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Original Article

Optimizing Solar PV Panel Performance Through Phase Change Material Cooling: An Experimental Study

Sachin Prabhakar Badgujar[1], Cheruku Sandesh Kumar[2], Hemant Krishnarao Wagh[3]

[1,2]Amity University Rajasthan, Jaipur, India.
[3]R C Patel Institute of Technology, Shirpur, Maharashtra, India.

[1]Corresponding Author : sachinpb.88@gmail.com

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Abstract *- Solar PV panels harness sunlight and transform it into electricity. However, increased temperature caused by solar radiation might reduce the production and performance of these panels. In order to hit this problem, paraffin, as a material with phase changes was used for cooling. This PCM has a significant latent heat capacity for melting and developing consolidation; therefore being effective in preserving the heat exchange between the incorporation of PCM in these structures helps manage the temperature by absorbing and releasing energy during the melting and solidification. Experimental approaches were utilized to examine the total thermal oversight and efficiency enhancement of photovoltaic panel conditioning using this PCM. A comparison to the traditional air circulating approach indicated that the recommended PV panel decreased the panel temperature by about 11.5°C. The overall performance improvement of the panel with phase change material implementation was almost 3%. The research investigation on the application of phase change materials for lowering solar photovoltaic temperature revealed positive findings, notably significant improvements in both electricity production and efficiency. This innovative technology has been proven active in reducing the operating warmness of solar photovoltaic panels within the 35 to 40°C range, which results in improved efficiency and a greater life span of the panels. By utilizing PCM for cooling purposes, researchers have demonstrated its potential to enhance overall energy production and sustainability in solar power systems.*

Keywords *- Phase change material, Photovoltaic panel, Solar photovoltaic, PCM, Performance.*

1. Introduction

The fast growth in greenhouse gas emissions and the subsequent escalation in global warming, driven by the revolution, high-tech advancements in industries, increased global electricity ingesting, and expanding populations, have raised significant concerns about environmental degradation worldwide.

This has directed to a rising emphasis on renewable energy sources as a sustainable solution. Among these, solar photovoltaic (PV) systems stand out due to their low maintenance costs, straightforward installation process, and high-efficiency levels. [1-3,6].

Solar PV panels generate electricity by translating solar energy into electric energy, typically achieving efficiencies between 15-20%, with the remaining transformed into thermal energy. However, the surface temperatures of photovoltaic cells can quickly exceed 40°C, surpassing the ambient temperature. This rise in temperature negatively impacts the effectiveness of the cells, with performance decreasing by approximately 0.2 - 0.5% for a degree Celsius rise in temperature [7,8].

To address this matter, several conserving strategies have been discovered. Active solutions, such as water spraying, water jackets, and immersion, have shown effectiveness but are often unsustainable due to water scarcity and reliance on external energy sources [4-6]. Consequently, investigators have twisted their devotion to passive systems, including air, water, and conductive cooling [9-12].

One promising passive preservation approach involves the adoption of phase change materials for conductive cooling. PCM-based cooling systems have demonstrated encouraging results in terms of thermal conductivity and form stability, outperforming traditional air-based passive cooling technologies in thermal management and overall performance [13-14]. Additionally, the incorporation of fins in PCM-based cooling systems has been investigated to enhance thermal performance and reduce PCM melting time [15].

Additionally, the usage of fins in PCM constructed cooling arrangements has been studied to improve thermal performance and shorten PCM melting time [17-18]. Recent research has focused on novel techniques, such as combining composite PCM with fins, to provide synergistic benefits and improve thermal performance [9,12].

In summary, the use of PCM-based cooling systems, particularly those with extended graphite and fin designs, offers the potential for reducing temperature-related efficiency losses in solar PV panels. These novel technologies possess an opportunity to boost thermal control and system productivity in general in comparison to traditional cooling techniques like heat sinks[19,20]. Recent research has focused on innovative approaches, such as combining composite PCM with fins, to achieve synergistic benefits and improve thermal performance. Despite these advancements, there remains a research gap in effectively addressing the temperature management of panels to optimize their electrical performance. This thesis aims to fill this gap by exploring thermal control methods experimentally using a PV-PCM device with various retrofit designs. The primary aims of this paper are as follows:

- Degradation of the electrical productivity of cells with a rise in temperature under continuous incident heat flux radiation.
- Improvement of temperature transmission and control in photovoltaic panels using phase change materials.
- Study the outcome of various arrangements and orientations of fins in the PCM.

