# Performance augmentation of PV panels using phase change material cooling technique: A review

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**Abstract** The solar photovoltaics as an environmentally beneficial technique, have emerged as an important source of electrical power, to meet rising energy requirement and supplanting the corresponding shortages in traditional energy sources. Due to a considerable portion of the solar radiation dropping on photovoltaic cells is converted to heat; the photovoltaic power plants' efficiency is reduced. The photovoltaics panel efficiency decreases if the temperature increases, this depends on the type of solar cell used. Controlling the temperature of the solar photovoltaics has become essential to improving photovoltaic panel efficiency, especially in places where the ambient temperature is extremely high. The current paper evaluates the literature related to the application of phase change material for temperature management and electrical efficiency enhancement in photovoltaics modules. The major goal is to identify the important research topics in order to ensure that the technology performs as expected and commercially viable. Various strategies must be examined and enhanced for the site under study in order to achieve the greatest photovoltaics panel performance. According to the findings, the inorganic phase change materials offer a high capacity for cooling solar cells. Only places with high year-round solar radiation and less seasonal transitions climatic fluctuations will be cost-effective for phase change material-based photovoltaic systems. However, less thermal conductivity, in addition to low cooling are two primary issues for phase change material.

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## 1 Introduction

The country's energy consumption is a major indicator of its economic progress. In 2030, energy consumption is predicted to rise by 33% compared to 2010 [1][2]. Generally, 67% of electricity is generated by fuel-fired power plants, which emit hazardous pollutants that contribute to global warming [3]. As a result, renewable energy sources (RESs) featured is the best option to meet the predicted massive increase in energy demand in power systems [4]. Photovoltaic (PV) systems are one of the currently available, highest effective, and well-known renewable energy sources [5][6][7]. The PV was first developed in 1953 at Bell Labs, using a semi-conductor band gap to convert the sunlight into electrical power [8]. As a result, researchers have put a lot of work into developing current PV production technologies [9][10]. The PVs have been classified in a variety of categories depending on their materials. Basically, PV cells can be divided into two types: wafer-based and thin-film cells. Silicon PV cells, in specifically, are classed as mono-crystalline, polycrystalline, or amorphous [11][12].

There are a number of sources of degrading the efficiency of the PV modules. Dust, panel temperature, shading, and other losses occur in solar PV systems under real-world operating conditions [13]. The global horizontal irradiation (GHI) is strong in the summer months, which leads to produce extra power, however it increases the module temperature $(T_{PV})$ due to low speed of wind $(V_W)$ and high ambient temperature $(T_{amb})$ [14][15]. According to

the supplier datasheets, every 1 ℃ rise in $T_{PV}$ over the standard test condition (STC) decreases the panel efficiency

about 0.45%, as given by Eqn. 1 [16].

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**Nomenclature**

| | | | |
|---|---|---|---|
| A | PV module area, [m] | q | elementary charge, [1.60217646×10⁻¹⁹ C] |
| BIPV | building integrated PV | RES | renewable energy sources |
| $f_{PV}$ | PV derating factor, [%] | $R_s$ | series resistance, [Ω] |
| GHI | global horizontal radiation, [W/m²] | $R_{sh}$ | shunt resistance, [Ω] |
| G | solar radiation, [W/m²] | STC | standard test condition |
| $G_T$ | average hourly solar irradiation, [kW/m²] | T | absolute temperature, [℃] |
| $G_{T,STC}$ | solar irradiation at STC, [1 kW/m²] | $T_{amb}$ | surrounding temperature, [℃] |
| I | output current of the cell, [A] | $T_{STC}$ | PV panel temperature at STC, [25 ℃] |
| $I_{ph}$ | inverse saturation current, [A] | $T_{PV}$ | actual PV panel temperature, [℃] |
| $I_{sat}$ | saturated current, [A] | V | Output voltage of the cell, [V] |
| $I_{SC}$ | short circuit current, [A] | $V_{OC}$ | open circuit current, [V] |
| $I_0$ | reverse saturation current, [A] | $V_t$ | thermal voltage, [0.0259 V at 25 °C] |
| K | Boltzmann constant, [1.3805×10⁻²³ J/K] | $V_w$ | speed of wind, [m/s] |
| n | diode ideality factor, [1 for an ideal diode] | $\eta_{PV}$ | panel electrical efficiency, [%] |
| $P_{PV}$ | PV nominal output power, [W] | $\eta_{STC}$ | PV panel electrical efficiency at STC, [%] |
| PCMs | phase change materials | $\beta_r$ | efficiency of PV cell, [%/℃] |
| PR | performance ratio | γ | solar radiation intensity coefficient |
| PV | photovoltaic | | |

