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**STUDY OF PV SOLAR THERMAL ABSORBER
AND COLLECTOR COUPLING AS A
COMBINED PVT MODEL**

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Master's Thesis

Supervisor

Asst. Prof. Dr. Yaser ALAIWI

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The thesis titled STUDY OF PV SOLAR THERMAL ABSORBER AND COLLECTOR COUPLING AS A COMBINED PVT MODEL prepared by MUTHANNA OSAMAH YOUSIF KASHMOOLA and submitted on 01/09/2024 has been **accepted unanimously** for the degree of Master of Arts/Master of Science Mechanical Engineering.

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Muthanna Osamah Yousif KASHMOOLA

Signature

DEDICATION

To begin, I would like to express my gratitude to Allah, the Highest, for providing me with the mental and physical capacity, as well as the direction, wisdom, information, and expertise necessary to finish this research.

This thesis is completely and utterly devoted to my mother and father. There are no words that can adequately convey what you mean to me, and there is nothing that can make up for what you have done for me. There is nothing that I can compensate you for. I shall keep doing everything in my power to live up to the standards you have set. In conclusion, I would want to express my gratitude to my family, other relatives, and the friends who have supported me throughout this research.

PREFACE

I might want to thank my administrator: Asst. Prof. Dr. Yaser ALAIWI Please let me express. my profound feeling of appreciation and gratefulness to both of you for the information direction and unrestricted help you have given me. I want you to enjoy all that life has to offer. and further achievements and accomplishments throughout your life.



ABSTRACT

STUDY OF PV SOLAR THERMAL ABSORBER AND COLLECTOR COUPLING AS A COMBINED PVT MODEL

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A PVT (photovoltaic thermal) system is a type of solar energy system that combines the functionality of both photovoltaic (PV) and solar thermal systems. In a PVT system, the solar cells are used to generate electricity, while the thermal absorber is used to collect and store heat energy. The heat energy can then be used for various applications, such as space heating, water heating, or even power generation through a thermoelectric generator. The combination of the two technologies in a PVT system can lead to increased energy efficiency and overall system performance. The collector model is used to predict the heat transfer between the thermal absorber and the heat transfer fluid, taking into account factors such as the collector design and the fluid flow rate. The coupling of these models is important to predict the overall performance of the PVT system, taking into account the interactions between the electrical and thermal components. The models can be used to optimize the design of the PVT system and predict its performance under different operating conditions. It is important to note that the accuracy of the PVT model depends on the accuracy of the individual component models and the validity of the assumptions made in the model. The effect of packing factor of thermoelectric cooler (TEC) module on the performance of photovoltaic thermal (PVT) integrated thermoelectric cooler (TEC) fluid collectors has been analyzed in this thesis, by considering three different types of PV modules, namely opaque (glass-to-tedlar), semitransparent (glass-to-glass) and aluminium base (glass-to-aluminium). The performance of the opaque PV-TEC collector without duct/tube was studied when partially and fully covered with TEC.

Keywords: Photovoltaic Thermal (PVT) Collector, Thermal Efficiency, Electrical Efficiency, Collector Efficiency Factor, Numerical Model.



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ABBREVIATIONS

| | | |
|-------|---|---|
| SECD | : | Solar Energy Conversion Devices |
| PVT | : | Solar Photovoltaic Thermal |
| CNN | : | Convolutional Neural Network |
| OFDMA | : | Orthogonal Frequency-Division Multiple Access |
| RL | : | Reinforcement Learning |
| TEC | : | Thermoelectric Cooler |
| SWH | : | Solar Water Heating |

1. INTRODUCTION

Renewable energy sources have gained significant interest, particularly solar and wind energy, as a sustainable means of electricity generation. Solar energy, which is created through nuclear fusion in the sun, is considered the principal source of renewable energy. To capture this energy, various solar energy conversion devices (SECD) have been developed, including photovoltaic modules that convert solar energy into electricity and flat plate collectors that convert solar energy into thermal energy. A hybrid SECD, called a solar photovoltaic thermal (PV/T) water collector, converts solar energy into both thermal and electrical energy simultaneously.

1.1 NEED FOR SOLAR PV/T WATER COLLECTOR

The following reasons demands for the need of Solar PV/T water collector systems in place of solar PV module:

- a. Performance of PV module is more sensitive to its operating temperature. Hence as a mean to control its operating temperature.
- b. To reduce the area occupied by two individual SECD such as the PV module and the FPC.
- c. To generate electrical and thermal power simultaneously
- d. Efficient operation at low and medium latitudes with favorable weather condition.
- e. Effective utilization of solar radiation with this flexible system.
- f. Possibility of maintaining module operating temperature within a range.