By addressing these, the study searches for ways to improve thermal control in addition to the overall yield of panels, thereby mitigating temperature-related efficiency losses and advancing the adoption of renewable energy technologies.

2. Literature Review

The literature on solar panel thermal control can be categorized into inactive, active, and PCM cooling. Research includes both investigational and computational studies, with many focusing on mathematical models. In PV with PCM, improving the thermal conduction of PCM is a key area of interest, with promising methods such as harnessing, wire mesh, and PCM nanoparticles.

2.1. Passive Cooling of PV Module

Several studies have focused on passive cooling strategies for PV modules. Yang et al. [26] and Usami et al. [27] used a simulation model (PVWALL-1.0) to study PV-Wall air duct efficiency. Brinkworth et al. [28] and Nouria [29] used CFD TRNSYS software to investigate thermal regulation efficiency. Fossa et al. [30] studied natural convection in a PV module channel using the ANSYS model. Yun et al. [31] introduced a ventilated photovoltaic façade, showing a temperature reduction from 76.7°C to 55.5°C, leading to a 15% efficiency improvement. Anderson et al. [32] considered copper heat pipe cooling for cells, where heat pipes effectively dissipated heat via natural convection.

2.2. Active Cooling of PV Module

Active cooling involves using pumps or fans to circulate water or air over PV cells. Brogren and Karlsson [33] demonstrated that forced water cooling doubled the power output. Krauter [34] showed a 10.3% performance increase using a water film over the module. Wilson et al. [35] used gravity-fed water cooling, observing a temperature drop from 62°C to 30°C and a 12.8% performance improvement. Tonui and Trip Anagnostopoulos [36] compared natural and forced air circulation, noting parasitic power consumption and maintenance issues in active systems.

2.3. PV-PCM System for Thermal Regulation

PCM offer an inactive system to lower the temperature of the panel as a solution, releasing latent heat and maintaining stable temperatures. Hasan et al. [37] demonstrated that PV-PCM systems kept PV module temperatures below 40°C for six hours, enhancing performance. Huang et al. [38] extensively studied PCM efficiency and fin configurations, finding improved thermal conductivity and electrical performance. Maiti et al. [39] and Tan [40] also reported enhanced device reliability and efficiency using PCM. Karthik et al. [41] showed a 10% efficiency increase panel using Glauber salt.

2.4. Mathematical Models and Simulation

Various mathematical models and simulations have been advanced for PCM systems. Smith et al. [23] used finite difference and finite volume models to predict system performance. Biwole et al. [42] employed CFD models with enthalpy methods. Park et al. [43] developed a transient model for TRNSYS energy simulation, while Cellura et al. [44] used COMSOL MULTIPHYSICS for PV-PCM studies.

2.5. Selection of Materials

The selection of phase change material is perilous for the variable temperature of PV plates, primarily determined by the PCM's melting temperature. However, the influence of ambient temperature cannot be overlooked, especially when raising the PV panel temperature. Many researchers opt for PCMs with melting temperatures of about 53°C, which may not be superlative for all conditions. In hotter weathers where environmental temperatures can reach 47°C, PV panel temperatures may soar to 60 to 70°C. Thus, PCMs with higher melting temperatures (50 to 55°C) are preferred for such conditions [21,22].

Considering climatic conditions in India, where the normal ambient temperature remains above 30°C, selecting a PCM with a liquidous temperature below this average is crucial for the effective temperature regulation of PV panels. Among various PCMs, Paraffin emerges as the most suitable option for the present experiment, ensuring efficient temperature control of the PV panel.

For the purpose of experimentation, 200W photovoltaic cells were purchased from Zun Solar in Delhi. Table 1 provides the technical characteristics of solar cells in the typical surroundings of 1000 w/sq meter and a cell at 25°C.

