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REVIEW ARTICLE

Innovative Strategies for Enhancing Energy Efficiency of Photovoltaic Thermal Panels

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ABSTRACT

Photovoltaic thermal (PVT) panels are sustainable energy systems that transform solar energy into both electricity and thermal energy. This article investigates strategies aimed at improving energy efficiency. These strategies encompass the utilization of next-generation absorber materials, advanced structural designs, cooling techniques, and nanotechnology-based solutions. The article addresses various material and structural designs aimed at enhancing energy efficiency and cost-effectiveness. The development of cooling techniques and the implementation of nanotechnology-based solutions possess great potential to further increase the energy efficiency of PVT panels. In terms of ensuring sustainability in the energy sector and reducing energy costs, the application and continuation of research in this area are of utmost importance. This study aims to contribute to the development of solutions for enhancing the energy efficiency of PVT panels and guiding research in this field by providing a valuable resource for policymakers, researchers, and industry professionals in the energy efficiency and sustainable energy sectors.

Contents

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1. Introduction

Photovoltaic thermal (PVT) panels, a combined system of PV panels and solar collectors [1], have emerged as a promising solution for harnessing solar energy [2] to address the growing global demand for sustainable and clean energy sources [3–5]. These hybrid systems efficiently convert solar energy into both electrical and thermal energy, offering potential advantages over traditional photovoltaic (PV) panels and solar thermal collectors [6]. PVT technology has the potential to significantly enhance energy efficiency and reduce energy costs, which are essential for achieving sustainability in the energy sector.

Despite the potential benefits, the energy efficiency of PVT panels (Figure 1) is constrained by various factors, such as material properties, structural design, and cooling techniques. Over the past few years, extensive research has been conducted to explore innovative strategies for improving the energy efficiency of PVT panels [3, 4]. This research has led to the development of novel materials, advanced structural designs, cooling techniques, and nanotechnology-based solutions that have the potential to significantly enhance the performance of PVT panels [7].

Strategies aimed at enhancing the energy efficiency of PVT panels can contribute to the development of sustainable energy sources and the reduction of energy costs. Therefore, increasing knowledge and understanding of strategies for improving the energy efficiency of PVT panels is regarded as a significant step in the energy sector.

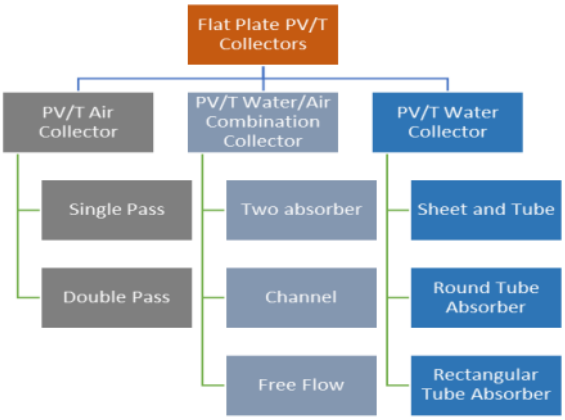


Figure 1 The different cooling techniques [8]

The implementation of strategies for enhancing the energy efficiency of PVT panels and the augmentation of knowledge and understanding regarding these strategies are of great importance in terms of ensuring sustainability in the energy sector and reducing energy costs. Expanding knowledge and understanding of strategies for enhancing the energy efficiency of photovoltaic thermal panels can provide significant contributions to the development of sustainable energy sources and the reduction of energy costs. The in-depth review presented in this article aims to contribute to the development of solutions for enhancing the energy efficiency of PVT panels and guiding research in this field. These efforts will help achieve sustainability in the energy sector and reduce energy costs.

2. Enhancing Energy Efficiency through Material and Structural Design

One of the strategies for enhancing the energy efficiency of photovoltaic thermal (PVT) panels is the improvement of material and structural designs. In this section, various materials and structural designs employed for boosting the energy efficiency of PVT panels will be examined.

2.1. Absorber Materials

Absorber materials play a crucial role in the absorption and conversion of solar energy in PVT panels. Traditionally, silicon-based materials have been utilized for solar energy absorption. However, next-generation absorber materials offer higher energy efficiency and cost-effectiveness. These materials include copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), and perovskites [9]. The use of these materials can significantly enhance the optical and thermal performance of PVT panels, leading to a considerable improvement in energy efficiency.

