

FABRICATION OF DUST IMPACT ON SOLAR PANELS & PV/T SYSTEMS USING NANO-ENHANCED PHASE TRANSITION MATERIAL AND NANOFLUIDS

Dr. Fahim Rahim Sheikh

Assistant Professor, Department of Mechanical Engineering,
Pankaj Laddhad Institute of Technology & Management Studies, Buldana (MH), India

fahimsheikh786@gmail.com

ABSTRACT

The present study provides a thorough experimental investigation into the performance improvement of photovoltaic thermal (solar panels) systems in the presence of dust accumulation, utilizing various thermal management strategies. five systems were investigated: a monocrystalline solar panel, a standalone photovoltaic panel, a water-cooled PV/T system, a PV/T system integrated with phase change material, and a PV/T system that integrates nano-enhanced phase transition material and silicon carbide (sic) nanofluid. The electrical power output, thermal efficiency, and overall performance were evaluated under both clean and dust-covered conditions through the execution of experiments at flow rates spanning from 5 to 10 lpm. According to the findings, the PV/T-nephase transition material-nanofluid system obtained the highest overall efficiency of 84.12% at 7 lpm. It exhibited superior temperature reduction, with the solar panels surface temperature decreasing by up to 62%. Electrical efficiency was enhanced by 2.5% when compared with conventional water-based systems. at a rate of 7 lpm, dust accumulation resulted in a 3.62% decrease in electrical efficiency and a reduced electrical power output of up to 57.36 w. these findings emphasize the efficacy of incorporating nephase transition material and nanofluids in reducing temperature-related losses and enhancing system performance, even in hazy conditions that are common in semi-arid regions such as india.

Keywords - PV/PVT, Nano-enhance PCM, Nanofluid.

INTRODUCTION

The solar energy incident on Earth's surface is approximately 6000 times greater than the world's consumption, with a significant portion being wasted by humanity. In hot climatic locations such as India, this substantial potential is noteworthy. Many regions of the nation receive eight hours of sunshine for 300 days annually, with daily solar energy averaging between 6 and 7 kWh/m²[1]. The data indicates that the country possesses a wealth of solar resources that can be utilized to advance sustainable development and fulfill its energy requirements. According to the Ministry of New and Renewable Energy (MNRE), Maharashtra ranks third in solar energy potential in India [2]. Considering India's substantial solar potential, especially in areas like Maharashtra, where solar energy is plentiful, it is essential to explore technologies such as PVT systems to enhance energy capture. In our pursuit to optimize solar energy use, it is crucial to recognize the importance of effective temperature regulation in photovoltaic (PV) systems [3]. Ensuring optimal solar efficiency, reducing thermal deterioration, and sustaining consistent and reliable energy generation are crucial in varying environmental conditions. The efficiency of the PVT system mainly relies on the surface temperature and is inversely proportional [4]. To manage temperature adequately, a cooling system capable of dissipating the solar heat responsible for PVT heating is essential. PVT cooling systems can be classified into two categories: integrated technologies and emerging technologies. The existing cooling technologies include passive cooling, active cooling, and a combination of active and passive cooling systems [5]. Active cooling systems require operation without an external power source. Emerging

technologies include liquid immersion cooling, phase change material cooling, colorless and transparent silicon shielding, Peltier-based thermoelectric cooling, and microporous evaporation foils [6]. To achieve optimal effectiveness of the solar cells, it is essential to establish a cooling system in conjunction with the heating of the solar panels. Nanofluids, as active cooling agents, exhibit a significant capacity for heat transfer owing to their elevated thermal conductivity. Nanofluids comprise nanoparticles, including carbides, metals, semiconductors, and both single and multi-walled nanotubes, with dimensions ranging from 1 to 100 nm. These nanoparticles are combined with base fluids, such as water and ethylene glycol [7]. The cooling efficiency of nanofluids depends on the appropriate combination of nanoparticles and base fluids.

