Experimental study of the improvement of the electrical efficiency of a photovoltaic panel using a phase change material

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Abstract— **The present research examines how a phase change material (PCM) can enhance the performance of photovoltaic (PV) panels in terms of energy production. The aim of the study is to explore the effect of heat extraction on PV modules with and without PCM through an experimental approach. The PV modules, both with and without PCM, were compared based on their actual cell temperature records. The PCM was applied on the collector's backside. The results of the experiment indicate that, on July 10, 2023, the daily temperature of a PV/PCM module was 9°C lower compared to a standalone PV module. Furthermore, the PV/PCM module achieved a maximum energy output of 38.08 W, while the traditional PV module reached a maximum output of 35.36 W. Additionally; the PV/PCM panels demonstrated the highest level of electrical effectiveness of 15.13%, compared to the traditional PV's efficiency of 14.97%.**

Keywords: *Photovoltaic; passive cooling; PCM*

1. INTRODUCTION

The use of traditional energy sources to satisfy both residential and commercial demands is frequently expensive; pollute the environment, and finite [1]. Other alternative energy resources must be used and researched in order to solve these problems. Renewable energies, especially solar energy, are among today's most exciting fields and stands for a promising remedy that is practically unbounded today and being used more frequently [2] [3][4].

The intensity of incoming sunlight and the silicon cells' operating temperature are two factors that have an impact on the operation efficiency of solar PV panels [5]. The absorbed heat causes an increase in the temperature of the PV panel, which has a negative impact on its performance, as a result, as the surface temperature rises, the performance of the PV module declines [6][7][8]. The reduction in relative efficiency is approximately 0.45% with an elevation of 1 ◦C above the expected ambient temperature 25 ◦C, to improve PV module effectiveness, the PV temperature must be reduced utilizing active, passive, or combination cooling methods [9][10].

Maghrabie et al [11] investigated the effectiveness enhancement of photovoltaic modules experimentally and discovered that the use of an air cooling process decreased the temperature on the frontal surface of the photovoltaic panel by roughly 10% and the temperature of the reverse surface by 11%. Integrating various thermal systems into PCM as passive refrigeration models for efficient monitoring of temperature [12][13][14].

That several experimental studies had also previously been carried out to reduce the interface temperature of PV modules and enforce heat energy using phase change materials [15]. Bria et al [16] conducted with the simulation study using ANSYS fluent software the impact of PCM thickness on the electrical efficiency of the PV/PCM system using the RT42 Paraffin.

Nizetic et al [17] carried out the investigation that resulted in the manuscript a novel and efficient PV system passive cooling method, the experiment have used many smaller PCM-filled containers to make comparisons for every configuration's efficiency to that of the standard approach. According to the findings, the novel PV-PCM passive cooling technique can lead to better productivity by 10.7% although the traditional model, which employs a single full PCM container, reveals just a 2.5% boost.

According to the literature, the PV/PCM module has been previously the focus of restricted studies. The purpose of this research is to show the impact of latent cooling on standard PV panels utilizing RT47. An experimental setting for 2 distinct photovoltaic modules combined with and without PCM, was currently established. And the experimental measurements of temperature reduction and power production have been conducted over during day on July, 10th 2023; the study was conducted in the Moroccan city of Sidi Ifni.

2. METHODOLOGY

This part describes the system layers, as well as their integration and configuration. Furthermore, the investigated elements and the testing process are explained in the remaining sections.

2.1. System Components:

2.1.1. Photovoltaic Module

The JI.SOLAR 3 system from Spain's "Masterled Sarl" was chosen as the standard photovoltaic board. PV cells made of polycrystalline silicon were chosen for the reason that is less costly than monocrystalline cells. Monocrystalline photovoltaic cells have been discovered to be appropriate fewer rays of sunlight, Although polycrystalline solar panels work best in areas that receive a lot of sunlight and warm places. Due to the extremely hot weather in the region where our experimental investigation is being conducted, the polycrystalline panel was selected. The PV cells under examination are displayed with their electric properties in Table 1.

TABLE 1. ELECTRICAL PROPERTIES OF A PV PANEL, AND THERMAL CHARACTERISTICS OF THE PCM (RT47)

Item	Specific	Value	Specific	Value
PV system	Peak Power (P_m)	60 W	Cell type	Polycrystalline
	Optimal Voltage (V_m)	22.4 V	Module efficiency	15.4%
	Current in Operation (I_m)	2.68 A	Length	0.9 m
	Voltage at Open Circuit (Voc)	23.1 V	Width	0.5 m
	Current at Short Circuit (I_{SC})	2.76 A	Area (A)	0.45 m^2
	Temperature Sensitivity Coefficient	0.45/°C		
PCM	Point of Material Melting	41-48 °C	Solid density	880 kg/m^3
	Energy Required for Fusion	160 kJ/kg	Liquid density	770 kg/m^3
	Heat Transfer Efficiency	0.2 W/m°C	Specific heat	2 kJ/kg.K

