change materials (PCMs) are special substances able to absorb and release large amounts of heat, either sensible or latent, through the changing from one to another physical state. They are considered by specifically designed phase change temperatures, allowing for greater energy storage densities compared to sensible storage mediums and techniques. Great amounts of energy can be stored in the isothermal process of solidifying and then later discharged by melting the material. Phase change materials (PCMs) can be divided for three types: Organic compound, inorganic compound and eutectics compound. Example of the first types is the salt hydrate. The common example of the second type is the Paraffin. A combined salt of lithium and sodium carbonates is an example of eutectics [15]. Figure 4 presents the classification of PCMs.

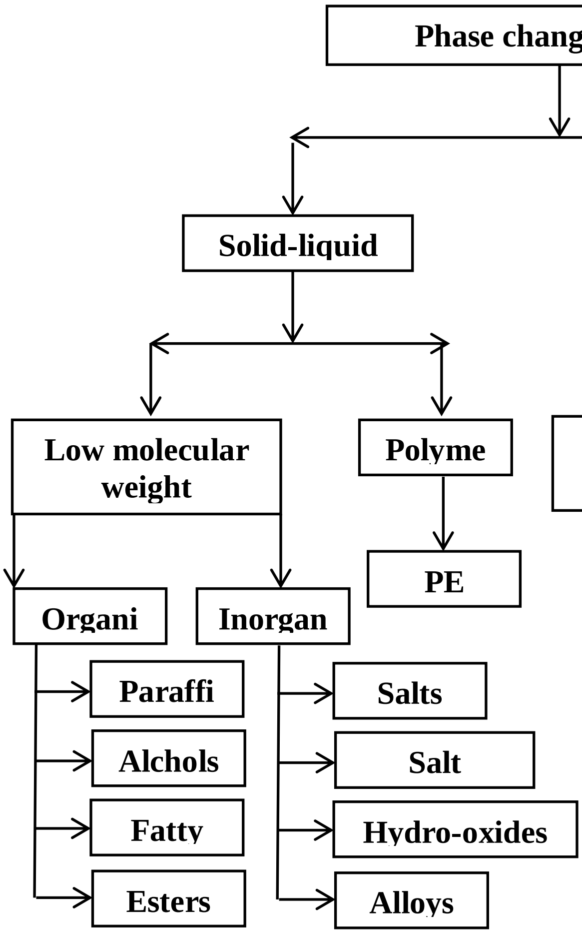

Figure 4. Classification of PCMs

As mentioned, PCMs is an effective procedure to store heat. Thus, it can be used to absorb extra heat from the PV panel in case if the PCMs were attached to the panel. And, the of PV panels' passive cooling method hasn't been as much in concentration in comparison with the active procedure when it comes to the application of PCMs. Nevertheless, at the first stage of design, it's necessary to study the highly suitable PCM that gives maximum dissipation of heat for a certain case and in a specific climate prior the investigational setup, which gets expensive as well as timewasting. Thus, it is necessary to support the study by serving a model-based optimization approach to develop the application of PCM. To advance the efficiency, synthetic cooling is utilized to controller the temperature of panel. The PCMs can be involved with the 3 highly famous employed cooling approaches, meaning that fins, cooling by (water spraying or micro-channels) upon the surfaces of panel. Investigations evinced that as soon as the different features of PCMs are recognized, a choice process is established that regards the PCM's temperature of melting, thermal conductivity, and latent heat. Also, the results reveal that saleable PCM is the highly auspicious selection, pursued via organic PCM, chiefly owing to their supreme chemical properties in comparison with the eutectic and inorganic PCM [16]. Additionally, an analysis depicted that the temperature of solar cell dropped by more than 15oC employing PV in amalgamation with PCM, causing one and a half times more energy than conventional model [17].