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$$\eta_{PV} = \eta_{STC}[1 - \beta_{STC}(T_{PV} - T_{STC})] \qquad (1)$$

Reducing the PV module's temperature in hot and humid conditions will significantly enhance the PV module's electrical output [17]. As a result, the PV panel cooling becomes necessary to prevent the overheating of solar cells. The thermal regulation strategies in the PV panels are used to maintain the temperature of the PV panels as low as possible around the standard test condition (STC) in order to increase its efficiency [18][19][20][21]. Cooling strategies that reduce the thermal loads have been also demonstrated to be effective in increasing the lifespan of solar panels [22].

The present study is accomplished with the purpose of better understanding of PV-phase change material (PCM) cooling technology, representative accomplishments, unresolved issues, and significant hurdles to practical implementation. The operating principles of the PV panels, systems explanation, and the effects of temperature on its electrical efficiency are investigated. The cooling techniques of the PV panel using PCM are presented. Eventually, the present study introduces the barriers, challenges, and suggestions for future work, as well as the main conclusions.

## 2 Working Principles of PV Systems and Its Performance

The working principles of PV systems depend on the incident faced solar irradiation, where photon is grabbed using P-N junction, resulting in a prospective variety through the connection. The charge carriers then pass, producing a photo-current that is parallel using a P-N junction diode. **Figure 1** shows the electrical circuit of solar cells. The represented circuit that is the most employed module to depict the energy building of a single solar cell, with the cell model's current output stated as follows [23].

$$I = I_{ph} - I_0\left[\exp\left(\frac{V + IR_s}{nV_t}\right) - 1\right] - \frac{V + IR_s}{R_{SH}} \qquad (2)$$

where;

$$V_t = \frac{KT}{q}$$

The surface temperature of the solar panel is one of the factors affecting the energy conversion process. The overheats of panels as a result of high surface and ambient temperatures, lowers the efficiency and power production significantly. As a result, the suggested operating temperature of panels is ranged from 0-75 ℃ [24]. **Eqns. 3** and **4** can be used to identify the relationships between the power output and the electrical efficiency of PV panels and its temperatures [17].

$$P_{PV} = P_{PVn}.f_{PV}\left(\frac{G_T}{G_{T,STC}}\right) \times \left[1 + \beta_r(T_{PV} - T_{PV,STC})\right] \quad (3)$$

$$\eta_{PV} = \eta_{T_{STC}}.\left[\gamma.\log_{10}(G_T) + (1 - \beta_r.(T_{PV} - T_{STC}))\right] \quad (4)$$

where $\gamma$ is the coefficient of solar irradiation intensity for PV panel [25][26], $\beta_r$ is the efficiency of a panel in (%/°C), and it usually about 0.004 to 0.005/ °C [27].
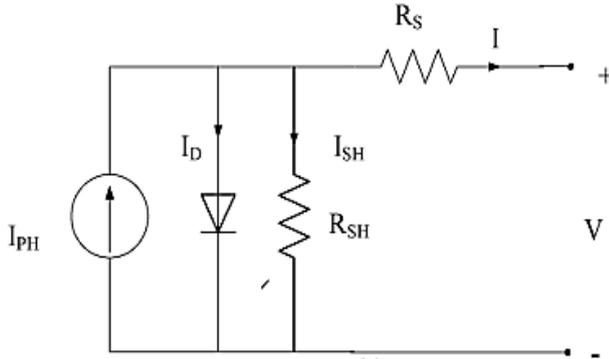


Fig. 1 A single PV cell circuit [23].

Increasing the ambient temperature of panels over 25 °C, $V_{OC}$ drops dramatically and the $I_{SC}$ rises significantly, as shown in **Fig. 2**. This is due to exponential dependence portion of saturation current ($I_{sat}$) on temperature, which causes the inconsiderable increasing of $I_{SC}$ [28]. The panels temperature has a direct effect on the capability to generate power, and the temperature coefficient governs this effect. In comparison to normal operating circumstances of 25°C, the percentage of temperature coefficient reflects the increase in the electricity production as the temperature rises and falls. **Table 1** also shows the performance of STC and temperature coefficients for several types of PV panels [29]. As a result of all of this, it is essential to extract heat from the PV by employing proper cooling technologies to mitigate the negative effects of cell temperature and regulate the working temperature.