1.2 COGNITIVE MODEL

The following are the needs which demand the performance prediction using cognitive models. They are:

- a. To study the periodic performance variations in SECD more accurately
- b. To validate experimental results
- c. To obtain results in an expected manner

1.3 MOTIVATION

Warm opposition between the sun powered cell and the safeguard plate ought to be diminished to upgrade the warm presentation of the PVT framework. To diminish misfortunes due by opposition between the numerous layers of the PVT, a slight leading

(Cu/Al) sheet can be used as the PV module's establishment rather than tedlar. This arrangement lessens the quantity of layers, bringing down warm obstruction and upgrading heat transmission between the sun oriented cell and the streaming liquid. To additional the business scale improvement of this innovation, it is basic to examine the activity of the leading base PVT in different climate circumstances and districts. Be that as it may, input factors like geology (weighty traffic zones, contaminated environmental elements, etc) and environment (dust, tempests, showers, etc) are challenging to characterize and incorporate into a basic numerical model. It is vital to foster a new, wise displaying approach fit for connecting both subjective and quantitative variables to PVT framework execution. Computerized reasoning based delicate processing advances may be utilized as an option in demonstrating the directing (Cu/Al) base PVT framework. The proposed model's productivity can be expanded further by using a compound illustrative concentrator with a leading (Cu/Al) base PVT gatherer. The exercises of the directing (Cu/Al) base PVT sun oriented warming framework ought to be explored when boiling water is extricated from the tank to get a superior comprehension of the proposed PVT framework in a genuine setting. This study will offer a superior comprehension of the utilizations of the Cu/Al base PVT gatherer regarding the expected heated water withdrawal.

Traditional disaster recovery focusing on rebuilding quickly doesn't allow designers, managers or beneficiaries identify and incorporate renewable energy application and energy efficiency measures into disaster relief shelters. The technological innovation and cost reductions in solar energy utilization are likely to provide shelter residents with sustainable electricity, heating, and hot water. At same time, applying PVT systems on shelters can contribute to energy sustainability and restraining environmental pollution.

1.4 OBJECTIVES

The goals of this study are to examine the performance of the. The following are the aims of the current study:

- a. Characterize and evaluate the thermal modeling of a photovoltaic thermal (PVT) collector with and without a conducting base.
- b. Photovoltaic thermal (PVT) collector energy and exergy study for various base materials.
- c. Enhancement of photovoltaic (PV) module electrical power by integration of thermoelectric cooler (TEC) module in collector design, taking into account three

distinct types of PV modules, namely opaque (glass-to-tedlar), semitransparent (glass-to-glass), and aluminum base (glass-to-aluminium).

Construction of artificial neural network (ANN) models for semitransparent, opaque, and aluminum-based photovoltaic thermal (PVT) integrated thermoelectric cooler (TEC) fluid collectors.

1.5 METHODOLOGY

As a result of the discontinuous and eccentric person of sun powered radiation, demonstrating the result execution of photovoltaic (PV) and photovoltaic warm (PVT) frameworks might be troublesome. Generally, a warm model in view of energy balance conditions is utilized to gauge framework execution [5]. Albeit the warm model is fit for anticipating framework execution with sensible exactness in clear sky circumstances, the real framework yield strays from the numbers obtained by the warm model under murky/shady atmospheric conditions. Moreover, the warm model requires the thought of various elements as well as the arrangement of a convoluted differential condition. This research explores the thermal environment of temporary shelters and the incorporation of solar energy technologies. Lightweight envelope structures of temporary shelters are distinct from those of conventional permanent houses in terms of the indoor thermal environment. Additionally, the PVT collector, a hybrid system of PV panels and solar thermal collectors, is a type of renewable energy application. When the PVT system is affixed to the shelter roof and utilized to meet the shelter's energy demands, the performance output characteristics are different from those of an independent PVT system. Subsequently, the review should meet the accompanying specific examination goals. This postulation at first investigated the energy requests for impermanent havens as well as reference measures for everyday environments like sterile boiling water, prior to zeroing in on a run of the mill transitory safe house, a prefab home, as the review target. For the prefab house model, a little sun oriented photovoltaic warm (PVT) framework that can offer economical power, high temp water, and different administrations was planned. Then, utilizing hypothetical, trial, and recreation strategies, its exhibition and pertinence to the prefab home model were researched.

1.6 THESIS ORGANIZATION

The proposition makes sense of the model used to perceive minuscule things in a video succession utilizing the profound learning thought. The exposition is broken into six parts.

The review means to upgrade the precision and execution season of distinguishing objects of different sizes in a video succession.

fourth Section This part centers around the utilization of past work in object identification and acknowledgment, with the outcomes contrasted with the proposed strategy. The recommended model is depicted inside and out, just like its execution.

Section 5 (End and Subsequent stages): The discoveries got in this part depend on the various executions framed previously. The part additionally talks about future exploration headings.