Nowadays, the researchers are focusing on harvesting more power from PV module by reaching to high benefit and low losses or side effects. The extracting of heat from the panel and absorbing it as a latent heat is one of the optimal solution. Where, the heat can be released later when the night comes. However, there are several methods of cooling the PV panel by utilizing (PCM), as shown in Figure 5.

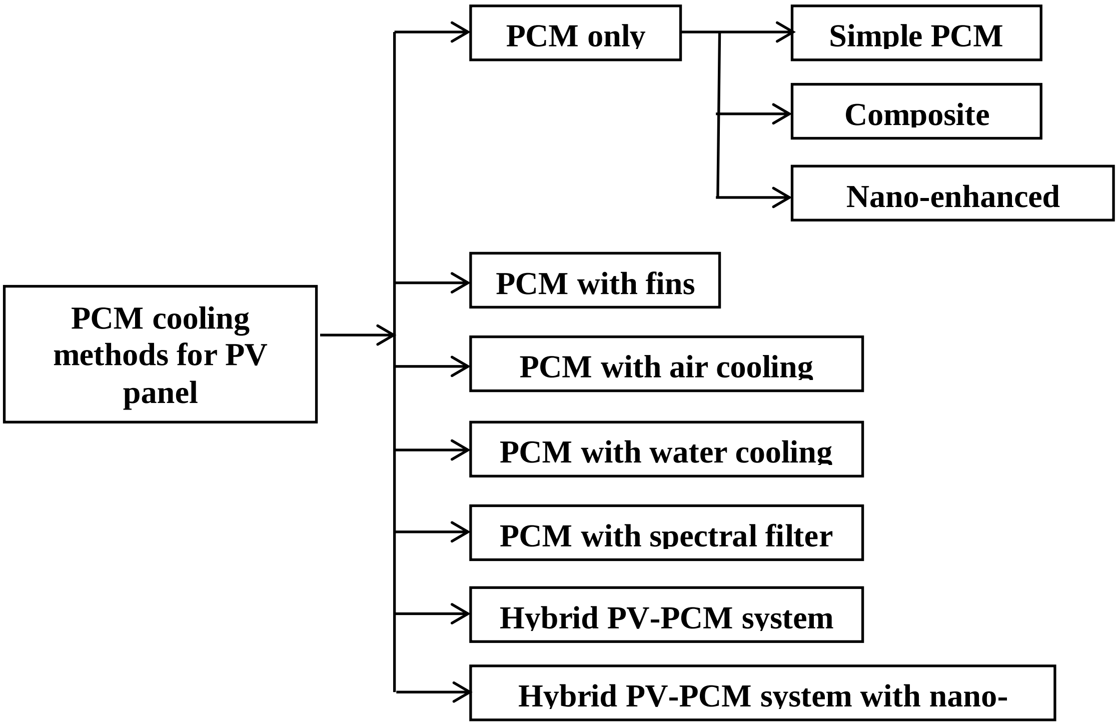

Figure 5. Methods of cooling the PV panels using PCMs

4. Recent techniques in cooling of PV panels by PCMs

By reviewing the available studies within this field for the last decade, it can be noticed that majority of the works were experimental based with an amount of theoretical studies, including mathematical models, numerical analysis or computational processing. However, numerous of review studies [18-25] have been conducted to introduce a general overview upon the development of PV panels that uses PCMs for cooling. They propose some examples of the current applications and available data. The current review studies focus upon various configurations, such as:

- Selecting suitable PCMs, better loadings and sizes, as well as attaching or design techniques.
- Technical challenges in the systems.
- Phase-change behaviors during high temperatures.
- Measuring the performance of PV panel before and after the using of the PCMs.
- Involving nanomaterials within PCMs.