A multitude of research studies focus on Phase Change Material (PCM)- based cooling fluids to enhance the efficiency of PVT systems, which possess elevated heat capacitance and thus absorb greater amounts of heat from the cell. Paraffin wax is a prevalent phase change substance. It is cost-effective, non-toxic, eco-friendly, and possesses a broad operational temperature range for PVT applications [8]. Al-Imam et al. [9] examined the thermal and electrical efficiency of a compound parabolic concentrator (CPC) photovoltaic-thermal (PVT) system utilizing phase change material (PCM) in an outdoor experiment. Overall, PVT efficiencies were observed to be approximately 55-63% on sunny days and 46-55% on semi-cloudy days. Browne et al. [10] also discovered that PCM PVT systems enhance overall efficiency. Hasan et al. [11] examined the function of phase change materials (PCM) in building-integrated photovoltaic (BIPV) systems. The study indicates that among five distinct types of phase change materials examined, the most notable reduction in cell temperature was approximately 18 °C.

Kazanci et al. [12] examined the application of phase change materials in a photovoltaic-thermal system for residential heating and cooling. The PVT efficiency was determined to be roughly 42.8%, while the standalone PV efficiency was 13.59%. Hasan et al. [13] investigated the total energy of a solid-liquid phase change material-based photovoltaic system in two distinct climates. The statistics indicate that Ireland and Pakistan attained average efficiencies of 14.6% and 20.3%, respectively. Fiorentini et al. [14] examined an air-based PVT system integrated with a PCM storage unit within a reverse cycle heat pump, achieving 9% electrical efficiency and 45% thermal efficiency for an HVAC application. Nonetheless, the improvement in electricity efficiency is insufficient to offset the responsibility. Researchers in this field attempted to integrate nanofluids with photovoltaic-thermal (PVT) systems. Karunamurthy et al. [15] enhanced the thermal conductivity of paraffin phase change material by integrating CuO nanoparticles, hence augmenting the heat transfer rate of the thermal energy storage system.

Khandari et al. [16] investigated the utilization of nanofluid as a substitute for water in the cooling of a PVT system. The utilization of a nanofluid in place of water was deemed crucial for enhancing thermal conductivity in this system. CFD analysis was identified as a valuable method for elucidating the motion of nanofluid, specifically alumina-water, and pure water. The author found that the heat transfer efficiency of the base fluid was enhanced with a greater quantity of nanoparticles. Nanofluids composed of alumina and water exhibit a heat transfer coefficient that is 12.1% superior to that of plain water and 43.1% superior to that of Ag-water. Rajab et al. [17] investigated the possible impacts of nanofluids as thermal transfer mediums in a PVT system via a FORTRAN-based computational model. The outcomes were juxtaposed with a preliminary empirical model. The proposed PVT system underwent testing at three sites—Lyon,

France; Mashhad, Iran; and Monastir, Tunisia—to evaluate the influence of climatic conditions on the results. The investigation indicated that water served as the basic fluid and proved to be more successful than ethylene glycol. Thermal conductivity was reported to increase with nanoparticle suspension concentrations from 0% to 4%. The data indicate that the electrical and thermal performance was optimal in the coldest semiarid climate found in Monastir, Tunisia. Adriana et al. [18] investigated the thermophysical properties of three oxide-based nanoparticles—Al₂O₃, TiO₂, and SiO₂—in water by numerical analyses to identify the superior material. Researchers discovered that the incorporation of nanoparticles altered the thermophysical properties of all examined materials, enhancing their thermal conductivity by 12% or greater. The thermal conductivity and Reynolds number of the nanofluid increase with an increase in nanoparticle concentration, thereby elevating the convection heat transfer coefficient. Sardarabadi et al. [19] examined the effectiveness of a PVT-phase change material system cooled with ZnO-water nanofluid. This experiment utilized paraffin wax as a substitute for phase change material (PCM). The electrical exergy efficiency increased by 23%, and the performance improved by 13% compared to conventional PV modules while employing the proposed phase change material/NF hybrid system. Hosseinzadeh et al. [20] conducted experiments on a PVT-phase change material system cooled by ZnO-water nanofluid to assess its efficiency. The suggested PVT-phase change material, chilled with NF, exhibited superior thermodynamic performance compared to the control system. The proposed system enhanced energy efficiency by 65.71% and exergetic efficiency by 13.61% in comparison to traditional photovoltaic (PV) and water-based PVT-phase change material cooling systems.