2. LITERATURE REVIEW

Renewable energy sources, derived from natural resources such as sunlight, wind, rain, tides, and geothermal heat, are highly significant for the sustainable development of our planet. With increasing energy demand driven by rapid industrialization, the need for environmentally friendly energy technologies has become critical. Coal, oil, and natural gas, which are nonrenewable and environmentally damaging, are slowly getting replaced by renewable energy sources. Among these sources, solar energy has gained popularity due to its abundance, environmental friendliness, and free availability. In recent years, research has expanded considerably in the field of solar energy technologies, aiming to close the potential gap between future energy supply and demand [8].

2.1 SOLAR ENERGY

Sun oriented energy is the most bountiful energy asset that anyone could hope to find to mankind, with the Earth catching it at a speed multiple times bigger than the pace of human energy use [9]. Indeed, while just around 70% of approaching sun based energy arrives at the World's surface, it actually sums to 3.9 million EJ consistently [10]. In fact, this amount of solar energy is approximately twice the amount of all non-renewable energy ever consumed by humankind [11], making solar energy incredibly attractive as a potential solution to the world's energy demands. Subsequently, it's no big surprise that sun oriented energy has recently been a famous area of examination, with experts researching its maximum capacity to give the world's all's energy requests.

Sunlight based energy strategies cover an extensive variety of energy administrations, including warming, cooling, regular lighting, and power for different purposes. Essentially, solar energy conversion is a family of diverse technologies that can be harnessed to cater to an assortment of energy service requirements.

Converting solar energy to heat is a relatively simple process, as the sun's rays will be absorbed by any material object placed in its path. However, ensuring that the absorbed energy is maximized while minimizing losses to the surroundings requires specialized techniques and devices specific to the desired temperature and application. The required temperature may vary significantly, ranging from 25°C for applications like swimming pool heating to 1,000°C and even up to 3,000°C in solar furnaces, to achieve the desired outcome.

The chosen technique will depend largely on the temperature requirements for the specific application [13].

Passive solar heating involves utilizing solar irradiance incident on buildings by utilizing transparent materials such as glazing (including windows, sun spaces, and conservatories), and regulating heat loss and gain within the structure without relying heavily on pumps or fans to maintain optimal temperature conditions. In other words, it is a technique for keeping buildings comfortable by harnessing the sun's energy through passive means.

2.2 SOLAR WATER HEATING SYSTEMS OVERVIEW

Boiling water warming for both home and business structures is a developed innovation with a typical yearly development pace of generally 16% that is broadly utilized in many countries all through the world. The worldwide introduced limit of Sunlight based Water Warming (SWH) frameworks was anticipated to be 185 GWth (giga wattsthermal) in 2010, with exceptional accentuation on their utilization in the home area. At the end of 2010, SWH systems reportedly resulted in 85% of the total installations, with single-family homes in New Zealand benefitting from these systems the most, accounting for 95% of all solar thermal systems installed, accordingly shown in Figure 2.1.

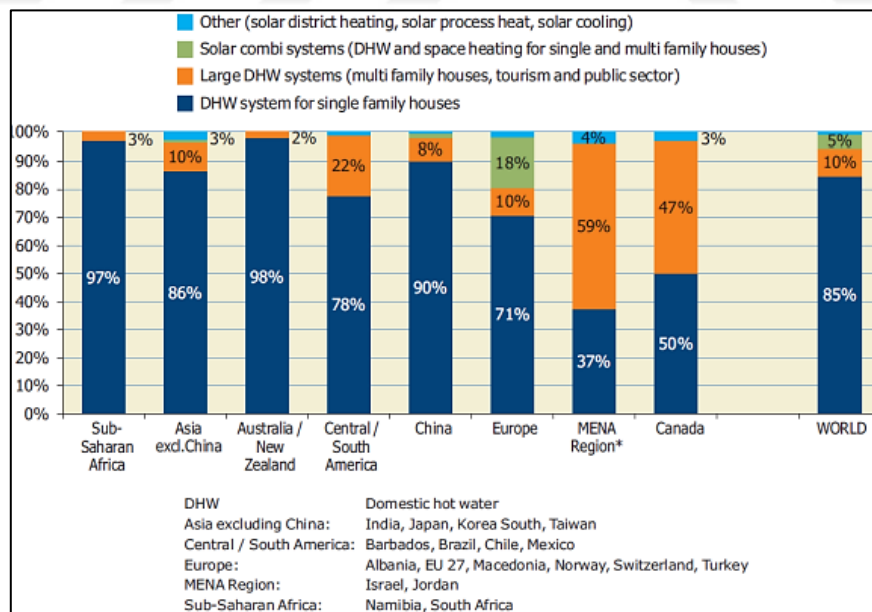


Figure 2.1: Sun-Arranged Warm System Application Spread for Completely Settled Covered Water Finder Limit Toward the Finish of 2010[15].