2.1.2. Phase Change Material

RT47 functions as the phase change material in the combination PV/PCM module under investigation. This is considered as a natural PCM that makes use of the phase-change processes surrounding the liquid and solid (fusion and refrigerate) to hang onto and release large quantities of thermal energy while preserving a reasonably steady temperature. The RT47 were selected due to their benefits, which included affordability and availability in nearby stores, and it was added to the system in its raw form, without any further purification. Phase-change materials are very effective at storing both warm and cold energy, even if there are only small quantities and minimal temperature fluctuations available. Table 1.1 discusses the RT47's thermal characteristics as the PCM used in the experiment.

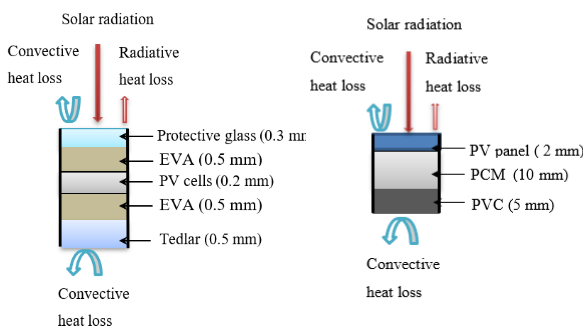
2.2. Installation and Functioning of the System

The phase change material is positioned on the rear surface of the Photovoltaic (PV) panel with a thickness of 4 cm. This specific thickness was selected based on superior performance compared to other thicknesses, as reported by Bouzelmad et al [18]. The polyvinyl chloride (PVC) layer ultimately provided protection for the PCM. To avoid interfering with the two electrical poles, part of the panel appeared uncovered at the back, as provided in Fig 1 (b), while Fig 1 (a) shows the separate photovoltaic panel; for comparative analysis.

Fig 2 showed the fundamental composition and layout of the PV and PV/PCM panels. glass cover, (EVA1), PV cells, (EVA2), and Tedlar are the five layers that make up a PV panel. In addition to PV elements, the PV/PCM system also includes a RT47 layer and a cover made of (PVC) materials.

(a) **(b)**

Fig 1. (a) Conventional Photovoltaic (PV) panel and (b) Hybrid PV/PCM module.

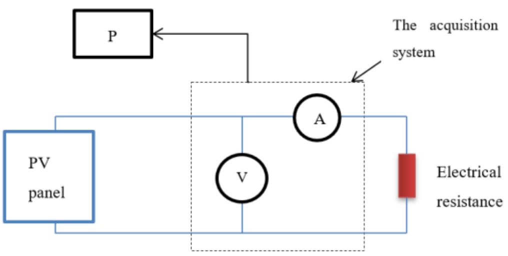


(a) **(b)**

Fig 2. The fundamental configuration of the Photovoltaic (PV) panel (a) and the PV/PCM module (b)

2.3. Experimental protocol and parameters investigated

The experimental equipment comprises a PV/PCM module, a standard PV panel without PCM, 3 temperature sensors with Arduino mega 2560, and a PC for the memory systems. During this experiment, measurements were conducted of the ambient air temperature as well as the voltage, current, humidity, and temperatures from each panel. The voltage and current have been recorded from 2 different systems, as shown in Fig 3 (a). 15 Ω is the electrical resistance (R) used to control voltage and current and avoid short circuits, in addition to the surrounding temperature, were collected at two different locations from the front of the two modules (see Fig 3 (b)). On a computer, the data collected was stored for later examination. Table 3 describes the measuring tools and apparatus utilized for collecting the data for this investigation. The Moroccan city of Sidi Ifni was the site of the experiment.



(a)

(b)

Fig 3. (a). PV panel electrical setup, and (b) temperature sensor installed on the front side of the PV and PV/PCM panels to measure temperature.

TABLE 2. THE SOURCE OF THE MEASUREMENT DEVICE'S ELEMENTS

Items	Equipment or reference	Accuracy
Temperature	Temperature Sensor DS18B20	±0.5 °C
Humidity	Humidity sensor DHT11	±5 %
Voltage	Voltage sensor Max471	2 %
Current	Current sensor Max471	2 %
Irradiation	BH1750 sensor	4 %

The experimental efficiency of sunlight to electricity ($\eta_{el,\ eff}$) of PV and PV/PCM panels is measured as the per-hour rate of variation in electrical performance during the two days, ($\eta_{el,\ eff}$) was calculated based on Eq. 3 focused on the DC production power (P_{el}), in which is calculated through a multiplication the highest voltage V by the current I as addressed in Eq. 3, while the solar power (P_s) The solar panel's power obtained from the sunlight was determined by multiplying the area of its face (A) by the solar irradiation (G) assessed utilizing Eq. 3.