Hassan et al. [21] investigated the thermal management and temperature regulation capabilities of graphene water within a PVT-phase change material system. The experimental settings employed in the research were $\phi_v = 0.05\%$, 0.1% , and 0.15% , and $Q = 20, 30$, and 40 LPM. The aluminum box and copper tube convey the molten phase change material (RT35HC) to the winding flow channel networks on the module's lower surface. The graphene-water-cooled PVT system attained the maximum η_{EE} , η_{TE} , and η_{ov} at $Q = 40$ LPM and $\phi_v = 0.1\%$, as demonstrated by the results. The percentages were 14.0%, 45.8%, and 60.3%, respectively.

While several studies have investigated the effect of nanofluids or phase change materials (PCM) independently in photovoltaic thermal (PVT) systems, very limited research has explored their combined integration. The present study is novel in that it experimentally investigates a hybrid PVT system combining nano-enhanced PCM (NePCM) and silicon carbide (SiC)-based nanofluid under Indian ambient conditions. This dual integration aims to maximize both thermal and electrical performance, offering a promising strategy for improving energy capture and conversion efficiency in solar applications. In the current article, a novel attempt to design a new PVT system that can effectively combine nano-enhanced PCM and SiC-based nanofluids to boost the performance of a traditional PVT system is presented. The fully developed system underwent extensive testing using multiple combinations of fluids, and the performance of the PVT system was systematically compared across these various configurations. It includes a NePCM-nanofluid-based PVT system with PV, PVT, and PVT-PCM systems.

Experimental analysis: In the present study, the photovoltaic module was cooled by an active cooling system utilizing forced water circulation and an external power source. The system's many components were developed and manufactured following an extensive literature review.

Experimental Set-up

Table 1 delineates the experimental architecture of the PV/T system, assembled from diverse components. The experimental investigations are conducted in Amravati, (ms) India, at coordinates 22.80° N, 77.70° E. The experiment was conducted in a southeastern direction and on a 19° incline. The outside environment during the experimentation exhibited an average temperature of roughly 25 °c, a wind speed of 12 km/h, and a humidity level of 90%. in the architecture of the PV/T system, the photovoltaic panel is linked to a receptacle containing a (phase transition material).

Table 1: Various Equipments with specification used in the experimental setup

S.No.	Equipments	Specifications	Measurement	No. of Equip.
1	solar panels		Watt	5
2	Water storage tank			2
3	Centrifugal Pump		HP	2
4	Flow valve	-	-	3
5	Gravity flow meter	Flow rate	Lit/min	3
6	Nano fluid storage tank			1
7	Heat transfer device			1
8	K-type temperature sensor	Temperature	°C	10
9	Water temperature sensor	Temperature	°C	6
10	Data storage devise	Temperature	°C	1
11	Solar radiation sensor		KW/Hrs	1
12	Ambient temperature sensor	Temperature	°C	
13	Volt & Current multimeter	Voltage and current	V and A	4

Table 2: Instrument Accuracy and Measurement Uncertainty

Instrument	Range / Accuracy	Uncertainty ($\pm$)
K-type Thermocouple	0–100°C / $\pm 0.75^\circ\text{C}$	0.5°C
Pyranometer (MS602)	0–2000 W/m ² / $\pm 1\%$	10 W/m ²
Rotameter	0–20 LPM / $\pm 5\%$	0.2 LPM
Multimeter (Voltage/Current)	$\pm 1\%$	0.1 V / 0.1 A
Thermal Conductivity Meter	$\pm 5\%$	0.01 W/m·K