Figure 2.2 portrays a normal schematic of a latent or dynamic Sun based Water Warming (SWH) framework. In confined systems, as seen on the left, insolation (the maintenance of

sun-oriented energy) warms the water in the riser tubes, making it stream upwards into the higher header tube and ultimately to the most elevated place of a safeguarded collecting tank. This, thusly, drives cooler water to the tank's base through an interfacing line into the lower header tube. By means of convection or thermosiphon process, this natural water flow ensures that heat is continuously transferred from the absorber fin into the water contained within the risers. The absorber is typically coated in black, thus enhancing the absorption of radiation.

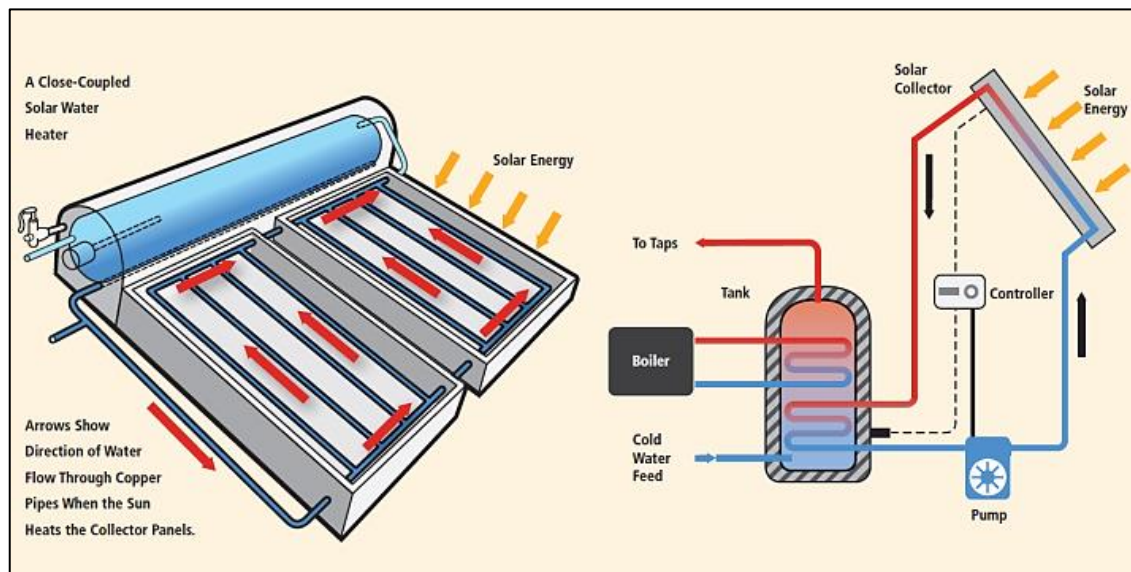


Figure 2.2: Nonexclusive Schematics of A Sun-Situated Warmed Situation, Left: Dormant (Thermosiphon), Right: Dynamic.

When it comes to large Solar Water Heating (SWH) systems, The length of the associating pipes among gatherers and tanks could develop so lengthy that the strain misfortune all through the framework turns out to be excessively perfect to utilize the thermosiphon interaction. To resolve this issue, a small electrical siphon should be introduced to keep up with constrained course. To streamline occurrence sunlight based energy receipt throughout the cold weather months, an extremely durable gatherer is many times introduced on the rooftop and leaned at a point 10° more prominent than the neighborhood scope. Such mounting points are not generally required assuming that the gatherer is fitted with a tracker that changes the tendency in light of the overall area of the sun. Because of their intricacy, tracker gadgets are chiefly restricted to huge sun oriented nuclear energy offices [16].

2.3 PHOTOVOLTAIC EFFECT

The utilization of photovoltaic technology is a crucial aspect in harnessing solar energy, Due to the photovoltaic impact, it promptly changes over sunlight based energy into electric power. This peculiarity is a subset of the photoelectric impact that happens when certain materials communicate, designated as semiconductors, are struck by photons. Such an event results in the release of an electron that can then be harvested using a specialized diode circuit, specifically the p-n junction. To explain the photovoltaic effect, the band gap theory is commonly used. It contends that there is an energy range known as the band hole where electrons are not steady and can reside in either the valence or conduction groups, contingent upon the energy hole. The categorization of materials depends on their energy gap

Based on the band gap theory, materials are classified according to their energy gap as follows:

- a. Materials with an energy gap (E_g) less than 5 electron volts (eV) are insulators because the electron cannot move from one band to another.
- b. Materials with $0 < E_g < 5$ eV are named semiconductors in light of the fact that an electron with enough energy might pass from the valence band to the conduction band..
- c. Lastly, materials with E_g less than 0 eV are conductors. Electrons in such materials can move freely between the two bands thus allowing the flow of current as the bands overlap.