## 3 Cooling Methods Principles of PV Systems

Various PV cooling systems, including passive and active strategies have been investigated and evaluated in the past to reduce the temperature of PV panels as shown in **Fig. 3** [30][31]. PCM, liquid and air established PV cooling systems are the most common cooling methods. These methods of cooling can be classified as active or passive. Pumps or blowers are typically used in active heat extraction systems to keep the solar panel at relatively reduced temperature as much as possible [32][33][34]. In

comparison to passive systems, active systems have been shown to be more effective at reducing excess heat from PV panels, resulting in improved PV efficiency. On the other hand, the active cooling, consumes more energy and costs compared to the passive cooling does not [35][36].
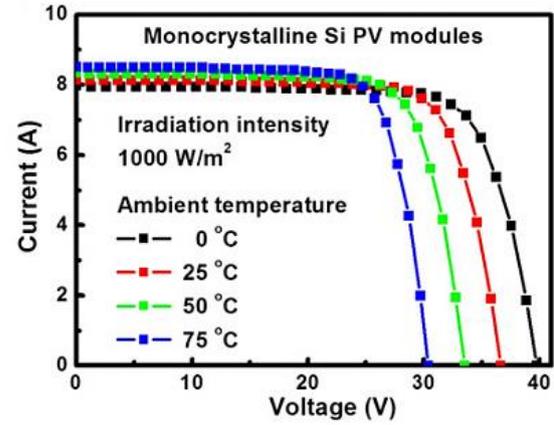


Fig. 2 Characteristics of current-voltage at 1000 W/m$^2$ solar intensity [28].

Table 1 The temperature coefficient and performance for several types of PV cells [29].

| Types | Temperature coefficient | performance of STC |
|---|---|---|
| Mono crystalline | (-0.4) – (-0.5) | 12.5% to 15% |
| Poly crystalline | (-0.4) – (-0.5) | 11% to 14% |
| Amorphous | (-0.35) – (-0.38) | 11% to 13% |
| CIGS | (-0.32) – (-0.36) | 10% to 13% |
| CdTe | -0.25 | 9% to 12% |

## 4 Cooling Methods for PV Systems Based on PCM

This section summarizes the recent papers to discuss the areas of current research and clarify the shortcomings in them, and thus develop a vision of the points that can be worked on in the future to enhance this technology.

The photovoltaic electrical production is a potential approach for meeting the daily energy concerns, but warming of the panels reduces the power conversion efficiency and shortens the module's lifetime. The charge carrier concentration rises as the temperature rises, increasing the short circuit current while decreasing the open circuit voltage. All of this leads to the solar panel's overall power output is reduced, so the thermal regulation

of PV panel is a critical issue [37].

The literature on PV cooling has a variety of techniques, with the majority of the work focusing on passive cooling systems that circulate air or water. On the other hand, these systems are unable to keep the cell temperature at an acceptable range. The active systems have a significant impact on system economics, increasing the cost to provide the necessary power to recycle the air/water cooling to improve the efficiency of the system. The goal of present review is to look into PCM's potential for PV cooling.
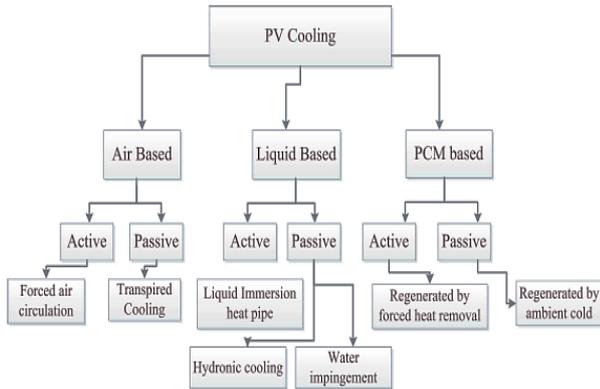


**Fig. 3** Commonly utilized PV cooling method [31].

### 4.1 Working principles of PV-PCM systems

The PV panels with PCM for cooling are a hybrid technique in which the PCM and panel are combined into a single unit to decrease the panel surface temperature and achieve an improvement in the system performance. **Figure 4** represents the working principles of the PV-PCM unit. The combined unit is made up of a PV panel and a PCM that are encased in an appropriate capsulation material and coupled to the PV panel's rear side. The PCM stores the heat accumulated in the PV panels, especially during the sunny hours when the PV panels' surface temperature is higher than the melting point of PCM. Without any outside energy input, the PCM begins to absorb the excess heat from the panels, maintaining the PV panels temperature close to its PCM's melting point. At a specific temperature, the PCM melting point is maintained by absorbing the extra heat accumulated in PV panels leads to the PCM begins to change from a solid state to a liquid state. The PCM continues absorb the heat from PV panels until it is transformed to a liquid phase.