All experiments were performed thrice to ensure repeatability. Standard deviations were calculated and utilized to present average values with associated uncertainty margins when relevant. The present study utilizes candle wax as the phase change material and incorporates nano-sic particles to improve the charging and discharging mechanisms. The tank contains a closed fluid flow system that transports nanofluid to an external heat exchanger to improve heat transfer and efficiency.

five experimental configurations are used to evaluate the effectiveness of this PV/T design: a solar panels-mono system, a poly solar panels system, a solar pv/t collectors linked to a water-filled container using water

as the working fluid, a solar pv/t collectors linked to a phase transition material-filled container with water, and a solar pv/t collectors linked to a nanoparticles-dispersed phase transition material-filled container using nanofluid. All solar panels and solar panels-thermal systems collect data simultaneously. Figure 1 shows the experimental configuration and schematic representation, encompassing a data gathering system, a laptop, a hot water storage canister, a nanofluid reservoir, and a support pole for photovoltaic panels.

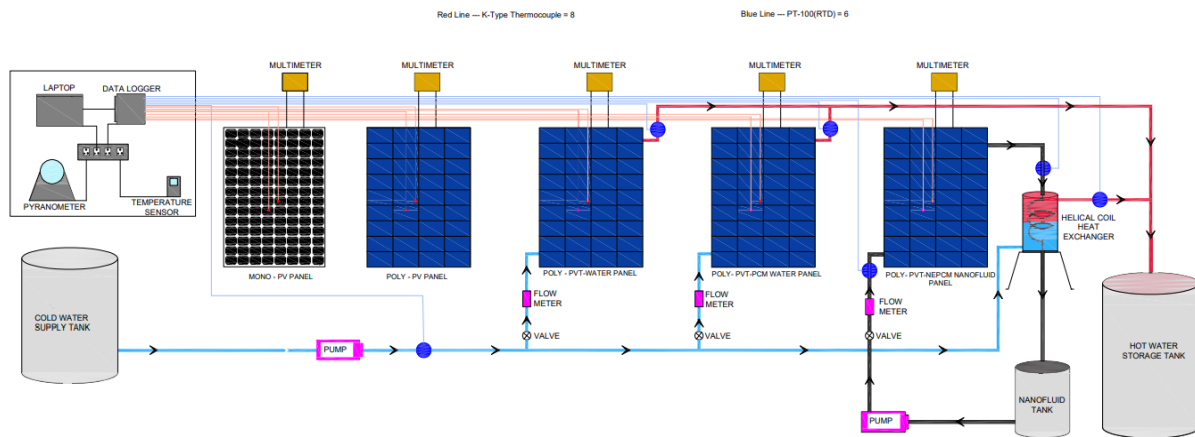


Figure 1: Experimental Configuration

Heat transfer is prevented by a 50 mm fiber glass barrier around the phase transition material container. Fig. 2 (a) shows the absorber's design and construction, emphasizing the collector's area's importance in thermal efficiency. The round tube absorber optimizes solar panels module thermal contact while minimizing collector area. Fig. 2 (b) shows the aluminum containers constructed with phase transition material and Nephase transition material. One pipe functions as an intake for the phase transition material, whereas the other expels heated vapor. The container features two pipes at the apex. Figure (c) shows that silicon oil is applied between the aluminum container and the solar panel to reduce air gaps and increase collector thermal capacitance.