The nature of the studies, either numerical or experimental researches, and the contribution of PCMs in enhancing the heat transfer through the PV panels are presented with some details in the following paragraphs. Indartono et al. (2015) [26] studied experimentally and numerically (software) the effect of the thickness of PCM in a tube attached to the panel in order to reach to the suitable thickness that is effective on improving the performance of (PV) by decreasing the temperature of it. The section area of tube was rectangular, while the material of tube was aluminum. The thickness utilized in experiments was ranged from 50 to 100 mm. The results have shown that there was an inverse relation between the thicknesses of tube with the cell temperature. Lower PCM causes a lower reduction on the PV temperature. At the

PCM thickness of 100 mm, the increase in average power was 24%, while it was 18% at 50 mm thickness. Savvakis and Tsoutsos (2016) [27] investigated experimentally the effect of temperature rise on the PV module's performance. A comparison was made between the developed (PV-PCM) system and the typical (PV) module. The maximum reduction of temperature that resulted by using (PV-PCM) system was about 11°C. The (PV-PCM) prototype's Life Cycle Assessment (LCA) was conducted for assessing the ecological performance. And, the outcomes displayed that the efficiency was improved by 8% using the PCM. The container fabrication of the PCM would lead to further improvement.

An experimental study was carried out by Hamdan et al. (2018) [28] to cool the photovoltaic panel using phase change materials. The idea depended on using two similar PV panels located beside each other. The first one was integrated with (PCM) on the back side, whereas the second panel was kept without PCM as a reference for comparison. The values of generated currents and voltages, temperature of PV panels and ambient temperature, as well as the incident solar irradiance were recorded for 28 days. The results showed that the system with PCM had given 2.6% enhancement in the performance comparing to the reference one. Fazri et al. (2019) [29] worked experimentally on three PV panels aided by PCM as a cooling medium. The first case was without PCM as a standard case. The two other tests used panels equipped with PCM1 (animal tallow) or PCM2 (paraffin). The results manifested that the cooling by still air (standard) was not effective comparing to the cases using PCMs. The PCM gave the solar panel better performance by maintaining the temperature of PV panel under 50°C. The cell without PCM recorded the maximum temperature of 65^{o}C, while PCM1 (tallow) and PCM2 (paraffin) recorded the maximum temperatures of 48oC and 42^{o}C, respectively.

Naghdbishi et al (2020) [30] experimentally investigated the Carbon Nanotube–Water/Glycol based nano-fluids influence upon a PVT regime incorporated with a PCM concealed collector. The passive cooling medium was organic paraffin wax. The result manifested that the suggested system can reduce the temperature of photovoltaic panel within (15-20%), so improved the electrical performance of the system. Kiwan et al. (2020) [31] documented analytically the effect of the covering of PCM (paraffin graphite) with an Aluminum (Al) sheet that fixed firmly to the frame of panel. And, the thickness was (15 mm of back panel that covered with PCM. The results elucidated that the efficiency of the system rises if the average temperature of cell exceeds the PCM melting temperature point. However, the PCM usage would negatively influence the efficiency of system; it acts as an insulation material from the rear side of the panel if the cell temperature of cell didn't surpass the temperature of PCM melting.

Al-Migdady (2021) [32] conducted a numerical study to improve the thermal conductivity of PCM. The improving of heat transfer of heat sink that subjected to a constant heat flux depended on the using of metal foam. The enhancement had given a uniform distribution of temperature for the PCM. The heat sink filled with 2 different types of PCMs, i.e. n-Eicosane and RT44HC. The results portrayed that the n-Eicosane reduces in PV temperature more than RT44HC. Thaib et al. (2021) [33] studied experimentally how to decrease the temperature range for the surface temperature of PV panel by using beeswax as a heat storage material. Phase change materials (PCMs) were tested in two shapes of containers, the first one was triangular, and the second was semi-circular. The result showed that the beeswax was the best for storage and low range of temperature. On the other hand, a comparison between the two containers semi-circular and triangular revealed that the average temperature of the surface panel of PV employing a semi-circular vessel was higher than that for triangle vessel. Finally, the voltage generated with beeswax was higher than the reference PV panels.

