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Performance enhancement of PVT Thermal modules by the Improved Whale Optimization Algorithm- A Review Paper

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Abstract - Solar energy has grown widely accessible and affordable in recent decades. Photovoltaics and solar thermal collectors have efficiency and exergy issues, despite their popularity. Photovoltaic thermal (PVT) collectors combine solar thermal collectors with photovoltaic cells. The report evaluates numerous PVT systems for private houses, including performance metrics, improvements, restrictions, and future research. The literature review discusses PVT cooling media specific materials. These systems include heat pumps with seasonal energy storage. PVT systems may reach 81% overall efficiency depending on system design and climate. The analysis suggests that solar power might help meet SDG-7's goal of affordable, clean energy. Decentralized and smart systems are pushed to enhance energy supply and address cost, pollution, and security challenges that grid-based energy systems have disregarded. This study examines the global transition to renewable energy utilizing solar photo-voltaic (PV) and solar or thermal (ST) technologies. Solar photo-voltaic systems and solar thermal energy for building heating will grow rapidly, it predicts. Review conclusions emphasize the need to create and deploy technical solutions, legislative interventions, and market-based measures to accelerate sustainable energy technology adoption. This article summarizes current research on working fluids, nanofluids, phase-change materials, cooling technologies, concentrating systems, and PVT-thermoelectric generators. This comprehensive literature review describes its goals and techniques. This in-depth examination of residential PVT systems illuminates their merits, shortcomings, and future research possibilities, which will help develop sustainable energy sources.

Key Words: Improved Whale Optimization Algorithm (IWOA), Levy flight concept, Photovoltaic-Thermal (PVT) modules, exergy efficiency, optimal thermal efficiency, renewable energy technologies

1. INTRODUCTION

Goal 7 of the Sustainable Development Agenda of the United Nations encourages widespread use of clean, affordable energy sources. There was a 13.2% increase in rural areas with access to electricity between 2010 and 2017 [2]. There are still 0.8 billion without access to electricity in the world [3]. Financial and political difficulties have plagued grid-based energy systems for decades. Decentralized or distributed energy systems, often known as smart systems, are growing in popularity as a means to increase energy supply while mitigating the energy trilemma's three interrelated problems of high pricing, high emissions, and low security. However, unanticipated results, such as reverse power flow, may need adjustments to the power system if distributed energy sources are integrated into the electrical distribution network. Therefore, advanced electrical systems are required for network management. There are about 400 components and technologies being developed to reduce carbon dioxide emissions [5]. Solar thermal and photovoltaic technology might provide power and heat both on and off the grid. [6].

2. RELATED WORK

2.1 Energy, Transformation, and Access:

Many countries are making the switch from fossil fuels to renewable energy because of the many financial, environmental, social, and economic advantages that will accrue from making this change [1]. A research on energy transition [5] says that in order to establish a sustainable energy future, renewable energy should account for 65% of the primary energy supply by 2050, with a total investment of $29 trillion until that year. By 2050, solar photovoltaic (PV) deployment is expected to reach 360 GW per year, according to another research [7], which predicts that renewable energy would account for 86% of electric power output. With the objective of satisfying the goals mentioned in the Paris Agreement [4], solar photovoltaics (PV) are projected to provide 13% and 25% of worldwide power consumption by 2030 and 2050, respectively. By 2050, solar PV is estimated to account for 25% of all new electricity generation, with 40% coming from rooftop systems and the remaining 15% from large-scale utility plants. Solar thermal accounts for 7% of world final energy consumption [8], with heating being the major energy end-use at 50% of global final energy consumption. There is presently more solar thermal capacity in China and Europe than everywhere else in the world combined (82% of the total) [9]. It is crucial to hasten the adoption of clean energy solutions via technical developments, regulatory interventions, and market activities in order to fulfill global heating, cooling, and electricity needs.