Once the panels surface temperature drops below the PCM's melting point, the liquefied PCM is solidified again. The extra heat received by the PCM from the panels is discharged into the environment, reverting the PCM to a

solid state. When the solar panels are not getting any solar irradiation during the non-sunshine hours the PCM solidification process takes place. The panels are passively cooled in manner and the energy conversion efficiency is improved without the use of power from the PV panels.
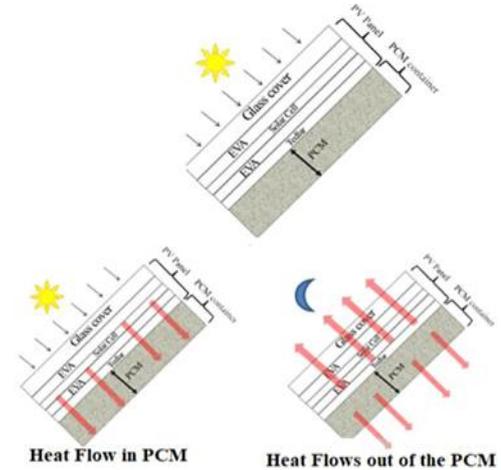


**Fig. 4** Working principles of the basic PV-PCM system [38].

### 4.2 PCM types in PV panel cooling systems

The eutectic mixes, organic and inorganic compounds are the three main categories of PCM [39]. The melting temperature, thermal conductivity, and latent heat of PCM identify the PCM suitability for a given requirement. A good PCMs must have a lot of latent heat, a lot of thermal conductivity, chemically stable, non-toxic, cheap, and non-corrosive [40]. The investigation by Islam et al. [33] provides details on the thermo physical characteristics of a perfect PCM. The PCM temperature must be within the acceptable temperature variety. The PCMs that have been commonly employed for PV cooling applications are addressed and studied in this section. The considerations for choosing the PCM melting point for a certain area are also explained. **Table 2** summarizes a comparison between the advantages and disadvantages of the different types of PCMs.

The organic PCMs are favored over inorganic PCMs because they do not react with the PCM-encased material and do not corrode. As a result, the leakage difficulties with organic-based PCMs are quite uncommon. Another advantage of organic PCMs is that they have a very low degree of sub cooling when compared with inorganic PCMs.

Hasan et al. [41] investigated the cooling effectiveness of organic and inorganic PCMs used for cooling of PV panels. The organic PCMs with lower thermal conductivity have been found to be helpful with low solar irradiation areas and PV panels with low surface temperatures as shown in **Fig. 5**. On the other hand, the inorganic PCMs with better thermal conductivity, such as slat hydrates, can deliver
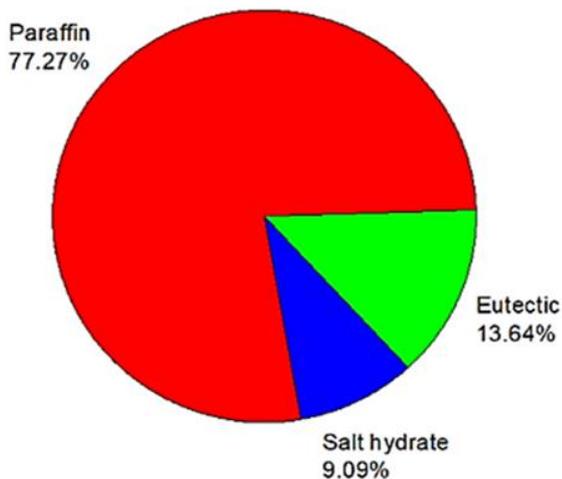


effective performance with PV systems operating in high solar irradiation environments.