According to the photovoltaic effect, solar energy is converted into electricity using semiconductors struck by photons, resulting in the release of electrons that can be harvested through a specialized diode circuit. The energy gap of the semiconductor material determines the likelihood of electrons transitioning from the valence band to the conduction band. The wider the energy gap, the less likely electrons are to transition, meaning such material is a poor conductor of electricity.

2.4 COLLECTOR OVERVIEW

Literature surrounding solar water heating (SWH) systems exhibits many areas that require consideration. Among these areas, collector performance tends to receive more attention as it is a crucial component of the heat transfer process on the solar side of the SWH system. The direct conversion of solar to thermal energy needed in heating is facilitated by the collector, thus making it critical. As previously mentioned, evacuated tube and flat-plate

collectors are the two common types of collectors utilized in SWH systems, with the flat-plate collector being the more widely used.

A level plate finder is comprised of a protect, straightforward cover sheets, and a covered box, as displayed in Figure 2.2. The protect is frequently developed of a high warm conductivity metal sheet with essential or related chambers or cylinders. The outer layer of the safeguard is painted or covered to upgrade brilliant energy retention and, in certain circumstances, to decrease the pace of brilliant outflow. The protected box offers backing and fixing while at the same time decreasing intensity misfortune at the authority's back or sides [17].

Nuclear power examination, which depends on the authority's energy balance in consistent state, is the most widely recognized strategy for breaking down level plate gatherer execution. This equilibrium characterizes how daylight is changed over into usable energy gain, warm misfortunes, and optical misfortunes. The force of sun-based radiation, G , can be utilized to demonstrate the energy of sun beams stirring things up around town plane of the sun powered gatherer with a surface region of A_n in m^2 [18].

2.5 LITERATURE ON THE SOLAR PHOTOVOLTAIC SYSTEM

Among various works of literature on the solar photovoltaic thermal system with and without a cooling system, the following literature studies are more useful in identifying current trends of research gap.

In a study gave an outline of various exploratory information connected with sun powered photovoltaic/warm water gatherers (PV/T). Strategies for working on the presentation of sun oriented photovoltaic/warm water gatherers (PV/T) units are likewise proposed. Overviews about innovative and new materials, heat transfer fluids, absorber tube geometries, etc., are presented in a simple manner. Moreover, it underlines the actual trend of the technologic and scientific world so far [19]. In [20], a review paper was presented on the various techniques utilized to enhance the efficiency of solar flat-plate collectors (FPCs). The paper discussed how altering the absorber plate design improves solar radiation capture, methods for minimizing overall heat loss, and the effects of using inserts and phase-changing materials. It also presented a detailed analysis of the effects of these techniques and different designs with their respective development methodologies, providing an improved understanding of the subject matter.

First, a review article was presented that discussed various types of solar PV/T (photovoltaic-thermal) collectors, such as air and water PV/T collectors, as well as water/air PV/T collectors. The article covered topics related to their design, fabrication, performance, simulation, and end results. It additionally underscored the benefits of utilizing PV/T innovation in water desalination, sun oriented cooling, sun based still, and sun powered nursery. The review's correlation results uncovered a significant expansion in the energy creation of sun based PV/T frameworks. As per the report, PV/T is a promising and right now moving innovation that requires significant improvement regarding cost decrease and general proficiency [21].

In addition, a comparative study was conducted using a simulation model of a Norwegian residential house. The study compared solar thermal, photovoltaic and PV/T systems, and calculated their energy performance and exergy balance. It was inferred from the comparison that a model building with only high-efficiency solar photovoltaic would be able to achieve near-net-zero energy balance [22]. Conversely, [23] did a correlation investigation of epitomized stage change material (EPCM), microchannel heat pipe PV/T, and standard PV/T frameworks. The review included superior recreation models for three particular PV/T frameworks, as well as contrasting information. The outcomes showed that the joined typical electrical and warm productivity of the EPCM, MCHP, and customary PV/T frameworks might accomplish 36.71%, 35.53%, and 31.78%, individually [24][25].

Another study involved a real-time experimental study of a direct solar water heating PV-T (photovoltaic-thermal) system. The study aimed to find optimal input conditions by varying the PV panel type, exposure angle, and depth of the reservoir. From the experiments, it was observed that the designed system was capable of generating hot water for a family of three to four, with any remaining electricity going towards domestic needs [26].

Additionally, it was inferred that the system had the capacity to produce over 20 liters of 79 °C water, showing the potential for water distillation. Overall, the study demonstrated the effectiveness of a direct solar water heating PV-T system in producing hot water that can be used for various purposes, while also providing electricity for domestic needs [27].