Energy efficiency improvements, a greater proportion of renewable energy, greater electrical connectivity, and lower greenhouse gas emissions are only some of the lofty objectives set for 2030 by the European Union (EU) [12]. The

European Union promotes the use of alternative energy sources in district heating and cooling systems. Reviewing the renewable energy initiatives sponsored by the European Union, however, found a paucity of urban-scale implementation, with most programs remaining theoretical and focused on increasing awareness and fostering cooperation [14]. Promoting real-world demonstration projects that think about tech, money, law, and society is essential. Half of all energy used in the EU goes toward heating and cooling, with buildings accounting for the vast majority of this demand [17]. The European Union (EU) relies on fossil fuels for 75% of its heating and cooling needs at the present time, with renewable energy sources providing the remaining 22% [19]. Aligning with the digitization of energy systems, the construction sector's digitalization may open up hitherto untapped avenues for growth. The European Union recognizes the threats to energy security presented by a widespread adoption of renewable energy sources, but it leaves it up to individual member states to decide how they will meet such problems, including via the use of nuclear power [20]. The European Union (EU) plans to take the lead in renewable energy by putting an emphasis on energy efficiency [21]. In conclusion, the necessity to create and rebuild infrastructure to enable the broad use of renewable energy sources has shifted the energy system toward greater capital costs and lower fuel prices, as shown by projection and roadmap studies [1]. The transportation sector's decarbonization goals, especially the adoption of electric cars, are predicted to boost electricity's percentage of the market's total energy demand [23]. In 2019, the worldwide solar PV industry expanded significantly, with PV output rising by 22% [24]. While the biggest PV market, China, saw growth slow down owing to the elimination of feed-in tariffs and grid integration issues, the United States had sustained growth in solar PV because to federal tax incentives and state-level legislation. The installed capacity of solar panels in the EU increased by 104% in 2019 compared to the previous year. Competitive solar energy costs, binding emission objectives for member states, tender/auction methods, self-consumption, digitization, energy storage, and corporate power sourcing are only some of the elements that have contributed to this expansion [22].

2.2 Latest PVT Review Articles:

Several comprehensive reviews of Photovoltaic Thermal (PVT) technology and its components were published between 2015 and 2020 [28]. One study looked at how various working fluids affected the efficiency of flat plate PVT collectors [28], underlining the need to examine nanofluids, bi-fluids, and cutting-edge materials. Single-, dual-, and nanofluid flows inside PVT systems were analyzed in another study [29]. Also discussed [26] were the economic and emission reduction benefits of employing nanofluids in PVT systems, as well as the stability of nanomaterials. There were a number of evaluations that looked at various facets of PVT systems. Some looked into the effectiveness of water- and air-type PVT collectors, as well as PVT's incorporation into building-integrated, concentrated, and heat-pump-integrated systems [7]. Techno-economic evaluations, feasibility studies, and long-term reliability research were all suggested as ways to improve PVT systems' performance and cost-effectiveness [15]. Several in-depth analyses [8, 9] were devoted to the topic of concentrated PVT systems due to their reputation for superior efficiency. These analyses inspected everything from first principles to design factors to efficiency ratings. Systems based on spectral beam splitting, waste heat recovery, and compound parabolic reflectors have all been the subject of previous studies [21].

Several evaluations looked into PVT-Thermoelectric generators, which integrate PVT with thermoelectric technology, and stressed the need for feasibility study, numerical analysis, and extended field experiments in real-world settings [4]. Phase-change materials (PCM) and thermal absorbers were the primary areas of attention for this comprehensive evaluation of cooling methods for PV and PVT systems [5]. These studies underscored the significance of creating PCMs for improved heat transfer [9], despite the scarcity of available numerical models and life cycle evaluations for PVT-PCM systems. Maximum heat transmission was shown to be largely dependent on the mounting techniques for thermal absorbers [26]. Several studies have shown that weather has an effect on PVT collector efficiency, underscoring the need of an all-encompassing study that takes climate into account [27]. Use of thermal energy from PVT systems was also mentioned for its possible financial advantages, particularly in building-integrated applications [15].

2.3 Aims of the Paper and Literature Review Methodology:

This article presents a thorough examination of the progress made in Photovoltaic Thermal (PVT) systems within the residential sector. The use of thermoelectric materials in power production is gaining popularity because of its ability to provide clean and sustainable energy. However, the poor efficiency of thermoelectric modules remained a major barrier to their widespread use. The purpose of this research is to review contemporary methodologies that strive to increase the performance of thermoelectric modules by optimizing the method used to construct them. In the process, certain research gaps have been encountered which are enlisted in the sections further along. PVT modules are a kind of thermoelectric device that generates both heat and electricity by using the strengths of thermal and photovoltaic (PV) technologies. One possible benefit of this study is the development of more efficient and cost-effective PVT thermoelectric modules, which might lead to a rise in the usage of renewable energy sources and a fall in greenhouse gas emissions. This study has implications beyond the realm of thermoelectric modules; it can help develop robust, efficient optimization techniques that can be used to a wide range of engineering problems.