2.2. Structural Designs

Various structural designs can be employed to enhance the energy efficiency of PVT panels. These designs include flat plate collectors, evacuated tube collectors, and concentrated PV-T systems.

2.2.1. Flat Plate Collectors

Flat plate collectors are the simplest and most commonly used PVT panels with fixed positioning. This design typically employs glazing and/or selective surface coatings to enhance solar energy absorption. Selective surface coatings help reduce thermal losses by lowering emissivity and increasing absorptivity [10]. Consequently, the energy efficiency of flat plate collectors can be improved.

2.2.2. Evacuated Tube Collectors

Evacuated tube collectors are another structural design employed to boost the energy efficiency of PVT panels. This design reduces thermal losses and increases energy efficiency by utilizing a vacuum environment with low thermal conductivity. Evacuated tube collectors are suitable for higher temperature applications and may exhibit better performance than flat plate collectors [11].

2.2.3. Concentrated PV-T Systems

Concentrated PV-T systems are a structural design aimed at enhancing energy efficiency by concentrating the direct normal irradiance on a focal point where a receiver tube through which the fluid runs is placed [4]. These systems employ optical components, such as parabolic or Fresnel lenses, to concentrate solar energy. Concentrated PV-T systems can significantly improve the performance of PVT panels by offering higher energy efficiency and lower cost advantages.

3. Enhancing Energy Efficiency with Cooling Techniques

Cooling techniques play a significant role in increasing the energy efficiency of PVT panels [12]. Reducing the temperature of the panels improves the energy conversion efficiency of photovoltaic cells and enhances the performance of thermal energy collection. Cooling techniques include natural air circulation, water cooling, and the use of phase change materials (PCMs) [13].

3.1. Natural and Forced Air Circulation

Natural air circulation is a passive cooling method that relies on the natural convection of air to dissipate heat from the PVT panels [13]. This technique can be a cost-effective and environmentally friendly option for improving the energy efficiency of PVT panels [14]. On the other hand, air can be blown by consuming exerting power. The air passage can be through a single or double passageways (Figure 2).

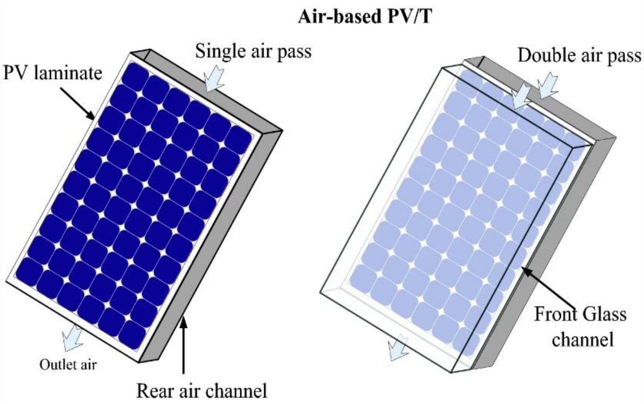


Figure 2 Air based PV/T (single and double) [15]

Even in forced air circulation, where a portion of the electricity generation is used in a fan to blow or suck air through along the passages, several experimental and numerical research has shown the effectiveness of air cooling and reported significant efficiency improvement with different fin types and arrangement [16–19].

3.2. Water Cooling

Water cooling is an active cooling technique that uses water to absorb and transfer heat away from the PVT panels (Figure 3). This method can effectively lower the temperature of photovoltaic cells, resulting in increased energy conversion efficiency and improved thermal energy collection performance.

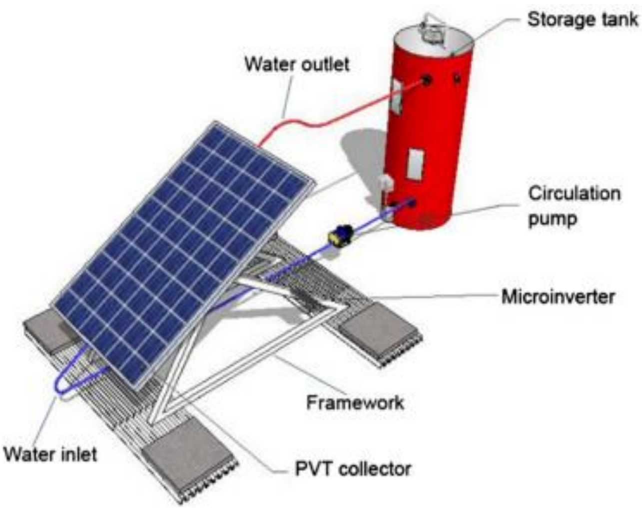


Figure 3 Water cooling [20]

In these systems, water is used as a fluid. Water has a high specific heat under atmospheric conditions. Thus they have high efficiency even at low mass ratios. In addition, the coolant can be recycled or used in single pass cooling systems.