A study was conducted to analyze the performance of a flexible photovoltaic/ thermal (PV/T) water collector system. The examination incorporates essential testing utilizing PV/T modules connected in series, as well as reenactment model discoveries from TRNSYS. A

correlation of the deliberate and mathematical information was likewise given. The review found that the two types of information were actually similar, with normal blunders of 5.29% and 12.04% for the electrical and nuclear power delivered by the framework, individually [28].

Another study introduced a changed photovoltaic/warm (MPV/T) framework utilizing an iron material documenting filled tube type plate PV/T framework (MIFTP). The analysts directed continuous investigations with five particular gatherings of sun-based radiation forces going from 300 to 800 W/m² [29]. When contrasted with regular cylinder plate PV/T frameworks, similar exploratory discoveries showed that the temperature of the MPV/T module was effectively brought down by 3.6-6.5 °C, and the all-out electrical proficiency rose by 20%. Besides, the MIFTP framework expected less opportunity to arrive at similar temperature differential between tanks. These studies provide valuable insights into the optimization of PV/T systems, offering pioneers in more efficient and cost-effective utilization of renewable solar energy [30].

Overall, these studies contribute to the advancement of renewable energy technology and provide valuable information on the performance and optimization of PV/T systems. They can be useful for researchers and engineers seeking to improve the efficiency and economic feasibility of such systems. Ongoing trial study is being led with five gatherings with changing sun based radiation force (300-800 W/m²). When contrasted with average cylinder plate PV/T frameworks, the near exploratory discoveries showed that the temperature of the MPV/T module was effectively brought down by 3.6-6.5°C, and the generally speaking electrical productivity rose by 20%. Moreover, the MIFTP framework expected less opportunity to arrive at similar temperature differential between tanks [31]. These findings illustrate that the proposed MPV/T system with MIFTP can maximize solar energy conversion efficiency and improve the economic feasibility of utilizing renewable solar energy. Therefore, further research and development of MPV/T systems with MIFTP should be encouraged to advance renewable energy technology and improve the effectiveness and affordability of these systems. This study's findings could be beneficial to engineers and researchers working to enhance PV/T systems' performance by increasing their energy efficiency and optimizing their economic viability [32].

2.6 LITERATURE ON THE SOLAR PHOTOVOLTAIC SYSTEM

One of the useful works of literature in identifying current trends and research gaps in solar photovoltaic systems is a review article by [33], which investigates various cooling methodologies for solar photovoltaic panels. The review expects to alleviate the adverse consequences of increasing temperatures while likewise looking to work on the effectiveness of PV boards working over the Standard Test Conditions (STC). The article zeroed in on showing the total aftereffects of each cooling innovation's bringing down of PV module surface temperature. By presenting the advantages and limitations of each cooling method, this work provides valuable insights into the optimization of solar photovoltaic systems. These insights can be used by researchers and engineers to develop more effective cooling techniques that can improve the performance and efficiency of solar photovoltaic panels, thus advancing the use of renewable energy. Therefore, [34] is an important literature study in identifying current trends in research on solar photovoltaic cooling systems. It provides a wealth of information on cooling methodologies, enabling researchers and engineers to identify the advantages and limitations of each method. This knowledge is crucial in developing new and more effective cooling systems for solar photovoltaic panels operating beyond the suggested temperature of the STC, ultimately improving their overall performance and efficiency.

Two literature studies, [35] and [36], are valuable in understanding the trends and research gaps in PV/T systems and identifying areas for improvement. [37] investigates PV/T frameworks from an electrical and warm point of view, underscoring their advantages over PV or sun based warm frameworks, and diagrams a few framework applications, for example, water-endlessly air water frameworks, nanofluid frameworks, and stage change material frameworks. The creators of this study suggest that, to expand the presentation of PV/T frameworks, more prominent accentuation ought to be put on the warm part as opposed to the electrical part [39].

As per area of interest and current bungling issues happen on PV cells because of expanded cell temperature and non-uniform temperature dispersion, bringing about diminished productivity and at times long-lasting primary harm because of warm burdens. Temperature minor departure from the outer layer of a sunlight-based charger can impact photovoltaic

framework power yield execution since they straightforwardly influence series opposition and cell temperature [40].

By reviewing the performance of PV/T systems and the design and operation of photovoltaic technology, these studies provide valuable insights into the optimization of solar energy systems. The findings of these studies can be used by researchers and engineers to improve the performance and efficiency of PV/T systems, by developing more effective cooling techniques, optimizing panel design, and improving temperature control. Therefore, further research in these areas is encouraged to advance the effectiveness and affordability of renewable energy systems. Overall, the studies by [41] and [42] demonstrate the importance of considering both the electrical and thermal aspects of solar energy systems and highlight areas in which further research and development is needed.