**Fig. 5** PCMs types applied with PV panels systems [38].

Hasan et al. [42] described the conditions for selecting the melting point of PCMs. The mean night temperature throughout warmer months and the mean panels temperature throughout the winter days are used to calculate this criterion. The night temperature was collected from the local metrological department and the mean panels temperature throughout cold season is determined according to the following formula:

$$T_{PV} = T_{amb} + \left(\frac{0.32}{8.91 + 2V_w}\right)G \qquad (5)$$

The PCM with a melting point over 35 °C was employed in 19% was investigated [43], whereas PCM with a melting point below 25 °C was employed in 15% of the investigations. The PCM having a melting point above 40 °C is commonly utilized in hot and arid climates such as the UAE and Saudi Arabia.

4.3  Experimental and numerical researches for PV-PCM systems

Utilizing of PCM for the control in temperature of solar panels has been examined in various experimental and

computational investigations. An examination of the PV-PCM unit, applying aluminous PCM box, RT25 as PCM, and fins for thermal conductivity augmentation was conducted [44] as displayed by **Fig. 6**. Hasan et al. [42] studied numerically and experimentally the efficiency of PV-PCM unit in hot weather using paraffin wax RT42 attached at the panel back surface in tight content. The results revealed that the PV-PCM system ultimately obtained 10.5 °C drop on the mean panel temperature at peak time, as well as, the output power from the system was improved about 5.9% on yearly basis. K. Kant et al. [45] researched numerically the influence of using RT35 PCM on the PV panel's efficiency. The results indicated that the solar PV module's productivity was enhanced by about 5%.
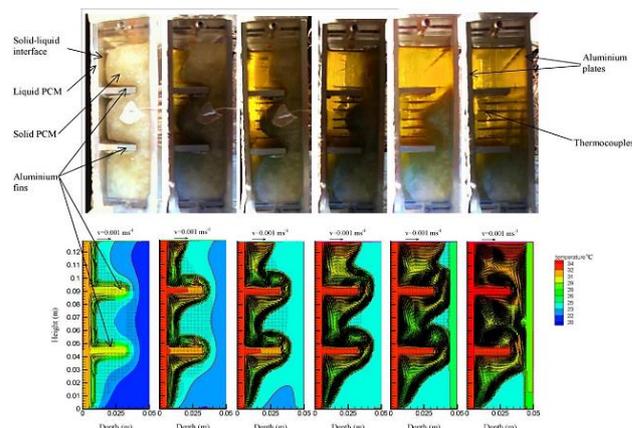


**Fig. 6** Photovoltaic image for a PV-PCM unit using fins throughout the PCM melting process [44].

Stropnik and Stritih [46] investigated experimentally and theoretically the enhancement of PV panel using paraffinic organic type RT28HC. As indicated in **Fig. 7**, the results showed that the highest temperature variance recorded by the PV panel without PCM is greater than that with PCM by 35.6 °C. In addition, during one year the electricity production of PV-PCM panels is greater than that of PV without PCM by 7.3%.  Waqas and Jie [47] showed numerically the effectiveness of PV-PCM system in hot climate region. The PV panels with 65 W capacity and PCM with 40 ℃ and 44 ℃ melting temperatures were used in the study in Bahawalpur-Pakistan. The results showed that the PCM decreased the peak temperatures by about 29 ℃ and hence it increased the efficiency with 10%. The thermal performance of a combined BIPV-PCM system was investigated theoretically and experimentally by Aelenei et al. [48]. The results indicated that the maximum thermal and electrical efficiency recorded about 12% and 10%, respectively.

The PV–PCM system is able to keep the solar panel temperature below 38 °C for an hour and a half, according to a 2D numerical simulation model [49].

**Table 2** Comparison of organic, inorganic, and eutectics PCMs.

| Classification | Organics | Inorganics | Eutectics |
|---|---|---|---|
| **Advantages** | • Low or none undercooling.<br>• Thermal and chemical stabilization.<br>• High heat fusion and no corrosives.<br>• Wide temperature range.<br>• Compatibility with other materials. | • High thermal conductivity.<br>• Greater phase change enthalpy.<br>• Low volume change and cost. | • High volumetric thermal storage density.<br>• Sharp melting temperature. |
| **Disadvantages** | • Low thermal conductivity.<br>• Lower phase change enthalpy.<br>• Relative large volume change.<br>• Inflammability. | • Undercooling and corrosion.<br>• Phase separation.<br>• Lack of thermal stability. | • Low thermal conductivity.<br>• Corrosion in high temperature. |