Paraffin wax RT-42 is a substance of organic origin whose temperature of melting varies between 38°C and 43°C. Table 2 shows the parameters of PEG 1000 as reported by its manufacturer[23].

Table 1. Characteristics of the experimental photovoltaic panels

Parameter	Value
Model	Mono PERC
Pmax [W]	200
Current, ISC [A]	9
Open-circuit voltages (VOC) [V]	27.7
Electrical efficiency (%)	16.5
Operation temperature ranges	0 to 75
Size	151x68x3.6 cm3.

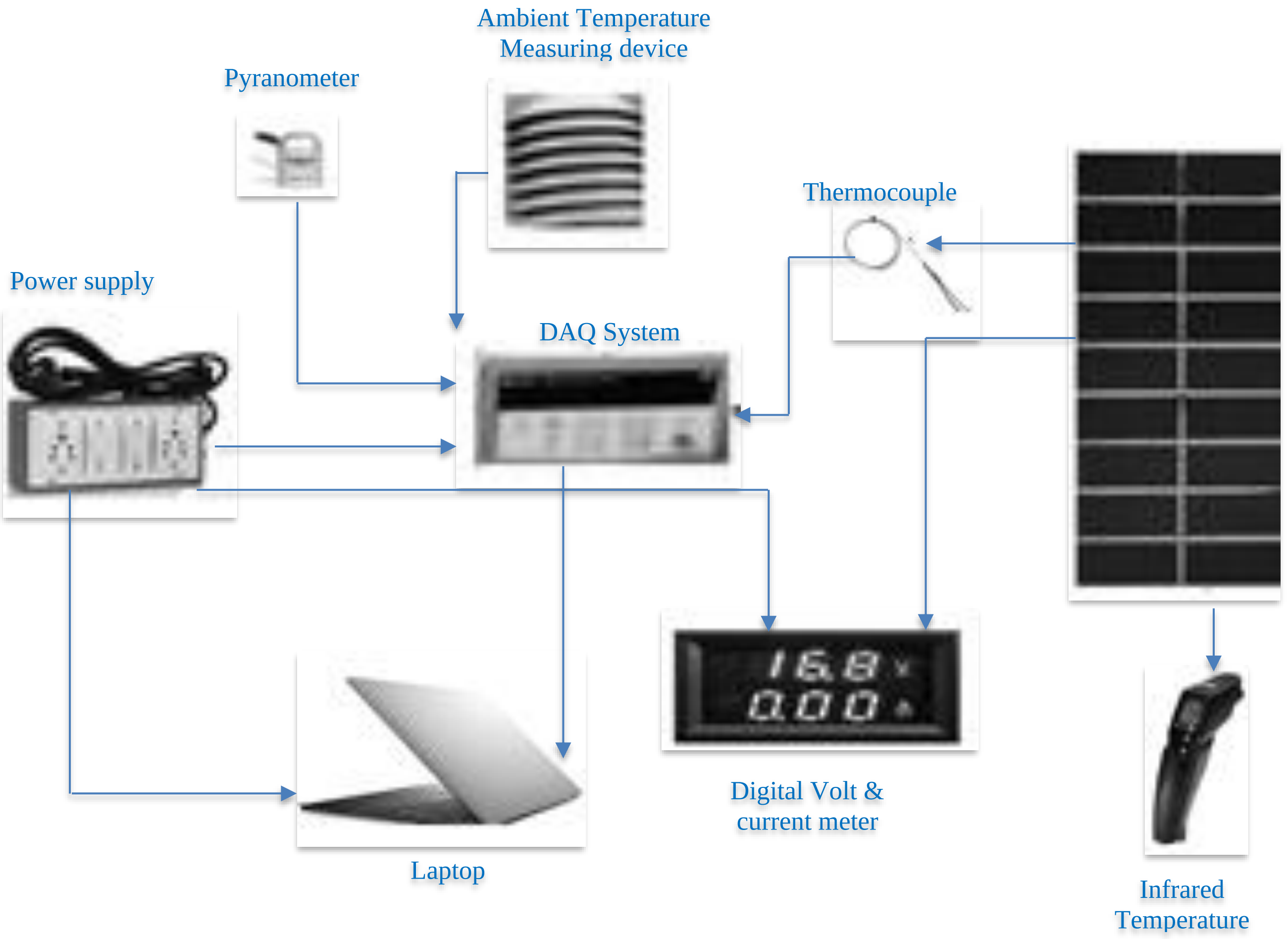

Fig. 1 Illustration provisions of the experimentation

Table 2. Characteristics of phase change material

Molecular category	Paraffin wax
Colorful physical appearance	White Waxy Solid
The point of melting	38-43°C
Flash Temperature	260°C (500°F).
Density [kg/m3]	880
Liquid density, ρl [kg/m3].	760
Conductivity of heat, K [W/m.K]	0.2
Maximum operating temperature Tmax [◦C]	76

3. Investigational Arrangement and Procedure

The first image shows the conceptual construction of the coupled panel and PCM, whereas Figures 1 and 2 represent the experimental design. The system involves a naked solar photovoltaic panel, a PCM with a panel, a data recorder, an electronic voltmeter, and current meters.