Anand (2022) [34] focused on enhancement the thermo-physical properties of the PCMs utilized with solar applications, especially PV panels. The performance enhancement of the PCM was carried out utilizing nanoparticles with several weight fractions (1, 2 and 3%). The test of thermal cycles reported up to 500 cycles and emphasized the excellent thermal reliability. The difference in the onset melting point was -1.43% to +0.53%. The difference in the peak melting point was -0.03% to +1.52%, and the difference in the latent heat of fusion was -6.67% to 9.94 %. These variations are within acceptable limits for the PCMs, and they are suitable for a yearlong application. Hassabou and Isaifan (2022) [35] developed numerically how to make passive cooling type of the PCM in a PV solar module. They focused upon the heat capacity as well as the volume averaging method as a good way to solve the common problems (accuracy, period of time, and computational efforts). The results of simulation demonstrated an agreement with analytical solutions. The results of comparison between the exact analytical solutions and the numerical for heat capacity method were clear, and the error presented was unimportant into the lowest area of domain. As well, the interval of temperature was very close up to the exact analytical solution which was a proof upon the accurateness of the seeming heat capacity formulation forecasts.

Arifin et al. (2022) [36] investigated the electrical performance of PV panel numerically (simulation) and experimentally by adding three types of phase change materials (paraffin, beeswax, and soy wax). The three cases with the PCMs were compared with the reference case utilizing the PV only without adding PCM. According to the simulation, paraffin, beeswax, and soy wax PV panels possessed average temperatures of (45.8^{o}C, 42.6^{o}C and 48.6^{o}C), correspondingly, at a (1100 W/m2) intensity. And, the investigational outcomes appeared that the working temperature of PV gained the best reduction from 60.7^{o}C to 52.5^{o}C when the PCM beeswax was used at a (1100 W/m^2) intensity. Also, the outcomes displayed that the PV with PCM beeswax cure as a passive cooler could rise the highest PV output power of (3.04 Watt) as well as the highest PV efficacy via (0.94%) through dropping the highest PV temperature via (8.2^{o}C) in comparison with the PV with no cooling regime. Bhakre et al. (2023) [37] studied numerically the thermal performance of PCM-PV system. Water was a moderate cooler and two containers were used for that study. The first one was filled with PCM, while the second container was filled with water. The thickness of PCM was 50 mm. The study based upon a simulation done by ANSYS-FLUENT software at different orientations and conditions. The results initially showed that no important variation was noted in the melt fraction of PCM and the temperature PV panel beyond the suggested thickness. Further study showed that a rise in the regime location from (30°) to (90°) lowers the PCM and PV panel average temperature. This reduction in temperature caused a total rise into the average electrical efficacy of (14.93%) and (1.35%) at (30°) and (90°) regime locations, correspondingly.

Hussain et al. (2023) [38] conducted an experimental study to utilize the (PCM) based cooling method lengthways with fins made of aluminum to lessen the PV panel temperature. The temperature and efficacy of PV panel surface are the target factors in this study. And, the outcomes were compared with the values of traditional PV panel at the angle of the inclination of (30°, 45°, and 60^o) with regard to the ground. Also, the investigational outcomes appear that the efficacy of PV panel augmented via (6.85%, 6.82% and 4.2%) for the angle of the inclinations of (30°, 45° and 60^o), correspondingly. Additionally, the matching highest drops of temperature were (13.1, 12.9, and 8.5^{o}C). Durez et al. (2023) [39] introduced a modelling to optimize the PCM-based passive cooling of the solar PV panels into the multi climate circumstances. The study included a comprehensive mathematical model and carried out a simulation employing (3) various PCMs (RT21, RT35 and RT44) incorporated with the PV panels during the summer season. And, the results evinced that the integrating PCM caused a reduction of the temperature of PV panel's surface, resulting in a (6%) rise in the efficacy as well as a (16%) improvement in the electrical output. Specially, if employing a PCM having a (21°C) melting temperature, the highest temperature of cell through the summer working reduced from (65°C) to (38°C). The same reductions of temperature were noted if utilizing PCMs having melting temperatures of (35°C) and (44°C).