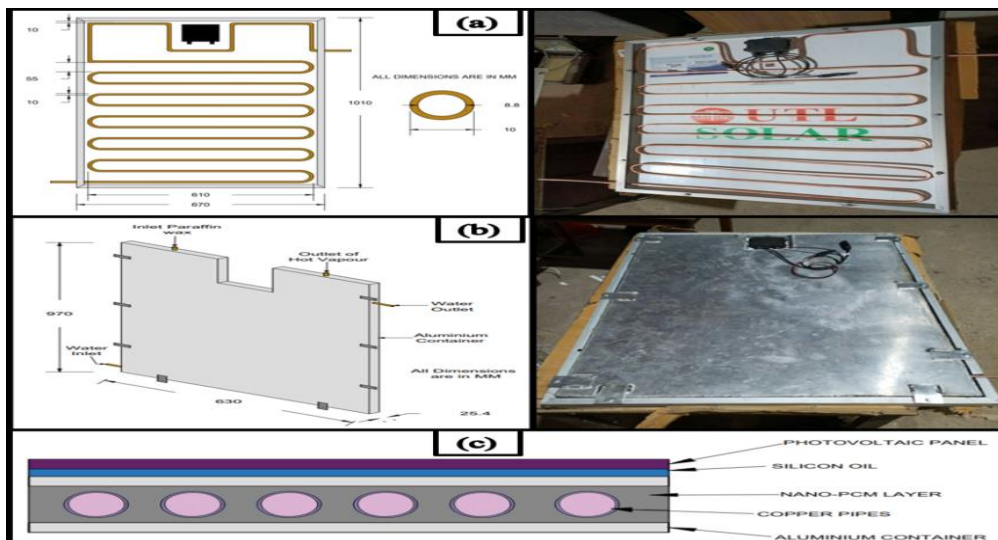


Figure 2: (a) Engineered and built absorber (b) Phase transition material and Nephase transition material aluminum enclosures (c) integrated solar panels/t collectors' cross-section

Table 2 shows the helically coiled tube heat exchanger's dimensions. Copper cylindrical shapes improve heat exchanger water heat transfer. This indirect heat exchanger has an internal heat exchanger. A 250-mm-diameter, 600-mm-long horizontal stainless-steel cylinder is insulated with 50 mm glass wool. Fig. Shows the intended and built heat exchanger.

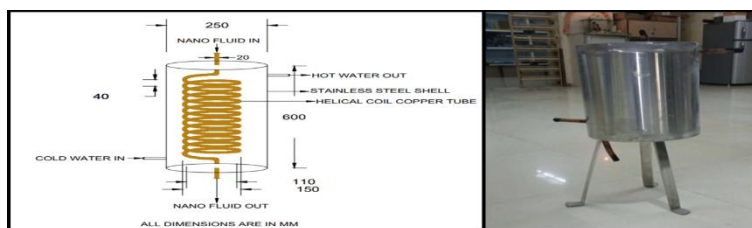


Figure 3: Heat Exchanger

Preparation of Nanofluids

US-based US Research Nanomaterials, Inc. supplied Table 3 SiC nanoparticles. These nanopowder were preheated at 250°C for an two hrs. to eliminate moisture. SiC nanoparticles were dispersed in deionized water at a specified weight % to make the nanofluid. The first 40 minutes were spent shaking the mixture in an ultra sonicator. Nanoparticle aggregation was removed for six hours using an ultrasonic probe sonicator. A magnetic stirrer at 650 rpm for 50 minutes formed a homogenous and stable suspension.

Table 3: SiC Used Nano-powder Specifications

Item	SiC Nano powder specs
Manufacturer	USA Research Nanomaterials, Inc.
Appearance	Grey-white powder
Purity	99+%
PH value	3–7 at 20 °C
Grain size nm	45–65 nm
Density g/cm ³	3.22
Heat conductivity (W/m·K)	370–490

This method produced nanofluids at concentrations of 1, 2, 3, and 4%. The FESEM image of silicon carbide nanoparticles between 40 and 60 nm is shown in Fig. 4 (a). The Liquid Density Tester measured nanofluid density. A Rheometer attached to a PC for data collection and storage measured nanofluid viscosity at different volume concentrations and temperatures. The nanofluids' thermal conductivity was measured with a KD2-pro. All density, viscosity, and thermal conductivity tests were repeated three times to ensure repeatability, and the average value was used to reduce random measurement errors.