When utilizing PCMs, the PV panel temperature kept lower than 40 ℃ for around 6 hours [41]. With the proper configuration of the optimized PCM cells, power output in PV-PCM hybrid system [50] was improved by up to 30% compared to reference one.Tan's [51] found that when compared to naturally cooled systems, the PV-PCM system achieved at least about 5% increase in the concentrated solar cells photo-electric generation and about 15 ℃ drop in the PV surface temperature.
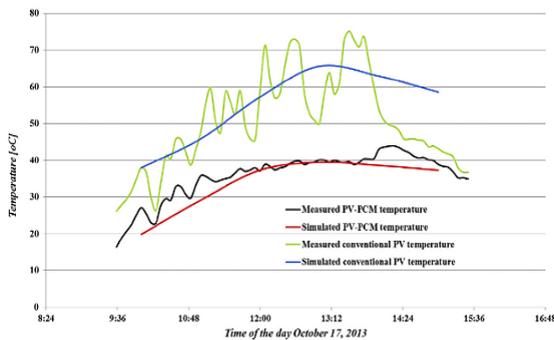


**Fig. 7** Measured and simulated temperatures for PV-PCM and standard PV panel [46].

### 4.4  Material selection

The PCMs uses by thermal energy storage applications has a lot of literature [40][52]. Hasan et al. [53] studied the PCMs that are employed in BIPV thermal management. The heat of fusion, thermal conductivity, and melting point of an appropriate PCM, as well as numerous designs and combinations for PV and PCM integration have been documented. The temperature control influence of five distinct PCMs on the PV panel efficiency was experimentally tested at three insolation levels [54][55]. As well, the properties of organic, inorganic, and PCMs eutectics integrated with solar cells were investigated. The results showed that the five PCMs had melting temperatures ranging from 21 to 30 ℃ and heat of fusion ranging from 170 to 240 kJ/kg.

Due to low solidification temperatures, Hasan et al. [53] reported that some potential PCMs were unable to remove the latent heat during the discharge process, whereas eutectics of fatty acids, such as Capric–Palmitic and Capric–Lauric performed well. The optimal container volume for PCMs was explored in order to maintain a low panel temperature during an extended period of time [54]. Due to its high phase change point, low heat of fusion, and weak thermal conductivity, the Granular PCM GR40 was found to be equally effective as solid–liquid PCM RT25 in sustaining lower and steady temperature [56]. **Table 3** reviews the characteristics of the PCMs used in the PV systems cooling applications in previous studies.

### 4.5  Thermal conductivity enhancement of PCM

To achieve the requisite thermal management, solar panel and PCM combined systems must achieve a rapid thermal dissipation from PV panel, unfortunately the PCMs have a low thermal conductivity in general. Best viable solutions are to use a synthetic approach to improve the PCM's generally low heat conductivity.

Using water as an integrated system with PCM system is one of the solutions to improve the thermal conductivity, and adding nanoparticle material is one of the most essential ways to enhance PV-PCM system's efficiency.

Raising the thermal conductivity of PCM is a realistic approach. Majority of research has been achieved using fins

into PCMs boxes. The majority of scientists used fins inserted in the PCMs and installed in the PCMs enclosures. Huang et al. [56] studied the impact of fins spacing, widths, and types on the systems efficiency. Numerical simulation was used to investigate the influence of numerous fins designs on heat transfer enhancement [57]. Malvi et al. [58] illustrated the employ of conductive fins, mesh, or encapsulation within the PCMs layers for improving the PCMs thermal conductivity.

The literature showed that employing metal fins improved the thermal performance considerably, as the temperature distributions inside the PCMs container became more uniform and temperature increased the panel modules are highly limited [44][49][50][54][56][59][60].

Fins promote heat exchange and thermal uniformity in bulk of PCMs, in addition to they can prevent exposure to fluid flow, reducing the convective heat exchange in melted PCMs [57][61]. As the PCMs volume are lowered by the size of metal fins, the period of thermal control decreases [50][62]. Another potential issue is the raised weight of metal fins for the thermal management capability [62]. Furthermore, due to the development of bubbles under the fin throughout PCMs melting, the fins boost heat resistance [63].

## 5 Barriers and Challenges of PV-PCM Cooling Systems

### 5.1 Melting of PCM

The majority of the research focuses on the effect of the PCM on PV performance during specified times when the conditions are favourable for PCMs, such as surrounding temperature and high irradiation. The efficiency in real-world situations is similarly understudied. The PV-PCM system employs the PCM with a high heat capability and thermal conductivity. On the other hand, the standards of choosing the PCMs melting temperature are not well established in previous studies. Lowering the melting temperature of the PCM at about 25 °C can keep the PVs panels in correct temperature choice for short periods of time before becoming ineffective after peak insolation hours.