Merzah et al. (2024) [40] investigated a passive cooling method using nano-enhanced PCMs, which gather the extra heat through the peak daytime and release it at low temperatures. The specific heat is (2000 J/kg.K) for stiff material, aluminum fins, and PCM and a (0.2 W/m.K) thermal conductivity. The distribution temperature exhibits an important decrease in the temperatures of surface with the rising concentrations of Al_2O_3. And, the best situation was at (0.5wt%), attaining about 50oC. Thus, the electrical efficiency increases with the concentration. Mustafa et al. (2024) [41] presented a simulation on the effect of nano-fluid addition as well as the shape of pin fin (PF) through the PCM's melting and freezing for the PV panels. Also, two pipes were devised, and numerous pin fins (PFs) were implemented to every pipe. The organic (PCMs) were encapsulated into a compartment around the pipes and PFs. In addition, the parameter is the shape of PF (circular, triangular, square, and rectangular). The nano-fluid is utilized into the pipes. Furthermore, the results indicated that using triangular PFs gives the uppermost temperature of fluid into the outlet. A lower heat transfer coefficient was gained in the circular PFs.

5. Remarks from previous studies

By analyzing the studies under consideration, the followings can be noted:

- The phase change materials are usually: Paraffin, bio-products, and salts.
- The PCM thermal performance can be enhanced utilizing different nano-particles, such as: Al_2O_3, TiO_2, CuO and ZnO.
- The melting point of the PCM ranges between (21^{o}C) and (60^{o}C).
- The thickness of the PCM layer ranges between (15 mm) and (100 mm).
- The temperature of the PCM during the operation with the PV system can rise up to 75^{o}C.
- The temperature of the PV panel with the using of PCM can be as low as 37^{o}C in the summer time.
- The efficiency of the panel can be enhanced up to 15% using the PCMs.
- Additional improvement can be observed using fins, and by design suitable configurations or containers for the PCMs.
-

However, Table 1 shows a comparison for the features of the studies under consideration in the current work.

Table 1: Comparison for the features of studies under consideration

[Ref]	Yr.	PCM	Melt point (^{o}C)	Thick. (mm)	Method	Configuration	Results
[26]	2015	coconut oil, & palm oil (CPO)	24	50-100	Experiment & software	A simulation was conducted for determining the PCM thickness' product as well as to obtain the optimal PCM volume. 80 mm was the optimal PCM thickness, and in ambient temperature about (27-30℃). Crude Palm Oil (CPO) has a better performance than the coconut oil.	The great temperature discrepancy between the references of PV and (PV/PCM) took place at a PCM thickness of (100 mm), i.e. (9.6℃). By a (100 mm) PCM thickness, the PV efficiency and output power were higher than the reference by 24% and 2%, respectively.
[27]	2016	Paraffin wax	27	N/A	Experiment	Improving typical PV module by designing a sufficient container and filled with PCM.	The efficiency has been improved by 8.6 %. The container of PCM was responsible for the uppermost influence upon the (PV/PCM) regime performance. The role of the steel components and PV laminate was less important.
[28]	2018	N/A	27	N/A	Experiment	Two identical PV panels were installed side by side. The PCM was integrated on the back side of one of these PV panels. A micro-converter with all necessary accessories to conduct the work were also used. The generated currents and voltages, temperatures and were recorded.	The results show that the system with PCM had given 2.6 % enhancement in the performance comparing to the reference one.
[29]	2019	Tallow and paraffin	39 and 46	50	Experiment	The first case has done without PCM as a standard case. The two other tests used panels equipped with PCM1 (animal tallow) or PCM2 (paraffin).	The maximum temperature of the solar panel without using a PCM was 65 ^{o}C, and it happened at 12:15 PM. The maximum temperature achieved by PCM was less than 50° C.
[30]	2020	Paraffin wax	57-60	N/A	Experiment	The (PVT/PCM) regime performance can be enhanced regarding the viewpoints of energy and exergy. And, in the built regime, the organic paraffin wax is applied as the nanoparticles of PCM and (MWCNT) are supplemented to Ethylene Glycol besides water as base fluids for forming uniform nano-fluids in height thermal conductivity.	The electrical efficacy of (PVT/PCM) regime was (3%) higher than that for the reference one. And, the result showed that the suggested system can reduce the temperature of photovoltaic panel between 15-20%. The enhancement in the thermal performance was 10-15%.
[31]	2020	Paraffin graphite	47	15 mm	Experiment & numerical	Evaluating the performance of the PV panel, and compare the outdoor experimental test measurements with the theoretical results.	The PCM material influence upon the PV module efficacy depicts some increasing. The measured efficacy still ranging between (10%-12%) for the time (8:30 A.M. to 2:30 P.M.). However, the PCM usage may negatively influence the efficacy of