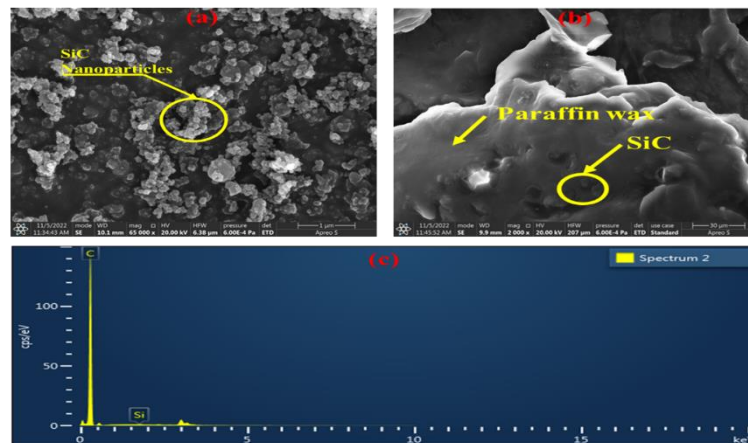


Figure 4: a) SiC nanoparticle SEM; b) SiC-Candle wax SEM; c) Paraffin/nano-SiC EDX.

Preparation of Nano-phase transition material

SiC nanopowder and paraffin were mixed to make the samples. In candle wax, nanoparticle mass fractions (wt.%) of 0%, 0.1%, 0.5%, 1%, 2%, 3%, and 4%. The Ultrasonic Shaker was utilized to perform the mixing process, which entailed vigorously shaking the samples for 60 minutes at 30 kHz while applying heat (800W). This process ensured the creation of a uniform and stable suspension, excellent dispersion, and the elimination of sedimentation. The samples underwent two testing rounds. The initial phase entailed visual inspection of all candle wax-nano-SiC samples for homogeneity and color differences. Color and homogeneity changes indicate nanoparticle assimilation into wax. The second stage involved evaluating fluidity, viscosity, and thermal conductivity by thermo-physical properties testing, which validated the improvements observed in the paraffin. Table 4 presents a detailed account of the assessed qualities of candle wax. The phase transition material container is manufactured on a considerable scale following the determination of a precise mass fraction through experimentation.

Table 4: Candle wax Properties

Candle wax properties	Range
Temperature of fusion (°C)	45 and 67 °C
Density (kg/m ³)	930 kg/m ³
Adhesiveness	15-19
hypothetical	0.25

Figure 4 (b) depicts silicon carbide nano-particles embedded in paraffin, measuring between 40 and 60 nm, as demonstrated by a FESEM image. EDX and EDS were used to examine the SiC-paraffin sample (Fig. 4(c)). EDX and EDS can precisely determine the morphology of material less than one cubic micron. This gadget is connected to a SEM to collect elemental data from the sample. XRD was used to scan SiC-paraffin samples. These photographs demonstrate the effects of SiC nanoparticles in paraffin and support the combination's condition. SiC nanoparticles were chosen for their high thermal conductivity (370–490 W/m•K), stability, and compatibility with aqueous fluids and candle wax. Paraffin was chosen as the primary phase change material (phase transition material) due to its mild melting point (46–68 °C), affordability,

non-toxicity, and stable thermal properties within the working temperature range of photovoltaic-thermal (solar panel) systems. This combination ensures enhanced heat transfer efficiency without significantly raising the system's cost.

Calculation of system's performance

(1) E_s represents the solar radiation absorbed by the photovoltaic module and is expressed as:

$$E_s = I_s \times A_{\text{panel}} \quad (1)$$

A_{panel} denotes the module's surface area, and I_s represents the sun radiation impacting the module.

(2) The heat gain of the solar panel collectors can be determined as follows:

$$Q_{\text{gain}} = m \times C_p \times (T_{w_o} - T_{w_i}) \quad (2)$$

Where m denotes the mass flow rate of water, C_p represents the specific heat of water, and T_{w_i} and T_{w_o} indicate the intake and outflow temperatures of the water, respectively.