2.4 Review of PVT Systems:

PVT is a combination heat collector and photovoltaic that can generate both thermal and electrical energy. The efficiency of the photovoltaic cells is improved by pumping an operating fluid into the heat collector, and the quantity of energy generated by the footprint is increased when the two approaches are combined. A PVT may run on either liquid or air. In this segment, we'll talk more specifically about PVT solutions that are liquids, such water-based ones. Between 1978 and 1981 [8], researchers began investigating fluid-type PVT. In this chapter's first part, we differentiate between several forms of PVT technology and highlight the key objectives of each. Their electrical performance is discussed in the next subsection, while their thermal performance is discussed in the following sub-section. More information on how PV cells may be used to reduce temperature is provided in the fourth section. Martin Wolf [37] pioneered the use of PVT collectors for residential use in the 1970s with the intention of reaping benefits of a hybrid system in terms of both energy and heating. Although more research on PVT systems was undertaken after the 1990s (see references [7-13]), it wasn't until the 2000s that research on full hybrid PVT systems that efficiently meet heating and cooling needs in residential dwellings was thoroughly studied. Theoretical research by Vokas et al. [38] on hybrid PVT systems in various locales found that environment and solar radiation significantly impacted system output. For instance, in the Athens area, a PVT system with 30 m2 of PVT modules might provide around 47.79% and 25.03% of a home's heating and cooling needs. Since it is impractical to keep all of the peak thermal energy created by PVT in a storage tank, they discovered that having a suitable hot water demand is necessary to successfully utilize the energy. The water replenishment profile [6][8] also has an important bearing on PVT system size. Therefore, in a subsequent research [15], the authors made adjustments to the system by adding a reversible heat pump and zeolite adsorption chiller.

To convert solar energy into usable electricity, scientists developed the photovoltaic (PV) system. The photoelectric effect describes the process by which solar radiation is converted into electricity by a photovoltaic cell. Photons are the particles that make up sunlight. A massive amount of photons continuously pounce on Earth every second. These photons, whose energies vary with their wavelengths in the sun's spectrum, are of paramount importance. The photons that strike a photovoltaic cell may either be reflected, absorbed, or transmitted. In order to create electricity, photons must be soaked up. Electron-hole pairs are produced in proportion to the amount of incoming irradiation when photons with energy greater than the band-gap energy of the semiconductor are absorbed. In a photovoltaic cell, an electron in a semiconducting atom receives the photon's energy after absorbing it. When an electron gains enough momentum, it may leave its usual place in the valence band of an atom and go into the conducting band, reaching a free state and leaving a gap in the valence band. By traveling between the electrodes, electrons and holes help complete an electrical circuit. When a large quantity of photons strike a solar cell, the electrons within gain energy and become unbound, allowing them to move freely through the cell's electrical conductors. A solar cell or module's thin wires and built-in electric field provide the voltage needed to drive current through an external load. Power from individual cells may have their current output significantly increased. The heating efficiency of a PVT, like the electrical performance, is largely governed by its design. In order to get advantages in thermal performance, a glass cover, an absorber, and insulation must be sacrificed in electrical performance, and vice versa. There is a notable discrepancy between the thermal performance of a PVT collector and that of a conventional thermal collector. It is crucial to electronic circuit and system design, analysis, and optimization that thermal performance of PVT be understood. This is carried out to ensure their productive and trustworthy functioning, with the added benefit of controlling thermal stress and heat dissipation at the same time. Temperature is a critical characteristic that affects the thermal performance of PVT. The creation of heat during the operation of electronic equipment has a substantial effect on both their performance and dependability, especially in high temperatures. Increased temperatures may increase the breakdown of machinery and lead to decreased performance and functionality.