Incomplete melting is exacerbated by increasing the thickness of PCM. High melting temperature PCM larger than 30°C cannot maintain the PV at target temperature of 25°C, though it can maintain PV panels lower than a specific temperature during a long period. Subsequently, increasing the PCMs melting temperature can maintain the

PVs at slightly higher and uniformly temperature, eliminating the danger zones. While, decreasing the PCMs melting temperature can maintain the PV at low temperature, but only for a short time, giving the maximum efficiency. As a result, a balance must be struck among the PCMs melting temperature, thickness, in addition to efficiency.

Rather than the average ambient conditions, the PCM must be chosen based on the peak panel temperature measured. Chosen lower PCMs melting temperature based on the average surrounding temperature needed panel temperature positioned directly in touch with the PV. The PCMs with substantially higher melting temperature based on peak panel temperature put to maintain the optimal temperature variance for fast heat dissipation, as displayed by **Fig. 8**.
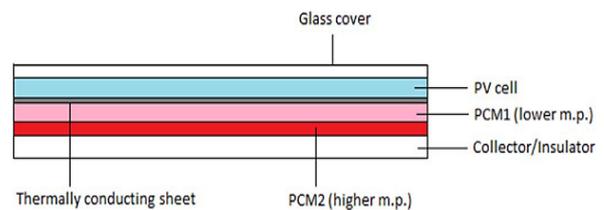


**Fig. 8** Multi PCM layers using for efficient cooling [64].

### 5.2 PCM solidification during night

The solidification of PCM during the night is a significant issue to enhance the efficiency issues. The majority of research studies overlook this factor, where the simulation models accurately anticipated the PCM temperature, but considerable deviations were discovered at night. The convection becomes a critical mode of heat exchange rate throughout the solidification of PCMs because the heat transfer involves complex flow geometries. Moreover, the PCM detaches from the vessel wall, increased the heat exchange resistance.

The top layers of high density materials are found to prevent the lower layers from melting and absorbing the majority of heat as sensible storage. This keeps the lower layers from melting throughout the day. These layers increase the thermal resistance and prevent the top PCMs layers from solidifying throughout the night. As a result, it is necessary to model and optimize the size of the PCMs for a certain unit. There is also a need to design new materials that can match the standards and suit the needs of the system.

**Table 3** Characterizations of some substances that used as PCMs.

| Ref. | PCMs Name | PCMs Classification | Solidification Temp (°C) | Melting Temp (°C) | Storage capacity (kJ/kg) | Specific heat capacity (kJ/kg·K) | Thermal conductivity (W/m·K) | Density (Kg/m³) Solid-Liquid |
|---|---|---|---|---|---|---|---|---|
| [65] | Paraffin PE-HD foil | Organic | NA | 34 | 251 | 251 | 0.19 | 0.76 |
| [66] | Eutectic aqueous solution | Eutectic | -9 | 0 | 280 | 2592 | 1.8-0.6 | 1115-1042 |
| [67] | Paraffin | Organic | 5 | 7 | 156 | 1.8-2.4 | 0.2 | 0.86-0.77 |
| [68] | RT58 | Organic | - | 58 | 179 | 2.4 | 0.2 | 900-720 |
| [69] | Paraffin | Organic | - | 22 | NA | NA | 1.15 | 1030 |
| [65] | Water copolymer-bound PCM | Organic | 0 | - | 63 | NA | 0.6 | NA |
| | | | NA | 34 | 182 | | 0.64 | |
| [70] | Paraffin wax (P-116) | Organic | NA | 44 | 226 | 2.510 | 0.16 | 817-788 |
| | Stearic acid | | NA | 58 | 169 | 1.590 | 0.29 | 965-847 |
| [71] | Paraffin wax (R40) | Organic | NA | 54 | 203 | 2.7-1.8 | 0.3-1.8 | 912 |
| | Honey wax | | NA | 58 | 217 | 3-2.2 | 0.6-2.1 | 953 |
| [72] | Paraffin wax | Organic | NA | 52 | 220 | 2.4-1.2 | 0.295-0.118 | 890-729 |
| [73] | calcium chloride hexahydrate | In-organic | NA | 28 | 45 | 0.34-0.5 | 1.085-0.550 | 1500 |
| [74] | Paraffin wax | Organic | 58 | 60 | 214 | 1.85 | 0.24 | 910 |
| [75] | Salt hydrates | In-organic | NA | 36.1 | 146.95 | 1.34-2.26 | NA | 1954 |
| | | | | 48.5 | 208.80 | 1.46-2.38 | | 1666 |
| | | | | 35 | 278.84 | 1.55-2.51 | | 1522 |
| | | | | 29.7 | 169.98 | 1.46-2.13 | | 41560 |
| | | | | 32.4 | 254 | 1.76-3.31 | | 1458 |
| [76] | Paraffin wax | Organic | NA | 46.7 | 209 | 2.89 | 0.498 | 786 |
| | $Na_2SO_4 \cdot 10H_2O$ | In-organic | - | 32 | 251 | 1.92-3.26 | 1.85 | 1460-1330 |
| | Rock | NA | NA | NA | NA | 0.84 | 0.45 | 1600 |
| [77] | Paraffin wax | Organic | | 46.7 | 209 | 2.89 | 0.138 | 786 |
| [78] | Paraffin wax | Organic | 58 | 60 | 214.4 | 0.9 | 0.2 | 850-775 |
| [79] | SSPCM | NA | NA | NA | NA | 1 | 0.2 | 850 |