(3) The thermal efficiency of the solar panels collectors is determined as

$$\eta_{\text{th}} = Q_{\text{gain}} / E_s$$

$$= (m \times C_p \times (T_{w_o} - T_{w_i})) / (I_s \times A_{\text{panel}}) \quad (3)$$

(4) Electrical efficiency of the solar panels collectors is calculated as

$$\eta_e = P_{\text{max}} / (I_s \times A_{\text{panel}}) \quad (4)$$

The calculation for maximum electrical power production is as follows:

$$P_{\text{max}} = V_{\text{oc}} \times I_{\text{sc}} \times FF \quad (5)$$

FF denotes the fill factor, which is computed as follows

$$FF = (V_{\text{mp}} \times I_{\text{mp}}) / (V_{\text{oc}} \times I_{\text{sc}}) \quad (6)$$

(5) The overall efficiency was expressed by the subsequent formula;

$$\eta_o = \eta_{\text{th}} + \eta_e \quad (7)$$

Where η_{th} denotes thermal efficiency and η_e signifies electrical efficiency.

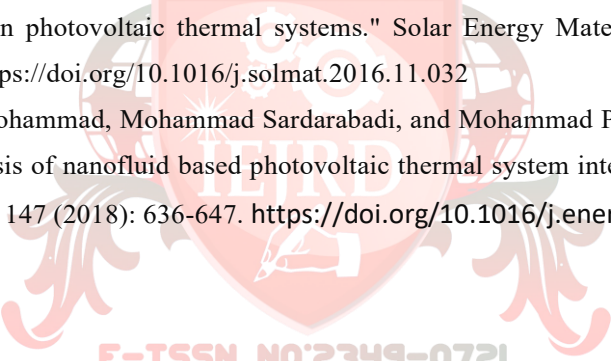
The tests were initially done to determine the thermophysical characteristics of the nanofluid and Nephase transition material. The field testing began after determining the nanoparticle concentration for the nanofluid and nephase transition material based on their thermophysical properties. All solar panels, PV/T and solar panel-nephase transition material-nanofluid instances were tested from 8 a.m. to 6 p.m. on 12 hot February and March days. The tests were executed concurrently, and the results were analyzed by comparison. The effects of six different discharge rates, varying from 5 to 10 LPM, were investigated.

REFERENCES

1. Ramachandra, T. V., Rishabh Jain, and Gautham Krishnadas. "Hotspots of solar potential in India." Renewable and Sustainable Energy Reviews 15, no. 6 (2011): 3178-3186. <https://doi.org/10.1016/j.rser.2011.04.007>
2. Ministry of New and Renewable Energy. "Annual Report 2022-23." Government of India, 2023.