3.3. Phase Change Materials (PCMs)

Phase change materials (PCMs) are substances that can absorb, store and release large amounts of thermal energy during their phase transitions, such as melting and solidification [21–24]. Their ability to store and release thermal energy at constant temperature makes them valuable for thermal management applications. As such, PCMs can be integrated into PVT panels to provide effective temperature control and enhance the overall energy efficiency of the system [22, 25].

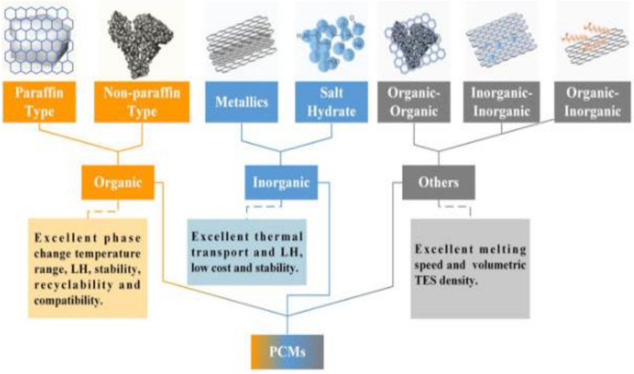
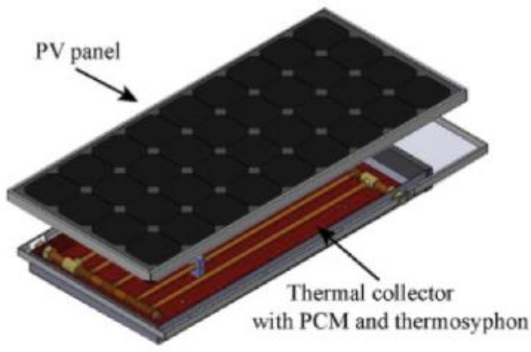


Figure 4 Phase Change Metarials [24, 26]

There are different types of PCMs (Figure 4) in a wide range of melting enthalpies and phase change temperatures, which should ideally be slightly above the optimum operating temperature of the PV modules. PCMs are typically incorporated into a thermal management of a PVT system mainly to manage and regulate the temperature of PV modules by absorbing excess heat from module and thereby maintaining their efficiency at higher levels, as well as preventing overheating and thermal fatigue, which in turn prolongs their lifespan.

As seen in Figure 5, PCMs are incorporated into a PV cooling system as either encapsulated or embedded in modules or heat sinks that are in direct contact with the PV cells, allowing for efficient heat transfer between module and the PCM.



(a)

Figure 5 Cooling with PCM [27]

During the phase change, PCM efficiently stores thermal energy as latent heat at constant temperature, keeping the PV temperature relatively stable even under unsteady insolation or variable ambient temperature.

3.3.1. PCM Slurry-based PVT Systems

Despite the fact that direct use of PCM in cooling circuits had several handicaps due to the instabilities of PCM and the problems with regards to their miscibility problems with carrier fluids, the recent advancements in science and technology, especially the encapsulation methods [28], PCM can now be an option in circulation circuits through PCM slurries (PCS), which enable the utilization of latent heat capacities of PCM while also eliminating the drawbacks associated with their miscibility in carrier fluids [29]. Over the last decade, the utilization of PCM slurries in cooling photovoltaics have made a great progress and stood out as a novel, promising and effective method [23]. With PCS, it is possible to draw 5 to 14 times more heat than could an ordinary heat transfer fluid, such as water, or the other way round, same amount of heat could be drawn in exchange for 5 folds less pumping power [30].

