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Development of a new PVt / PCM System for Heating and Power

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Abstract. This study presents a PVt/PCM design that combines heat exchanger and PCM storage to increase power output. The PCM first absorbs sensible heat and when it reaches the melting temperature, it absorbs latent heat and continues to melt. When the phase change is complete, the temperature of the PCM starts to rise. The design consists of a PCM tank under the PV panels and a PCM heat box. In this design-free PVt/PCM system, the thermal efficiency is enhanced by the ability of the PCM to store excess heat during peak radiation periods, and this stored thermal energy can then be released when needed, allowing heat to be used more consistently and efficiently. Energy balance equations were used to determine the thermal energy of the PVt during the summer day in the UK. MATLAB simulations show different heat conduction rates in PCMs. Thermal efficiency measures the system's effectiveness in converting solar energy into useful thermal energy. Incorporating PCM helps maintain PV cell temperatures, preserving electrical efficiency.

Keywords: Photovoltaic Thermal (PVt), Phase Change Material (PCM), Thermal Energy Storage

1. Introduction

Phase change material (PCM) is used to collect and store the heat behind a photovoltaic thermal (PVt) panel and then utilize it when needed. PV and PCM integration enable both power and thermal energy production. The duration and temperature of the phase change depends on the mass and thermal conductivity of the PCM and the heat transfer element [1].

Based on a range of features, such as the condition of substances before and after phase shift, four types of PCMs are defined: solid-solid, solid-liquid, solid-gas, and liquid-gas. The solid-liquid PCM has replaced all others as the go-to model for explaining phase changes. For the simple reason that their tiny volume difference and high latent heat capacity set them apart from other classes [2,3]. PCMs are divided into three categories: organic, inorganic, and eutectic mixes. Organic PCMs are mostly composed of hydrocarbons or fatty acids, which can be categorised as paraffin or non-paraffin, as stated by Mohamed et al. (2017). Some of the bene-fits of these compounds include their chemical stability, lack of toxicity, lack of corrosion, and compatibility with other substances [4]. According to Gunasekara et al. (2017), inorganic PCMs made of metals and salts are more cost-effective overall than organic PCMs due to their non-flammability and high latent heat per unit mass. [5].

This paper focuses on PVt/PCM Solar system design research with lightweight material with high thermal conductivity. The use of a 30 mm thick PCM layer with a phase change temperature of 25°C behind a solar panel has been shown to increase PV electrical efficiency by 10% [6]. The actively cooled PVt/PCM panel is said to realize the highest electrical and thermal energy gain resulting in an overall efficiency of 74.1% compared to 34.6% and 12% for the passively cooled PVt/PCM panel and reference PV panel, respectively [7]. This study aims to implement a design consisting of a heat exchanger filled with PCM and a PCM storage tank. Rajput & Yang (2018) in their investigation of PV module heating and cooling contrasted sin-gle-channel PVt collectors, heat sinks, and cases without cooling. An experimental investigation without cooling resulted in a panel temperature of 88 °C; the heat sink experiment produced a temperature of 66 °C, and the PVt module produced a temperature of 47 °C. With the identical operational conditions, the PVt system was found to be the optimal choice [8].

Alsaqoor et al (2023) employed MATLAB simulations while comparing the performance of PVT systems with and without PCM integration, demonstrating the benefits of PCM in reducing so-lar cell temperatures and improving electrical efficiency. The outcome revealed that the inclusion of PCM in PVT systems tremendously improved thermal and electrical efficiency. 14% electrical efficiency was obtained in the system having 0.25% greater than the system without PCM, while maximum electrical power was 21kW (3kW more than without PCM) . As part of the findings in the study, PV cell temperature and the coolant mass flow rate were inversely proportional to each other. The researchers concluded that the PVt/PCM system can result in improvement of thermal and electrical energy [9]. Mostafavi, A., et al. (2019) examined how a Cartesian fin affects transient temperature distribution in phase change materials (PCM). Their study involved constructing and solving energy conservation equations, leading to a significant contribution in deriving an equation for the component temperature distribution using a perturbation method. It was revealed that fins have dual effects on heat transfer into the PCM, im-proving heat distribution but reducing direct contact area with the heat source, resulting in a non-monotonic relationship between fin size and overall heat flow, and that the optimal fin size depends on the fin's heat conductivity and the thermal properties of both the fin and PCM, crucial for optimizing fin design [10].