3. Al-Shahri, Omar A., Firas B. Ismail, M. A. Hannan, MS Hossain Lipu, Ali Q. Al-Shetwi, R. A. Begum, Nizar FO AlMuhsen, and Ebrahim Soujeri. "Solar photovoltaic energy optimization methods, challenges and issues: A comprehensive review." *Journal of Cleaner Production* 284 (2021): 125465. <https://doi.org/10.1016/j.jclepro.2020.125465>
4. Joshi, Sandeep S., and Ashwinkumar S. Dhoble. "Photovoltaic-Thermal systems (PVT): Technology review and future trends." *Renewable and Sustainable Energy Reviews* 92 (2018): 848-882. <https://doi.org/10.1016/j.rser.2018.04.067>
5. Sato, Daisuke, and Noboru Yamada. "Review of photovoltaic module cooling methods and performance evaluation of the radiative cooling method." *Renewable and Sustainable Energy Reviews* 104 (2019): 151-166. <https://doi.org/10.1016/j.rser.2018.12.051>
6. Siecker, J., Kanzumba Kusakana, and B. P. Numbi. "A review of solar photovoltaic systems cooling technologies." *Renewable and Sustainable Energy Reviews* 79 (2017): 192-203. <https://doi.org/10.1016/j.rser.2017.05.053>
7. Omisanya, M. I., A. K. Hamzat, S. A. Adedayo, I. A. Adediran, and T. B. Asafa. "Enhancing the thermal performance of solar collectors using nanofluids." In *IOP Conference Series: Materials Science and Engineering*, vol. 805, no. 1, p. 012015. IOP Publishing, 2020. <https://doi.org/10.1088/1757-899X/805/1/012015>
8. Minea, Alina Adriana. "Hybrid nanofluids based on Al₂O₃, TiO₂ and SiO₂: numerical evaluation of different approaches." *International Journal of Heat and Mass Transfer* 104 (2017): 852-860. <https://doi.org/10.1016/j.ijheatmasstransfer.2016.09.012>
9. Al Imam, M. F. I., R. A. Beg, M. S. Rahman, and M. Z. H. Khan. "Performance of PVT solar collector with compound parabolic concentrator and phase change materials." *Energy and Buildings* 113 (2016): 139-144. <https://doi.org/10.1016/j.enbuild.2015.12.038>
10. Browne, Maria C., Brian Norton, and Sarah J. McCormack. "Heat retention of a photovoltaic/thermal collector with PCM." *Solar Energy* 133 (2016): 533-548. <https://doi.org/10.1016/j.solener.2016.04.024>
11. Hasan, Ahmed, S. J. McCormack, M. J. Huang, and Brian Norton. "Evaluation of phase change materials for thermal regulation enhancement of building integrated photovoltaics." *Solar Energy* 84, no. 9 (2010): 1601-1612. <https://doi.org/10.1016/j.solener.2010.06.010>
12. Kazanci, Ogun B., Martynas Skrupskelis, Pavel Sevela, Georgi K. Pavlov, and Bjarne W. Olesen. "Sustainable heating, cooling and ventilation of a plus-energy house via photovoltaic/thermal panels." *Energy and Buildings* 83 (2014): 122-129. <https://doi.org/10.1016/j.enbuild.2013.12.064>
13. Hasan, Ahmad, Sarah Josephine McCormack, Ming Jun Huang, and Brian Norton. "Energy and cost saving of a photovoltaic-phase change materials (PV-PCM) system through temperature regulation and performance enhancement of photovoltaics." *Energies* 7, no. 3 (2014): 1318-1331. <https://doi.org/10.3390/en7031318>

14. Fiorentini, Massimo, Paul Cooper, and Zhenjun Ma. "Development and optimization of an innovative HVAC system with integrated PVT and PCM thermal storage for a net-zero energy retrofitted house." *Energy and Buildings* 94 (2015): 21-32. <https://doi.org/10.1016/j.enbuild.2015.02.018>
15. Karunamurthy, K., K. Murugumohankumar, and S. Suresh. "Use of CuO nano-material for the improvement of thermal conductivity and performance of low temperature energy storage system of solar pond." *Digest Journal of Nanomaterials and Biostructures* 7, no. 4 (2012): 1833-1841.
16. Khanjari, Y., F. Pourfayaz, and A. B. Kasaeian. "Numerical investigation on using of nanofluid in a water-cooled photovoltaic thermal system." *Energy Conversion and Management* 122 (2016): 263-278. <https://doi.org/10.1016/j.enconman.2016.05.083>
17. Rejeb, Oussama, Mohammad Sardarabadi, Christophe Ménézo, Mohammad Passandideh-Fard, Mohamed Houcine Dhaou, and Abdelmajid Jemni. "Numerical and model validation of uncovered nanofluid sheet and tube type photovoltaic thermal solar system." *Energy Conversion and Management* 110 (2016): 367-377. <https://doi.org/10.1016/j.enconman.2015.11.063>
18. Sardarabadi, Mohammad, Mohammad Passandideh-Fard, Mohammad-Javad Maghrebi, and Mohsen Ghazikhani. "Experimental study of using both ZnO/water nanofluid and phase change material (PCM) in photovoltaic thermal systems." *Solar Energy Materials and Solar Cells* 161 (2017): 62-69. <https://doi.org/10.1016/j.solmat.2016.11.032>
19. Hosseinzadeh, Mohammad, Mohammad Sardarabadi, and Mohammad Passandideh-Fard. "Energy and exergy analysis of nanofluid based photovoltaic thermal system integrated with phase change material." *Energy* 147 (2018): 636-647. <https://doi.org/10.1016/j.energy.2018.01.073>



E-ISSN NO:2349-0721