							regime; it acts as an insulation material from the rear side of the panel if the temperature of cell didn't surpass the PCM temperature of melting.
[32]	2021	n-Eicosan and RT44HC	35, 41	N/A	Software simulation	Two-dimensional model (Fluent) to a PV panel aided by PCM heat sink and supported with metallic foam. The performance of PCM based heat sink is investigated for 2 types of PCMs, and for 3 different values of metal foam porosity ε (1.0, 0.97 and 0.90).	The thermal conductivity (k) of the heat sink is remarkably improved, and heat flows throughout the PCM towards the enclosure boundaries resulting in a further homogenous distribution of temperature in the PCM with less PV temperature. Also, for the heat sink that filled with PCM in conjugation with the aluminum foam, the PV temperature decreased by 5-7°C.
[33]	2021	beeswax	44.9	N/A	Experiment	PCM is attached to a solar panel of the type (Silicon Nitride Mono crystalline). And, the PCM situation includes a plate of aluminum having a (500 mm) width and a (0.4 mm) thickness. In the test, 2 different containers were used semi-circular and triangular. Also, the PCM utilized in every investigation was (8 kg).	The latent heat release occurs at a range of temperatures (44-57^{o}C). The overall temperature of panel surface is lower than that for the reference one. And, the mean upper temperature of PV panel surface employing a semicircular vessel is larger than the triangle vessel.
[34]	2022	CLM355, CLM433,	28.2, 26.09	20 mm	Experiment & software	The study showed the effect of different combinations of PCMs with different densities, thermal conductivities and specific heat capacities on the melting process. The effect of PCM temperature, wall temperature, and thickness on melt fraction has also been analyzed.	The difference in the peak melting point was -0.03 % to +1.52 %, and the difference in the latent heat of fusion was -6.67 % to 9.94 %. These variations were within acceptable limits for the PCMs, and they are suitable for a yearlong application.
[35]	2022	General	-	N/A	Software simulation (COMSOL Multi physics FEM software)	Developing a numerical simulation to describe PCM problems with minimal computational efforts and in height accuracy. The model was important to bridge the large scale gap between the macro-scale level within the PCM layer with moving melting front/ solidification and the scale of length for PV modules.	The outcomes of research revealed that the drop in the production of energy deviates between (2%) and (5%).
[36]	2022	soy wax, paraffin, and beeswax	43.9 – 45.06, 57 – 60.8 , 61.3 – 64.2	36	Experiment & software	Three cases with the PCMs have been compared with the reference case utilizing the PV only without adding PCM.	Compared to PV without a cooling system, the results shown that PV with beeswax might raise the ultimate power to 3W and the height efficiency of PV by 0.94% by reducing the height PV temperature by 8.2 $^{°}$C.
[37]	2023	General	23	50	Simulation (ANSYS-	A pair of distinct vessels, the first one is filled with PCM, and	The regime of (PVT/PCM) evinces the height electrical