Solar thermal collectors and heat exchanger-enhanced PVt/PCM systems have been extensively researched for their ability to improve energy efficiency and reduce reliance on tradi-tion-al energy sources by utilizing renewable energy for heat input. Research in this field focuses on developing efficient and cost-effective solutions for storing and releasing thermal energy on demand, with applications in solar energy storage, waste heat recovery, Heating, ventilation, and air conditioning (HVAC) systems, and more. This study presents a PVt/PCM design that combines heat exchanger and PCM storage to increase power output. The PCM first absorbs sensible heat and when it reaches the melting temperature, it absorbs latent heat and continues to melt. When the phase change is complete, the temperature of the PCM starts to rise.

2. PVT/PCM system modelling and design

The system is mainly composed of a flat plate collector with built-in PVt module, a heat storage PCM tank and a PCM filled heat exchanger. Figure 1 shows the system schematic of the PVT/PCM system. The system provides high efficiency hot water using a PVt module using a new type of inexpensive heat exchanger box filled with PCMs. the PCM tank and the PCM heat exchanger box behind the PVt module are arranged like a parallel separated tank that transfers lower heat to the medium and higher temperatures through heat conduction and phase changes. The system can realize two different operating modes by controlling the opening and closing of the valves: medium (25-30 °C) and medium high temperature (55-60 °C) heat generation on heating mode.

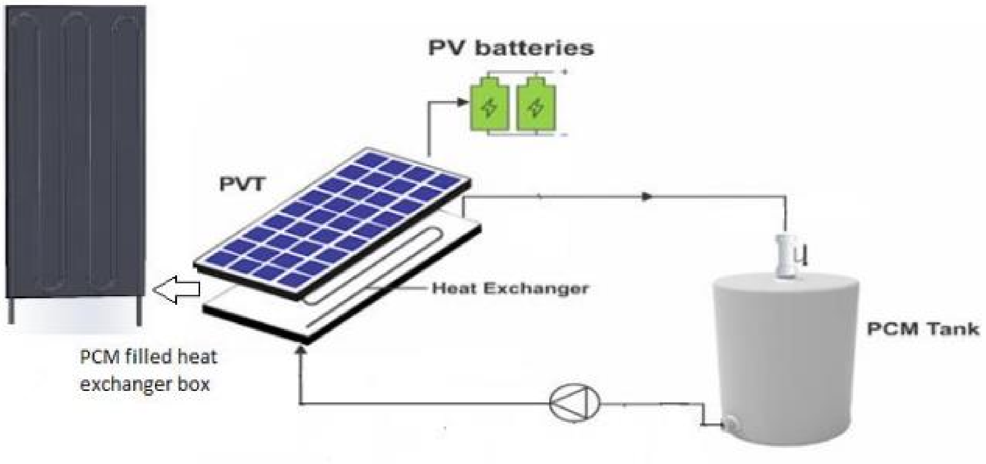


Figure 1. *Simplified illustration of the PVt/PCM system*

3. PCM filled Solar heat exchanger design

A double pipe HEX, designed to be placed behind the PV panel, consists of two concentric pipes connected at both ends to form a closed loop. In this setup, fluid flows through the inner pipe and exits through the outer pipe to extract heat from the 50W PV panel, enhancing thermal performance, energy efficiency, and reliability by increasing surface area contact between the working fluid and the PCM) when integrated into a PVt/PCM system.