As a result, keeping the temperatures of electronics components within safe operating ranges is crucial. Thermal analysis and modeling approaches help engineers understand the dynamics of heat transport, identify likely hotspots, and develop effective cooling measures to maintain optimal operating temperatures. PVT's thermal efficiency varies with the applied voltage. Voltage swings may affect the efficiency with which electronic components dissipate electricity, and hence their thermal behavior. Power usage and heat generated may both increase proportionally with voltage. Addressing thermal concerns and enhancing thermal efficiency may be aided by designing circuits that use less power and by managing voltage levels appropriately. Time, as it relates to PVT thermal performance, describes the evolving characteristics of electronic systems' thermal conductivity throughout the course of their lifetimes of use. Due to the constant operation and changes in job requirements, there may be oscillations in heat production and dissipation. Over time, the cumulative effects of thermal stresses may reduce the effectiveness and dependability of different parts. System designs that integrate suitable thermal management solutions, such as heat sinks, fans, or liquid cooling, and that account for the long-term thermal behavior and aging impacts of a product may guarantee reliable performance during its lifecycle. The development of effective thermal management techniques relies on the accurate assessment and modeling of PVT thermal performance. When engineers use simulation tools and methodologies, they may foresee and assess the thermal performance of electronic systems in a variety of operating situations and environmental conditions. Engineers may improve the system's performance and reliability by reducing the chance of failure due to thermal variables via thermal design optimization, which involves keeping key components at safe temperatures.

In Romania, the suggested system could meet about 58% of household needs, while in France, it could meet around 48% of demands with the help of a battery. They discovered that pc-Si cells produce more electricity with less heat than a-Si cells. Based on their findings, the authors conclude that hybrid PVT systems are practical for low-temperature water applications like household hot water consumption, providing anywhere from 60% to 87% of the necessary heat. When electrical energy is the predominant need, the scientists found that a totally covered collector was advantageous. However, a partly covered collector performed better in terms of thermal energy production. They did numerical analysis using computational fluid dynamics and carried out experiments to find out more. Cell temperatures were only decreased by natural ventilation when the intake temperature was high and there was a lot of insolation entering the cells. Research also found that pumped-water heat recovery was sufficient, with output temperatures exceeding 50°C. The insolation and intake water temperature were linearly related to the collector's usable thermal flux. The thermal energy performance of the hybrid system was better than that of a single BHE system. Heat extraction from the BHE was shown to be highly dependent on mass flow rate and intake temperature, as determined by parametric analysis. With a solar component of 67.5% and an irradiance of 600 W/m2, the highest temperature of the discharge water reached 40.8°C. In the event that there wasn't enough sunlight, the unglazed PVT collector could still charge the system's buffer storage tank. The research concluded that, for the loads evaluated, the system was not cost-effective and suggested further testing in multifamily dwellings.

2.5 PVT Bi-fluid and concentrated PVT:

These are situations in which it is desirable to produce electricity, heat, and cool the building all at once. In comparison to conventional PVT, concentrated photovoltaic-thermal (CPVT) systems are optimal for CCHP applications due to their high thermal efficiency. Decoupling the latent and sensible loads in air cooling systems was the primary emphasis of Al-Alili et al.'s CPVT collector-based hybrid solar air-conditioning application. Using the TRNSYS modeling software, they found that a solid desiccant wheel cycle using the collector's thermal energy was more efficient than using electricity to drive the vapor compression cycle (VCC). They used an absorption heat pump in combination with the CPVT system's high-temperature thermal energy to deal with cooling needs. According to the research, reflected optics enabled 10% greater electrical energy production than optics with Fresnel lenses at higher concentrations owing to chromatic aberration. When compared to standard PVT systems, CPVT fluid temperatures were found to be greater. Using fuzzy logic and the Levenberg-Marquardt parameter estimate approach. Since it is an innovative, practical, and potentially fruitful application for realizing net-zero emission buildings, the BiPVT syst has a substantial worldwide commercial potential [19]. Solar photovoltaic modules are incorporated into the BiPVT system, an energy-generating technology, as shown in [19], which displays how active air moves through the framework to heat interior spaces. The great transparency of the glazing material is a benefit of BiPVT systems. It serves several purposes, including shade, and improves collecting, which in turn boosts power output. Several structural elements are candidates for the BIPVT system. Locations farther from populated areas can lessen or at least moderate the negative environmental impacts of power plants, such as noise and greenhouse gas (GHG) emissions. Energy losses that occur during transmission and distribution have a major effect on the cost of electricity. To measure how much the transmission as the distribution of grid loss relies on readily available metrics, a function was developed using empirical data on things like per capita GDP, corruption awareness index, country area, urbanization level, environmental temperature, and grid organization parameter. BiPVT systems may reduce expenses by reducing the money required to create and maintain the grid infrastructure, which is necessitated by the demand for long-distance power transmission. In the long run, the utility and upkeep expenses are reduced thanks to the BiPVT applications. The social cost of carbon (SCC) can be reduced, and the BiPVT system also benefits the environment and people's health.