$$\eta_{el,eff} = \frac{P_{el}}{P_s} \quad (1)$$

$$P_{el} = V \times I \quad (2)$$

$$P_s = G \times A \quad (3)$$

2.4. Examination of Experimental Uncertainty

Indeed, there exists a potential for error to manifest at various stages of the experimental process due to factors pertaining to measurement and the measurand [19]. It is advised by these authors to assess the uncertainty associated with the instrumentation employed in the investigation. Various parameters of the quantity under study were documented and analyzed. The uncertainty levels corresponding to each sensor are detailed in Table 2. Equation 4, as delineated by Chandrika et al. [20], presents a method for computing the average uncertainty denoted as W_n.

$$W_n = \frac{a_n}{\sqrt{3}} \quad (4)$$

Herein, a_n represents the precision of the equipment as specified by the manufacturer.

3. RESULTS AND DISCUSSION

The open-air tests were conducted continuously on July 10, 2023. Measuring instruments were employed to gather data from both standalone photovoltaic (PV) and hybrid PV/PCM panels. The collected data included voltage, current, temperature, and power readings in each panel. Additionally, meteorological data, including surroundings temperature, humidity, and solar radiation for the city of Sidi Ifni in Morocco, were collected and are illustrated in Figure 4. As mentioned previously, the key objective in employing a PV/PCM panel was to improve the efficiency of conventional PV boards by lowering the solar cells' temperature. Successively, assessing the temperature of the photovoltaic cells emerged as a crucial characteristic when examining the hybrid PV panel. The impact of incorporating PCM on the temperature of the PV cells is illustrated in Figure 5.

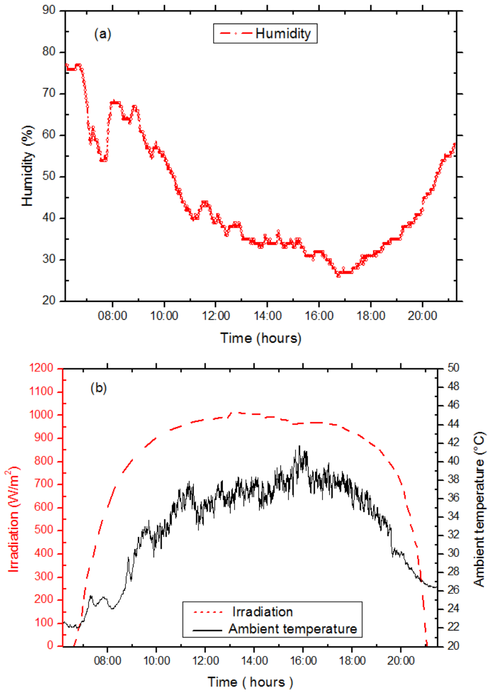


Figure 4.Meteorological data on July 10th, temperature, irradiation (a), and humidity (b).

In Figure 4(a), the weather data reveals a substantial morning humidity level, starting at 76% at 6:30 AM on July 10th and gradually decreasing to a minimum of 27%. This reduction in humidity contributes to an enhancement in the electrical power output of solar panels, aligning with findings from Kazem et al [21]. The improvement may be attributed to the increased solar irradiation acquired by the PV modules when moisture content is low. This phenomenon is associated with the subsequent rise in ambient temperature, depicted in Figure 4(b), which increases from 22.4°C in the morning to 41.8°C in the afternoon. Furthermore, Figure 4(b) illustrates the variation of irradiation over time for the same day.

The irradiation reached a maximum value of 1011 W/m². The concurrent rise in ambient temperature and irradiation led to an increase in the temperature of the standard photovoltaic (PV) module from 22°C to a peak of 66.5°C. In contrast, for the PV/PCM system, the temperature climbed from 22°C to a high of 57.5°C, which was approximately 9 degrees lower than the conventional panel, as depicted in Figure 5. The observation of reduced PV temperature in the PV/PCM module compared to the standalone PV module started at 12:30 PM, coinciding with the point where the PV temperature surpassed 45°C, representing the melting point of RT47. A study of Park and al [19], conducted under similar ambient temperature conditions (approximately 26°C), reported a maximum reduction of 5°C in the PV temperature for the PV/PCM panel in comparison with the conventional PV panel. This temperature decrease was assigned to the dissipation of thermal energy through heat absorption in the PCM layer.