Based on UK condition, Rubitherm RT28 HC was selected to fill the box that houses the designed double pipe heat exchanger RT28 HC is a pure organic heat storage material that utilizes phase changes processes between solid and liquid, for storing and releasing of thermal energy in large quantities at approximately constant temperature.

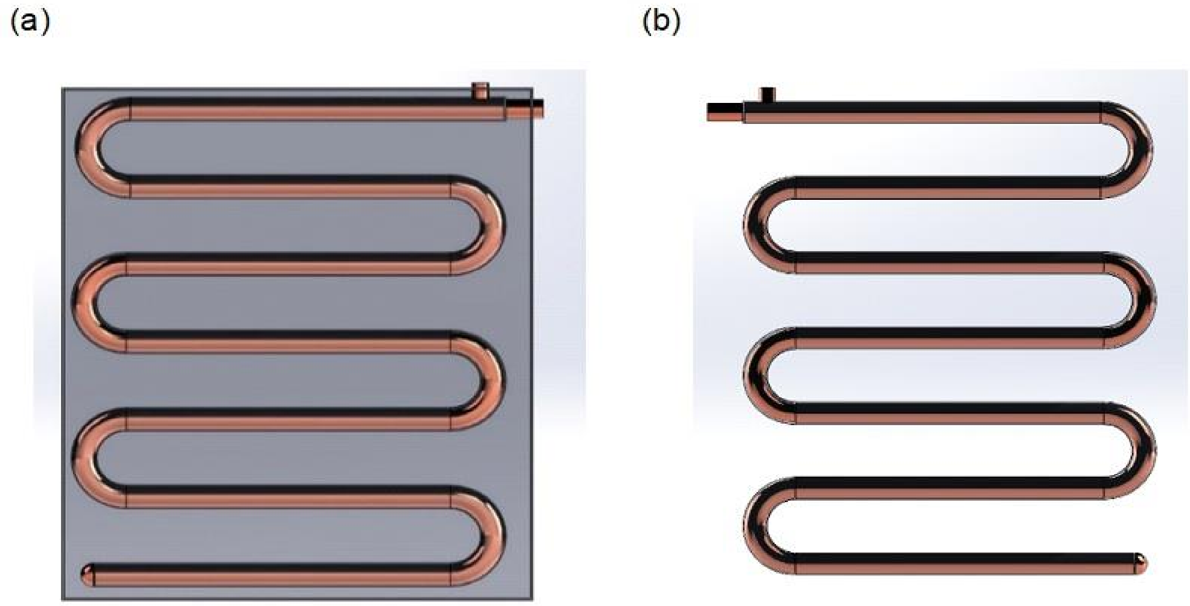


Figure 2. *(a) Double pipe HEX and box assembly (b) Double pipe HEX front view.*

Based on the parameter investigation, the optimum phase change temperature range of PCM in the heat exchanger box is 28°C, Rubitherm-RT 28 is filled with HC. Table 1 shows the PCM properties in the system.