Since BIPVT systems can provide both electrical and thermal power through the heating of water, air, or any other fluid for the construction with an acceptable degree of demand for electricity, they are economically and effectively appealing for residential and non-residential buildings like homes, hospitals, and many others. Because they rely on commonplace working fluids including air, water, refrigerant, and other bi-fluids for cooling, BIPVT systems have poor thermal performance. From 9 percent in 2015 to 11 percent in 2022, renewable energy will provide 11 percent of the world's energy needs. The use of nonrenewable energy sources in industry and residential space heating accounts for over 40% of global CO2 emissions. The use of BIPVT systems to lessen the use of fossil fuels and the operation of baseload power plants is therefore still a major challenge. How the BIPVT industry is structured. In addition, the system's many BIPVT applications, with roofs accounting for 80% of all BIPVT installations and other uses accounting for the other 20%.

Depending on the size and kind, the BIPVT technology may be applied in a number of ways that are aesthetically pleasing, unobtrusive, and functional from an architectural standpoint. Numerous experimental, analytical, and numerical modeling investigations have been carried out to thoroughly investigate the PVT-integrating BIPVT systems. Because they may produce both thermal and electrical energies at once, PVT systems have a high overall efficiency in terms of both surface area and possible installation costs. In addition, it works well for equipment with a big enough roof to accommodate it and that need both electricity and warmth. The effectiveness of the earth-air collector and PVT airflow collector on the roof was measured numerically. During the winter months, when electricity and space heating are most needed, the earth-air exchanger and PVT system were suggested. However, it was determined that the air heat exchanger was successful in raising the air temperature and the temperature of the solar modules.

A genetic technique was presented by Kino et al. for optimizing the energy and energetic properties of a BIPVT system between January and April. The effects of heating and cooling structures in hot and cold weather were studied. The dimensions of the collector's exposed area and the channel were studied to find the optimal balance between airflow rate, channel depth, and heat loss coefficient. What we learned through our analysis was that the system's relevance influenced the optimal circumstances. Aspect ratio didn't make much of a difference to the objectives, although it did affect several performance indicators. The solar uses of phase change materials (PCMs) were briefly discussed, with a focus on temperature management. PCMs may be made from air or water. Commonly available PCMs (PCMs) that meet the criteria of being inexpensive, nontoxic, and safe have a broad range of melting points. Using such components with greater melting temperatures under sunlight will allow the PVT system to remove more heat from the environment. Drying crops and heating and cooling systems may both benefit from the hot air produced by the BIPVT's PCM-based air supply. Various nanoparticles or phase-change material (PCM) integrated into the base fluids, which may be gases or liquids, have been found to improve the thermal performance of the system, as the heat transfer capabilities provided by conventional operating fluids are often insufficient for a variety of thermal engineering applications. Water desalination, thermal storage, and heat exchangers are just few of the thermal engineering applications that make use of nanofluids (NFs). These NFs are created when nanoparticles (NPs) are mixed with solvents. The better thermal conductivity, density, viscosity, latent energy, and specific heat of nano-enhanced phase shift materials (NEPCM) make them a promising candidate for improving the thermal characteristics of building-integrated photovoltaic-thermal (BIPVT) systems. Because of their cooling capacities and energy storage solutions, phase change materials and nano-enhanced phase change materials have found widespread use in a variety of technical applications, notably in HVAC systems. Thermophysical characteristics at various temperatures for a variety of NEPCM preparation methods have been recorded.