An acrylic material covers the bottom of the system, holding the PCM and the solar photovoltaic panel, allowing you to see the material melting.

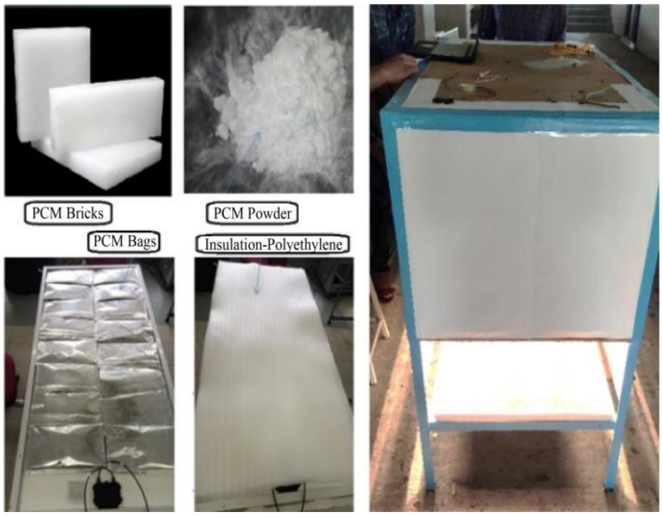

Fig. 2 Practical setup of the experiment

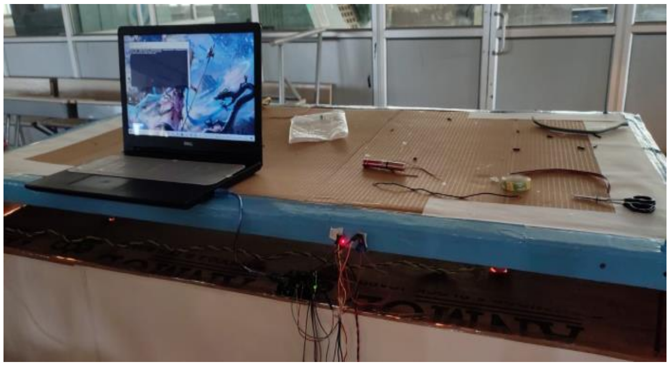

Fig. 3 Setup facility photograph

A total of fourteen thermocouples have been carefully placed to determine the temperatures at different points. Thermocouples are close to the exterior of the solar panel in order to determine the basal and Module temperature in the upper and bottom surfaces.

Furthermore, two thermocouples are mounted to each edge of the photovoltaic cells to measure surface temperatures, with an average measurement taken to ensure accuracy. Each panel's surface temperature is measured simultaneously.

To optimize the effects of the sun, an investigation was carried out at Shirpur, at longitude 21.3496° N and latitude 74.8797° E, at an inclined angle of 13° from twelve o'clock to three in the afternoon.

A logger was used to continually to capture ambient temperature (T), bare photovoltaic plate temperatures, and radiation from the sun (G). A data recorder was used to measure and record voltage(V) and current(I) measurements from the photovoltaic panels and photovoltaic with PCM. Figure 3 shows the setup layout in full [24,25].