Table 1. *Selected PCM type [11]*

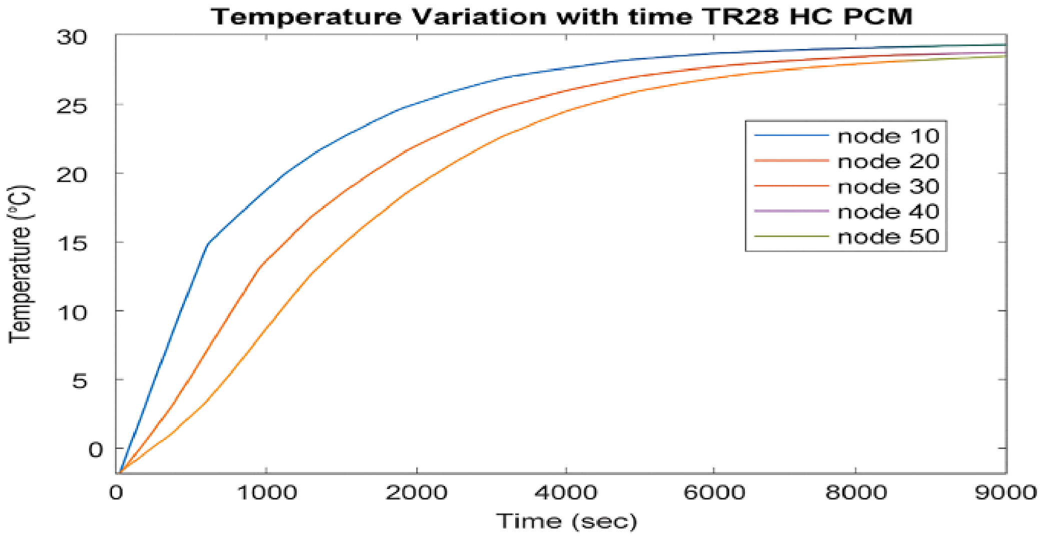
Selected PCM types	Melting Temperature [°C]	Heat Capacity [kJ/kg.K]	Heat Storage Capacity [kJ/kg]	Heat Conductivity [W/ (m.K)
RT28 HC	27-29	2	250	0.2
SP58	56-59	2	250	0.6

4. Results and Discussion

For this study, MATLAB is adopted to obtain a solution with respect to Finite difference method (FDM)for the modelled energy equation. The MATLAB code was used to model the heat distribution within the PVt/PCM over time, using a FDM to solve the heat conduction equation in a one-dimensional cartesian coordinate system. The physical properties of the the PCMs (RT28), such as thermal conductivity (k), density, and specific heat capacity, were considered in the modelling. To measure how quickly the heat spread through the HEX and working fluid, thermal diffusivity was put in place, which was obtained from the PCM's properties. For the effective functioning of the code, time and space discretization, which consist of the time step, mesh size, total simulation time, thickness of the PCM, and sample points, were defined.

For the RT28 HC PCM in figure 23, each line in the graph corresponds to the temperature at a specific node within the PCM over time. Nodes closer to the initial higher temperature boundary (node 10) heat up faster and reach higher temperatures earlier. As the distance from the heated boundary increases (e.g., nodes 30, 40, 50), the temperature rises slower. The graph shows how heat propagates through the material, with the temperature at each node eventually stabilizing as thermal equilibrium is approached.

(a)



(b)

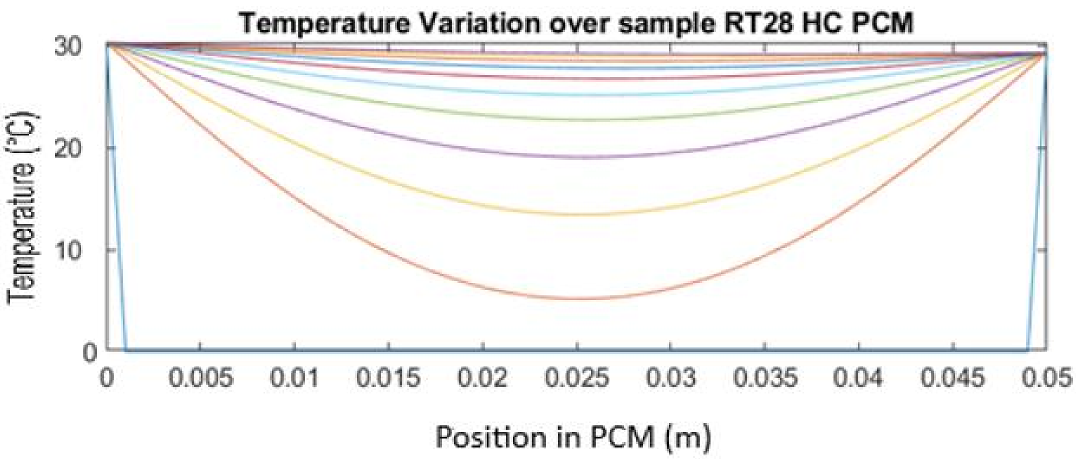


Figure 3. *(a) Temperature (°C) distribution in RT28 HC PCM. (b) Temperature(°C) distribution in RT28 HC PCM].*