As per a basic survey of photovoltaic innovation directed by [43], the climb in cell temperature and non-uniform temperature dissemination can cause area of interest and current bungling issues on the cell, bringing about a decrease in productivity and, at times, super durable primary harm because of warm burdens. Besides, temperature minor departure from a sunlight based charger's surface can impact the power yield execution of photovoltaic frameworks since they straightforwardly raise series opposition and cell temperature.

Further study proposed another cooling approach for sunlight based photovoltaic boards in which the two sides of the board are simultaneously cooled by water shower to examine the whole cooling impact on board execution under top sun oriented light levels. As indicated by the review, the concurrent cooling approach might help electric power creation by up to 16.28% and generally speaking PV board electrical productivity by up to 14.09% [44].

Overall, these findings suggest that the optimization of the temperature control and cooling techniques for photovoltaic systems can contribute to significant improvements in their performance and efficiency. Further research in this area is needed to develop more effective methods to reduce temperature variation and mitigate the negative effects of high temperatures on the cells. By doing so, it is possible to enhance the overall sustainability of solar energy systems, making them more accessible and reliable for broader applications [45].

Therefore, the studies by [46] and [47] provide valuable insight into the design and operation of photovoltaic technology, highlighting the importance of thermal management and

optimization for solar cell efficiency. This information can be beneficial for researchers and engineers working in the field of renewable energy to develop more effective and sustainable photovoltaic systems.

The working temperature of a sun oriented photovoltaic module, as indicated by [48], impacts its exhibition. To explore further, a mathematical model was made utilizing the Designing Condition Solver (EES) programming to all the more accurately estimate the exhibition of a sun powered PV module. The review was directed in Saudi Arabia under different climatic conditions and found that a recommended dynamic water cooling framework might bring down the module's temperature by generally 20%, bringing about a 9% expansion in sunlight based PV board effectiveness. [49] offered a technique to limit how much electrical energy and water expected for cooling sun oriented photovoltaic modules, especially in warm pieces of Egypt, in a comparable exploration. The review made a computerized cooling system for the sun oriented module in view of conventional water splashing. In view of temperature information, a numerical model was used to gauge the greatest passable temperature (MAT) of the sun powered photovoltaic boards and when to start cooling. Based on the proposed mathematical model, the study found that the solar photovoltaic panels yield maximum output energy when cooling begins at a MAT temperature of 45°C. Overall, these studies highlight the importance of managing the operating temperature of solar photovoltaic modules to improve their efficiency and performance. The proposed numerical and mathematical models provide a useful tool for predicting and optimizing the performance of these systems. The findings of these studies are relevant to engineers and researchers working in the field of renewable energy and can contribute to the development of more effective and sustainable photovoltaic systems.

2.7 LITERATURE ON THE SOLAR FLAT PLATE COLLECTOR SYSTEM

Among various works of literature on the solar flat plate collector system, the following literature studies are more useful in identifying current trends of research gap.

A recent study presented review on last one decade of experimental results associated with solar flat plate collectors (FPC). Performance improvement methods for solar FPC unit are also suggested. Overviews about innovative and new materials, heat transfer fluids, absorber tube geometries, etc., are presented in a simple manner. Besides, it features the ongoing mechanical and logical inclination [50]. Another research offered a definite outline of a few

methodologies used to help the productivity of sun based level plate gatherers (FPCs) in their review. Various choices were viewed as 1, including changing the state of the safeguard plate to all the more likely catch sun oriented radiation, limiting all out heat misfortune, utilizing embeds, and presenting stage evolving materials. The study also presented an in-depth analysis of the effects of these techniques and various designs, with a focus on the methodology used for their development [35]. In another review, [51] provided an overview of the various types of solar FPC units. The study considered the latest developments and discussed theoretical analyses related to the functional elements of the units, as well as some hybrid systems. The review also covered performance standards and test methods for solar thermal collectors. The main objective of this review was to keep solar energy-based engineers, researchers, and manufacturers up to date with the recent developments in the field of solar flat plate thermal collectors.

Generally, these examinations underscore the meaning of constantly upgrading the plan and execution of sun oriented level plate gatherers to expand productivity and adequacy. New materials and techniques, including as stage changing materials and additions, can altogether work on the general execution of these frameworks. These examinations' decisions are valuable to architects and specialists working in the field of environmentally friendly power, and they can assist with building more compelling and reasonable sunlight based warm frameworks.

Further study conducted an experimental investigation to improve the performance of solar flat plate collectors (FPCs) by using a frictionally engaged thermal performance enhancer in the design of the absorber tube. The experiment involved comparing the thermal performance enhancers in the absorber tube with a flat plate solar collector with a copper rod under the same operating conditions. The analysts analyzed the exploratory all-out heat move coefficient for the sun oriented FPC and found that the pole type warm execution enhancer gatherer beat the cylinder type warm execution enhancer authority and the smooth copper pipe sun powered FPC [52].