4. Nanotechnology-Based Solutions

Nanotechnology is an innovative approach used to increase the energy efficiency of PVT panels. Nanoparticles and nanofilms can enhance the optical and thermal properties of absorber materials, thereby increasing energy efficiency. Additionally, nanotechnology-based cooling techniques can improve thermal energy collection and the energy conversion efficiency of photovoltaic cells. There has been a great number of research focused on the development of better nanofluids that can be utilized in PVT systems (Figure 6) [31, 32].

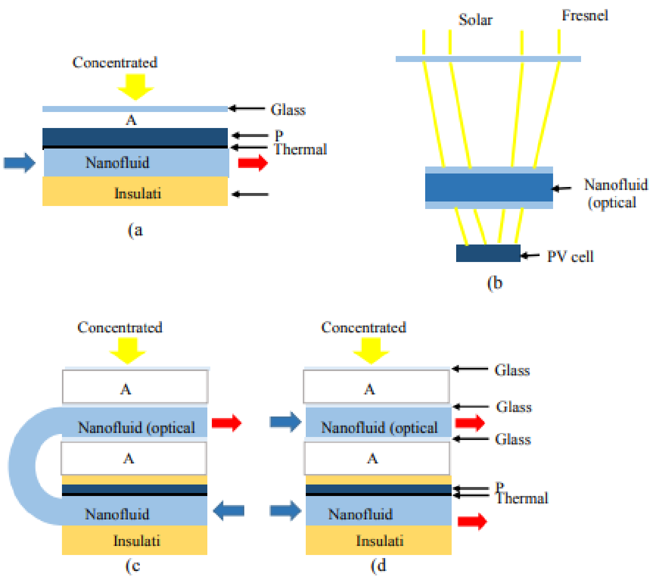


Figure 6 Schematic diagrams of PVT system with nanofluid [33]

It is possible to improve the flow properties by adding nanofluid to the base fluid [34]. As the base fluid, fluids with low thermal conductivity such as water, ethyl alcohol and motor oil are preferred.

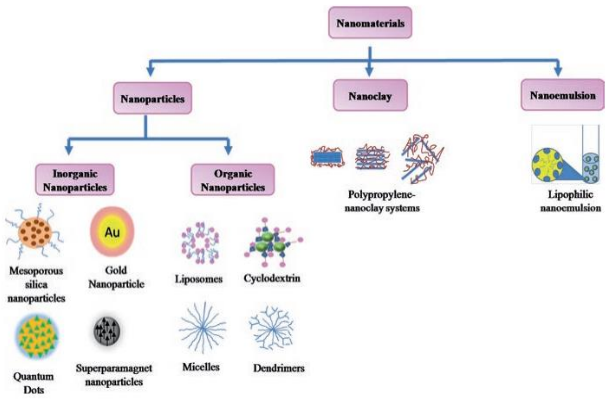


Figure 7 Nanometarials [35]

Nanoparticles, including but not limited to those seen in Figure 7 have been extensively used as additives in different carrier fluids, such as water or oils, in different volume of mass ratios in order to improve the overall heat capacity of the fluids and thus have an enhanced heat transfer nanofluid.

5. Conclusion

Photovoltaic thermal (PVT) panels are significant sustainable energy sources that allow for the utilization of solar energy as both electricity and thermal energy. In this article, strategies for increasing the energy efficiency of PVT panels have been examined. These strategies include improving material and structural designs, developing cooling techniques, and implementing nanotechnology-based solutions.

Through the reviews, it has been demonstrated that new generation absorber materials, advanced structural designs, and cooling techniques can enhance energy efficiency and cost-effectiveness. Moreover, nanotechnology-based solutions hold great potential for further improving the energy efficiency of PVT panels.

The implementation of these strategies and the increase in knowledge and understanding in this field are of great importance in terms of ensuring sustainability in the energy sector and reducing energy costs. Future research should contribute to the sustainability of the energy sector and the reduction of energy costs by conducting experimental studies evaluating the extent of success of these strategies in real-world conditions.

In conclusion, the implementation of strategies for increasing the energy efficiency of PVT panels and the continuation of research in this field play a significant role in ensuring sustainability in the energy sector, reducing energy costs, and combating climate change. This study aims to contribute to the development of solutions for enhancing PVT panels' energy efficiency and guiding research in this area by providing a valuable resource for policymakers, researchers, and industry professionals in the fields of energy efficiency and sustainable energy.

Conflict of Interest

The authors declared no conflict of interest.

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