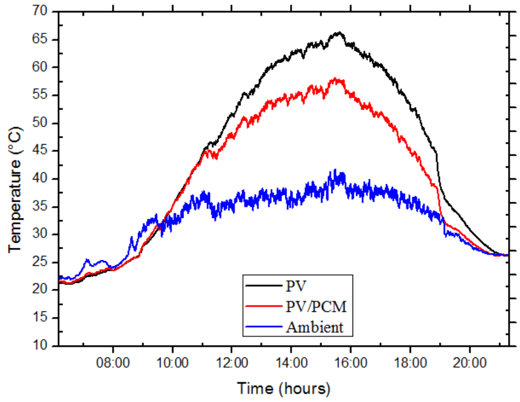


Figure.5 measured temperatures for both hybrid PV/PCM panel and conventional PV panel on July 10th

Applying Equation 2 to the maximum voltage and current measurements recorded for both panels unveiled peak output power values of 35.36 W and 38.08 W for the conventional PV and PV/PCM modules, respectively (as depicted in Fig. 6). The integration of Phase Change Material (PCM) resulted in a reduction in the temperature of the PV cells, thereby leading to an increase in the highest output power from the PV panels by approximately 2.72 W. A fraction of the solar energy absorbed by the PV cells within the PV/PCM panel was efficiently transferred into and stored within the PCM layer. This mechanism facilitated the cooling of the PV cells, consequently enhancing the overall performance of the hybrid PV/PCM collector.

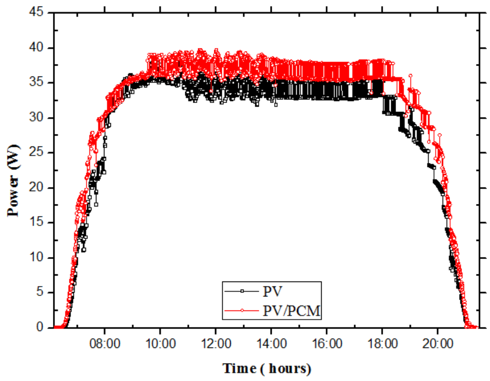


Figure 6. The calculated electrical power for the conventional PV and hybrid PV/PCM modules on July 10th

Following the computation of solar power acquired by individual solar panels utilizing the relationship delineated in Equation 3, the electrical efficiency of these panels was determined employing Equation 1.

Conclusively summarizing the findings, Figure 7 presents the solar power and electrical efficiency of both the conventional Photovoltaic (PV) and hybrid PV/PCM systems for the assessed day, July 10th. The maximum electrical efficiency recorded for the PV and PV/PCM modules was 14.97% and 15.13%, respectively (see Figure 7). The incorporation of Phase Change Material (PCM) into the solar module demonstrated a notable improvement in electrical efficiency, attributed to its ability to absorb an important portion of the heat absorbed by the PV cell.

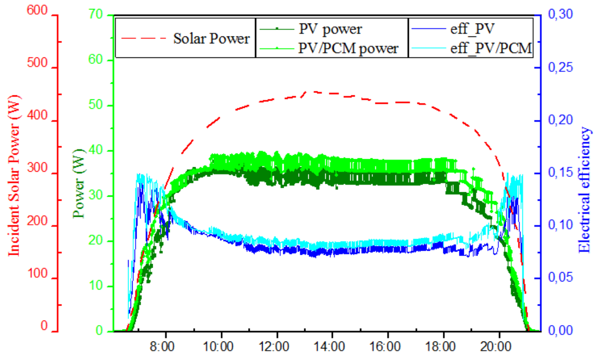


Figure 7. The incident solar power absorbed by the panel, the power output for two panels, and the electrical efficiency for both the conventional photovoltaic (PV) and hybrid PV/PCM throughout day of July 10th.

4. Conclusion

This study investigated the potential enhancement of the electrical performance of a standalone Photovoltaic (PV) panel through the integration of a RT47 Phase Change Material (PCM) into a hybrid PV/PCM subsystem. The evaluation was carried out under real-world weather conditions, with experiments conducted on July 10th, 2023, in an open-air environment. A comparative analysis between the conventional PV panel and the hybrid PV/PCM subsystem was performed, considering parameters such as PV temperature, as well as electrical metrics like current, voltage, and power. The key results are summarized below:

- ✓ Relative to a conventional Photovoltaic (PV) system, the PV temperature in the hybrid PV/PCM system exhibited a decrease, reaching a highest reduction of approximately 9°C, demonstrating the impact of temperature reduction achieved through PCM integration.
- ✓ The peak energy output for the conventional PV system was 35.36 W, whereas the hybrid PV/PCM system achieved a highest energy output of 38.08 W.
- ✓ PV/PCM panels demonstrated the highest electrical efficiency at 15.13%, surpassing the traditional PV system, which recorded the lowest electrical efficiency at 14.97%.

The perspectives of this research are to advance a hybrid Photovoltaic (PV)-based system by integrating nanofluid tubes and a layer of phase change material (PVT/PCM) in various configurations. Furthermore, the research endeavors to examine the impact of incorporating nanomaterials possessing enhanced thermal conductivity to improve the thermal efficiency of the PCM material. Experimental inquiries will be undertaken to assess the electrical output under real-world conditions.

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