NA: not available or not applicable

## 5.3 Thermal conductivity insufficiency

The overall structure depends on a rapid heat transfer procedure for extracting heat from PV panels and transferring it to another medium. The PCMs and its container must have high thermal conductivity. Where, the most PCMs have low heat transfer rates, so the thermal transfer rates from solar panels to PCMs, as well as from PCMs to the surrounding, may be slow. Furthermore, the limited thermal conductivity of PCMs causes a heat incline and stratification inside the PCMs containers.

According to the published researches, one of the most significant obstacles is the requirement to increase the low PCMs heat conductivity to create a faster heat dissipation reaction and longer heat control periods with solar cells.

Some heat transfer augmentation strategies are required to operate with low heat conductivity. Internal fins were utilized, while external fins mounted to the PCM container were employed. Although the fins can increase the total heat transfer from solar cells to PCM, also it can reduce the thermal regulation time period, as previously noted. Due to the fins, the PV-PCM system's overall weight can be an issue and a problem during the implementation process. More experimental and numerical researches are required to determine the impact of new possible materials, such as carbon fibre, metallic nano powders, and carbon nanotubes, on thermal transfer rates and systems efficiency.

## 6 Discussion

According to the review, the literature focuses on the potential of organic PCMs as a cooling agent. Evaluating the efficiency of integrated systems with PCMs, PV-thermal, and BIPV using theoretical and experimental procedures, as well as modelling/simulation studies verified through the experimental testing, may be found in the research. However, the potential thermal benefits of PCM, as well as the resulting impact on its lifecycle and year-round increases in power output, are limited. This section presents and discusses the current state of research, clarify PV-PCM shortcomings, and develop a vision for future research based on a review of the literature.

## 7 Conclusion

This study provides a detailed overview of prior investigations of the PCM-based procedure that can be operated to regulate temperatures of the solar cells. The present state of research in this area is summarized here, with a focus on identifying completed work, unsolved difficulties, promise, and impediments to practical implementation. The following are the main concluded pints depended on the previous studies:

1. The PCMs can efficiently decrease the working temperature of the PV panels by approximately 20 °C, leading to increasing the PV panel's electrical power conversation efficiency by about to 5%.
2. In comparison to colder places with low sun radiation, the PCMs have been ideally suited and economically efficient for regions within high surrounding temperatures and high solar irradiance.
3. To reduce one degree from the PV panels temperature, an average of 2.6 kg of PCM per meter square of panel area must be required. Such a large amount of PCM can raise the overall weight of PV panels by up to 40%, making them more difficult to place and install.
4. The organic PCMs, despite their low heat conductivity, researchers consider it more attractive with PV panel electrical and thermal management. While, the inorganic PCMs offer more favourable cost-effective advantages in terms of payback duration due to their high heat transfer rate and low cost.
5. The PCM-PV systems are more cost-effective with building integrated design where heat dispersion from the PV panel is problematic and heat reuse opportunities are plentiful.

The use of heat dispersion and conductivity enhancers in conjunction through PCMs has been shown to improve the performance of PV panels.

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