4. Results and Discussion

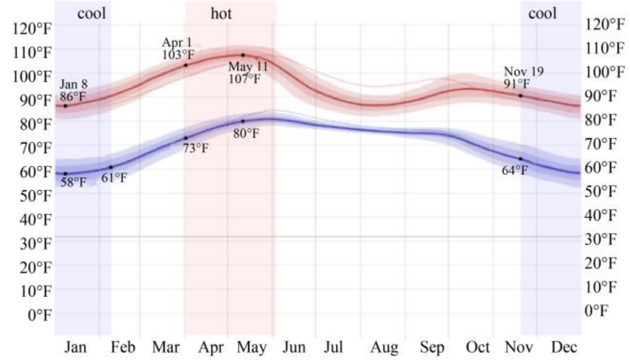

Fig. 4 Climatic statistics for an ordinary day in a particular month, expressed by maximum and normal ambient temperature[Source]

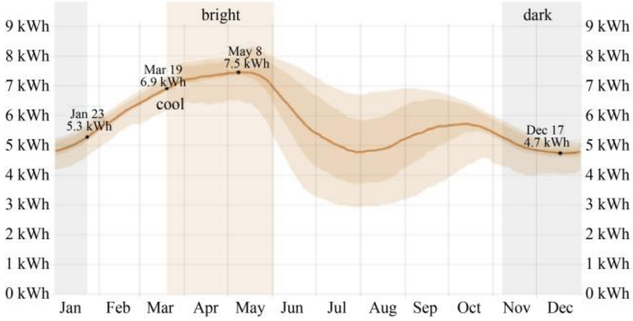

Fig. 5 Environmental statistics for an ordinary day of the month, depicting maximum and normal radiation from the sun [Source]

Solar energy and the surrounding temperature are important elements affecting the temperature changes of photovoltaic cells. Weather data, sourced from the Aurangabad meteorological station, provides insights into these parameters. Seasonal variations in weather significantly impact panel temperatures, with India experiencing hot and humid conditions during summer and milder weather in winter. Summer months, spanning from April to June, typically see average ambient temperatures ranging from 73–80°F, with peak temperatures reaching 103–107°F. Similarly, average solar radiation during summer months ranges from 610–650 W/m2, with peak values between 690–750 W/m2. Figures 4-5 display locally recorded climate information for any typical day during a given month in Maharashtra, India.

Average ambient temperature serves as a key indicator for assessing PCM performance, particularly in terms of its melting capabilities during daytime heating. An examination of annual meteorological data demonstrates that the median outside temperature stays below the temp of the PCM throughout the year. This suggests that even under cloudy situations or in the lack of intense sunlight, the PCM may not melt. Furthermore, the level of sunlight incident on the PV panel is important for establishing the necessary volume of

PCM and fitting the PCM container. Figure 5 shows that solar energy peaks in the summer and falls during the winter.

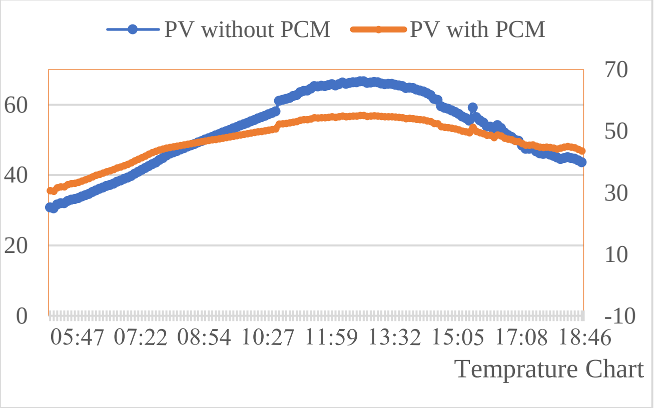

Fig. 6 Temperature dispersion between the basic solar panel and solar panel with PCM