This distribution plot the temperature profile at various time steps to visualize how the temperature distribution evolves within the PCM layer over time, in both TR28HC and SP50 PCMs. Validation outdoor and laboratory tests of the developed system will be carried out at the Zero Carbon Solar Laboratory at the University of Derby in the UK

5. Conclusion and Future work

This paper presents a new PVt/PCM system that can operate in two modes, medium low temperature, and medium high temperature, according to different building requirements while generating power. The medium low temperature design will also act as a preheater to achieve the high temperature. The designed HEX plays an important role in this process by transporting the stored thermal energy from the PCM to the fluid (water), which is then used for heating purposes. In addition to improving thermal efficiency, this mechanism indirectly supports electrical efficiency by helping to keep PV cells at optimum operating temperature.

The validation outdoor and laboratory tests of the developed system will be completed at the Zero Carbon Solar Lab at the University of Derby in the UK.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article. Additional information on data can be made available upon reasonable request from the corresponding author.

Author contributions

Tugba Gurler: Investigation, Methodology, conceptualization, investigation, validation, visualization, writing—original draft; **Taiwo Ayoade Idowu**: Methodology, Formal analysis, visualization. data curation, writing; **Sarah Yasir:** Investigation, conceptualization, validation, review, and editing; **Zaharaddeen Hussaini:** Methodology, validation, review, and editing; **Chris Sansom:** Validation, review, and editing

Competing interests

The authors declare that they have no competing interests.

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References

[1] Preet, S. "Experimental investigation of water based photovoltaic/thermal (PV/T) system with and without phase change material (PCM)", Solar Energy, vol. 155, 2017.doi: 10.1016/j.solener.2017.07.040
[2] Khan Z, et al (2016) A review of performance enhancement of PCM based latent heat storage system within the context of materials, thermal stability and compatibility. Energy Conversion Management 115, pp. 132–58
[3] Huang X, et al (2017) Morphological characterization and applications of phase change materials in thermal energy storage: a review. Renewable and Sustainable Energy Revolution, 72 pp. 128–145.
[4] Mohamed N.H., et al (2017) Thermal conductivity enhancement of treated petroleum waxes, as phase change material, by α nano alumina: energy storage. Renewable and Sustainable Energy Reviews, 70, pp. 1052–1058.
[5] Gunasekara SN, et al (2017) Phase equilibrium in the design of phase change materials for thermal energy storage: state-of-the-art. Renewable and Sustainable Energy Reviews, 73, pp.558–581.
[6] Gan, G. Xiang, Y. "Experimental investigation of a photovoltaic thermal collector with energy storage for power generation, building heating and natural ventilation", Renew. Energy, Vol. 150, 2020. doi: 10.1016/j.renene.2019.12.112
[7] Hamada, A. Emam, M. Refaey, H.A. Moawed, M. Abdelrahman, M.A. "Investigating the performance of a water-based PVT system using encapsulated PCM balls: An experimental study", Energy, Vol. 284, 128574, 2023.doi: 10.1016/j.energy.2023.128574
[8] Rajput U.J, Yang J. (2018) Comparison of heat sink and water type PV/T collector for polycrystalline photovoltaic panel cooling. Renewable Energy, 116, pp.479–491.

[9] Alsaqoor, S., et al (2023) The impact of phase change material on photovoltaic thermal (PVT) systems: A numerical study. International Journal of Thermofluids, 18.
[10] Mostafavi, A., et al (2019) Theoretical modelling and optimization of fin-based enhancement of heat transfer into a phase change material. International Journal of Heat and Mass Transfer. 145.
[11] Rubitherm Technologies (2024) SP58 Product technical data sheet. [Online]. Available athttps://www.rubitherm.eu/media/products/datasheets/Techdata_-SP58_EN_12072022.PDF. (Accessed: 18 September 2024).