2.6 Economics of PVT and CPVT Systems:

With an IRR of 13% and a discount rate of 3%, the system had a discounted payback period of 8 years. According to Calise et al.'s [15] analysis of the economic viability of solar trigeneration CPVT systems under varying policy situations, such systems cannot be economically viable in the absence of public financing programs. Feed-in tariffs (FiT) were highlighted as being crucial to increasing the system's viability. Comparing a prototype PVT manufactured from inexpensive materials to commercially available collectors, Gagliano et al. [16] discovered considerable cost reductions and a low payback index. They suggested setting pricing that take use of economies of scale to bring down the collector's entry barrier. Investment expenses and the price of electricity and gas in a certain region impact the investment return, as Gagliano et al. pointed out in a research comparing PV, PVT, and PV + ST (solar thermal) systems in various locations [16]. Despite bad economics in Split because to low local power and gas prices, PVT systems were proven to be viable in the colder environment of Freiburg.

3. DISCUSSION

Energy-system researchers have given PVT technology a lot of attention since it combines the benefits of photo-voltaic (PV) and solar or thermal collector methodologies. To better comprehend PVT performance, several KPIs have been studied. Since high temperatures have a detrimental effect on photovoltaic performance, PVT technology's ability to cool PV cells is a major benefit. Concentrating PVT (CPVT) systems, however, need novel absorber designs and enhanced heat transfer mechanisms to minimize excessive stagnation temperatures produced by thermal resistance. For effective heat removal, materials with a high thermal conductivity and electrical resistance are preferred. Thermal efficiencies of around 80% and electrical efficiencies of about 20% have been measured for PVT collectors that are cooled using water or nanofluids. Bear in mind that PVT systems' output is very weather-dependent. Available sun irradiation in the summer is usually adequate for PVT systems to produce enough electricity and heat energy. Power generated in excess during sunny days may be saved for evening or nighttime consumption. PVT systems may need supplementary systems in temperate areas throughout the winter. PVT system design relies heavily on the residential building's demand profile. In order to reach its full potential, the PVT cogeneration system requires efficient control algorithms for its many components. Electrical performance and long-term dependability are affected by the photovoltaic cells selected for use in PVT collector architecture. PVT systems have been shown in several studies to have shorter payback periods than those of standalone PV and solar thermal collectors.

4. OBSERVATIONS AND CONCLUSIONS

The passage you provided discusses various factors and considerations related to the efficiency and performance of PVT (Photovoltaic-Thermal) collectors. The key observations could be listed as:

1. When compared to others, PVT collectors often have a lower thermal efficiency. The disparity arises from a number of sources, including the inefficiency of converting solar energy into electricity, the low absorption coefficients and high emissivity of the materials used in PVT modules, the barrier to heat transmission, and the reflecting losses caused by the cover glass.
2. Methods of Incorporation: PVT collectors combine photovoltaic cells (PV) with thermal absorbers (TA) in a number of ways. Direct contact, thermal adhesive, and mechanical fastening are common methods, although they may cause problems such insufficient heat removal, the development of bubbles or gaps, and an increase in thermal resistance. It has been suggested that EVA lamination combined with mechanical press-fitting is the most efficient method of improving heat transmission.
3. When designing PVT collectors, the ideal cell temperature constrains the maximum system temperature that may be attained. PVT collectors function best in environments between 25 and 40 °C. High temperatures may reduce the electrical efficiency of crystalline solar cells, thus it's vital to take that into account. In certain applications, amorphous silicon cells with superior temperature coefficients may be preferable.
4. CPVT Methods: High heat flux on cells, uneven radiation flux distribution, and balancing electrical and thermal energy are all obstacles for CPVT systems that combine solar panels with heat pumps. Optimizing and developing control techniques for CPVT systems in various climates requires more research.
5. Combined cooling, heating, and power (CCHP) systems have the ability to use PVT and CPVT technologies. However, conventional PVT collectors need to be modified in order to absorb as much solar power as CPVT devices.
6. Nanofluids as optical filters and heat transfer coolants in PVT systems is a fascinating field of investigation. Studying optimization from several perspectives and taking into account multiple factors might assist improve performance. To fully grasp the techno-economic and ecological implications of proposed PVT systems, life-cycle assessment and decision analysis research must be conducted.
7. In order to effectively regulate temperature in high-temperature CPVT systems, novel thermal transmission methods, vis-a-vis nucleate boiling, may be necessary. Most PVT systems depend on laminar and turbulent flow for heat extraction.
8. There is an increase in cost when coupling PVT systems with heat pumps, however this may be mitigated by investigatingthe contemporary counterparts, such as lending energy produced by PVT technology to local communities or grids.

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