					FLUENT)	the second is filled with water. And, they were incorporated with a PV panel upon the backside. Firstly, a fixed PCM thickness was (50 mm) and the thicknesses of water vessel of (20- 30 and 40 mm) were regarded to obtain an appropriate configuration for the suggested (PVT/PCM) regime as well as the performance was studied at a (30-90°) regime location.	efficacy perfection of (3.57%) at (30◦) regime location, pursued via (45◦, 60◦ and 90◦), in comparison with the (PV/PCM) regime for the whole melting of PCM.
[38]	2023	$CaCl_2.6H_2O$	29	20	Experiment	The experimental study utilized the PCM based cooling method lengthways with the fins made of aluminum fins to lower the PV panel temperature. And, the cases were compared with the values of classical PV panel at the angles of the inclination of (30^o, 45^o, and 60^o) with esteem to the ground.	The investigational outcomes were found that the PV panel efficacy augmented via (6.85%, 6.82% and 4.2% for the angles of the inclination of (30, 45 and 60^o), correspondingly. And, the matching uppermost drops of temperature were (13.1, 12.9 and 8.5 ^{o}C).
[39]	2023	RT21, RT35, and RT44	21, 35, 44	-	Numerical study	The study conducted a simulation using three different phase change materials integrated with PV panels during the summer season.	The results exhibited that integrating the PCM caused a reduction of the temperature of PV panel's surface, resulting in a (6%) rise in the efficacy as well as a (16%) improvement in the electrical output. Specially, if employing a a (21°C) melting temperature with a PCM, the highest temperature of cell through the summer reduced from (65°C) to (38°C).
[40]	2024	PCM with nanoparticles (Al_2O_3, CuO, ZnO)	N/A	-	Simulation (SolidWorks)	Involving a passive cooling method by nano-enhanced phase change materials, which collect excess heat during peak daytime and release it at low temperatures. And, the rigid substance, the fins made from aluminum, and the PCM possessed a (2000 J/kg.K) specific heat as well as a (0.2 W/m.K), thermal conductivity (k), correspondingly.	the distribution of temperature discloses significant reduction in surface temperatures with raising the concetrations of Al_2O_3. And, the supreme situation was at (0.5wt%), realizing about 50 ^{o}C. Thus, electrical efficiency increases with concentration.
[41]	2024	Paraffin	28	N/A	Simulation	Presented a simulation on the effect of the inclusion of nano-fluid as well as the shape of pin fin through PCM melting and freezing of phase change for the PV panels. Also, two pipes were devised into the panel, and numerous pin fins (PFs) were implemented to every pipe. The organic (PCMs) were encapsulated into a compartment around the pipes and PFs. Additionally, the parameter was the shape of PF (circular, triangular, square, and	The results indicated that using (triangular PFs)of gives the uppermost fluid temperature into the outlet. The circular PFs result in a lower coefficient of heat transfer in comparison with the other PFs.

						rectangular, and circular). The nano-fluid was utilized into the pipes.	

6. Conclusions

There is an agreement that the using of PCM is useful to decrease the surface temperature of the PV panel. And, there is a variety in the utilizing of different types of PCMs. Some studies had focused upon the common types, like the paraffin, while the others took advanced PCMs mixed with nanomaterials or other heat storage materials. Advance studies may serve hybrid systems like the use of PCMs combined with the metallic foam panels. Also, studies are used to make comparisons between them in order to find the suitable PCM and corresponding application. The improvement of the photovoltaic panel leads the research to involve the PCMs with many configurations and methods to decrease the cell temperature. Several researches deal with the effect of the PCM thickness or the amount of cooling liquid and how to find suitable design arrangements. Added to that, the environmental impact is an important factor in evaluating the different methods of enhancement.

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