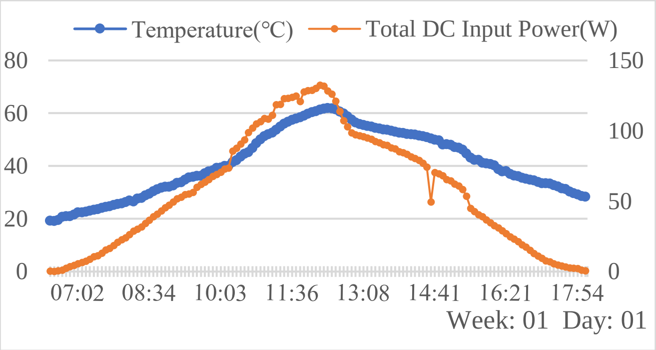

Fig. 7 Temperature and total input power between the basic solar panel and solar panel with PCM in a day

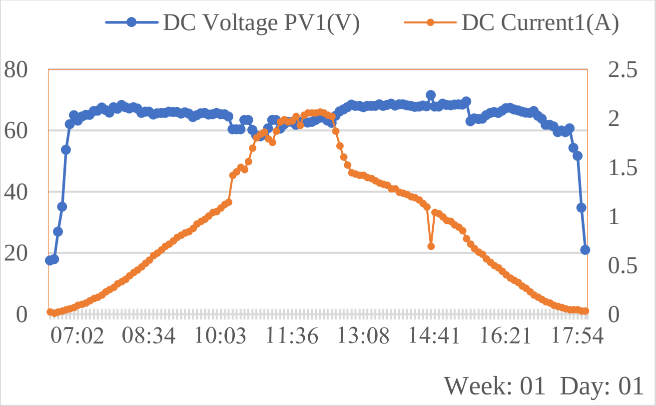

Fig. 8 Current and total voltage chart in a day

4.1. Photovoltaic Panel Assessment

The trials were carried out in Shirpur from January to June 2022. Solar energy, the outside temperature, and wind speed were the primary factors influencing the rise in PV panel surface temperature. Higher solar energy and temperature outside, combined with reduced wind speed, lead to higher cell temperatures at the surface. As a result, the trials were carried out from 11:45 a.m. to three o'clock in the afternoon to account for Shirpur's climate.

Throughout the investigation, the highest peak sunlight and the surrounding temperature were measured as 749 W/m2 and 107°F, correspondingly. Due to high sun radiation, the temperature of the basic photovoltaic panel reached 133.89°F at its peak. Temperature changes were noticed in the naked panel as an outcome of variable visibility of clouds and the speed of the wind.

Figure 6 represents the thermal variation among the panels: exposed solar photovoltaic cells and solar photovoltaic with phase change material. Figures 7 and 8 show the current and total voltage between the basic panel and PCM.

In January 2022, the outside temperature was recorded at 86.5°F and peaked at 91.5°F. The suggested phase change material substantially lowered photovoltaic temperatures while improving panel power effectiveness. Examination of June climate data, which showed the highest mean and peak outside temperatures of 91°F and 107°F, respectively, demonstrates that the mechanism may control solar panel heat even in hot climates.

5. Conclusion

The research study on a passive air conditioning system for photovoltaic cells was precisely constructed and effectively suggested, with PCM components used to improve performance. The findings demonstrated the efficacy of cooling the Photovoltaic (PV) panel and PCM, which dramatically reduced temperature while increasing the efficiency of electricity.

In the condition of lack of conditioning devices, the plain solar cell temperature climbed to 38.6°C, whereas the surrounding temperature remained at 32°C. Installing the photovoltaic panel led the panel temperature to 66.7°C. Additional contact with phase change material with photovoltaic cell resulted in a temperature drop to 55.15°C during the first 2 hours before gradually rising to 52.9°C, as opposed to the standard basic Photovoltaic panel reaching 48.25°C. As a result, the PCM + photovoltaic panel's performance increased significantly by 3.667%.

Finally, using materials with phase change resulted in decreased temperatures of the solar photovoltaic panels, enhancing their electrical generation and effectiveness. The resulting temperature decrease may help increase the lifespan of the photovoltaic panel. In addition, the suggested method was found to be profitable when resources were purchased in bulk. The yearly variability of climate variables, such as the outside temperature and radiation from the sun, was found to be mild at the testing site, rendering the PCM based photovoltaic panels suitable for hot weather.

In the near future, the application of this investigation will be broadened to include longer time frames and a variety of regional circumstances. In addition, attempts will be undertaken to anticipate and test the efficiency of a hybrid PCM based panel.

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