The findings of this study are significant as they indicate that using a frictionally engaged thermal performance enhancer in the absorber tube can improve the performance of solar FPCs. The use of a copper rod as a thermal performance enhancer proved more effective than the tube-type thermal enhancer and the smooth copper pipe in the solar collector . These

results can have practical implications for improving the design and performance of solar FPCs, and have the potential to contribute to the wider adoption of solar thermal systems in commercial and residential settings [53].

Further authors designed a square pattern solar FPC unit. In this study an attempt has been made to increase the rate of heat transfer by increasing the contact surface area from the inlet to the outlet. The water is used as the heat transfer fluid with two variable flow rates of 6.51 and 5.3 L/min. The real time experiments were carried out under the conditions of Baghdad, Iraq. The experimental results clear that the water with flow rate of 5.3 L/min causes the higher effectiveness and efficiency of the solar FPC than 6.51 L/min [54]. A new study designed a zig-zag pattern solar FPC absorber tube design. In this study an attempt has been made to increase the rate of heat transfer by increasing the contact surface area (between absorber tube and plate) from the inlet to the outlet. For this real time experiments were carried out under the standard conditions of Tiruchirappalli, India [54]. Experimental results inferred that zig-zag design with increased contact surface area shows 16.1% higher heat transfer rate than a conventional design. [56] superior the exhibition of the sun based FPC utilizing a novel methodology. The exploration was basically worried about expanding the convective intensity move coefficient by diminishing the cross-sectional region between the internal mass of the cylinder and the engrossing liquid. Heat move enhancers of two sorts were utilized and looked at: tube heat move enhancers and pole heat move enhancers. The trial discoveries showed that the pole type heat move enhancer beat the cylinder type heat move enhancer and the customary cylinder sun based FPC as far as intensity move rate. Besides, the bar type enhancer created only a bit of expansion in siphoning power, making it a more effective other option [74][75].

These findings highlight the importance of the design of heat exchangers in enhancing the efficiency of solar thermal systems. The use of an appropriate heat transfer enhancer can significantly improve the rate of heat transfer between the fluid streams, which is crucial for achieving higher overall performance. This research has practical implications for developing more effective solar thermal systems and can contribute to their wider adoption in a range of applications. The use of a rod-type heat transfer enhancer, in particular, may offer a promising option for improving the efficiency of solar FPCs, as it appears to provide a more efficient heat transfer rate than tube-type enhancers.

3. METHODOLOGY

This chapter mainly analyzes the PVT collector theoretically, and the performance evaluation methods of the PVT collector and the PVT system are presented. Firstly, based on the energy balance equation of the PVT module, an analytical solution is derived for the temperature distribution of the thermal absorber plate, then the expression of useful heat gain and thermal efficiency of the PVT module are obtained. The influence factors of photovoltaic efficiency are discussed. Secondly, the energy balance of water tank is analyzed, and assorted heat flow rates are obtained. In addition, the solar fraction is introduced to indicate the thermal performance of the PVT system. Finally, the heat transfer model of the roof integrated PVT collector is developed, which lays a foundation for evaluating the impact on the indoor environment of the prefab house and the energy-saving characteristics of the system.

3.1 INTRODUCTION

In light of the irregular and unusual person of sun-based radiation, displaying the result execution of photovoltaic (PV) and photovoltaic warm (PVT) frameworks might be troublesome. Customarily, a warm model in view of energy balance conditions is utilized to foresee framework execution [55]. Due to the discontinuous and eccentric person of sun based radiation, demonstrating the result execution of photovoltaic (PV) and photovoltaic warm (PVT) frameworks might be troublesome. Generally, a warm model in view of energy balance conditions is utilized to gauge framework execution [56]. Albeit the warm model is equipped for anticipating framework execution with sensible precision in clear sky circumstances, the genuine framework yield goes amiss from the numbers obtained by the warm model under foggy/overcast weather patterns. Besides, the warm model requires the thought of numerous variables as well as the arrangement of a convoluted differential condition. This research explores the thermal environment of temporary shelters and the incorporation of solar energy technologies. Lightweight envelope structures of temporary shelters are distinct from those of conventional permanent houses in terms of the indoor thermal environment. Additionally, the PVT collector, a hybrid system of PV panels and solar thermal collectors, is a type of renewable energy application.

3.2 PRINCIPLE COMPONENTS OF SOLAR PV/T WATER COLLECTOR

3.2.1 Photovoltaic Module

This research utilizes a polycrystalline photovoltaic module of 40 Watts rated capacity in order to convert sunlight into electricity. Table 3.1 provides detailed technical specifications of the photovoltaic module, while Figure 3.1 shows a front and rear view of the module. With the photovoltaic effect, the module is able to transform solar energy into electricity.

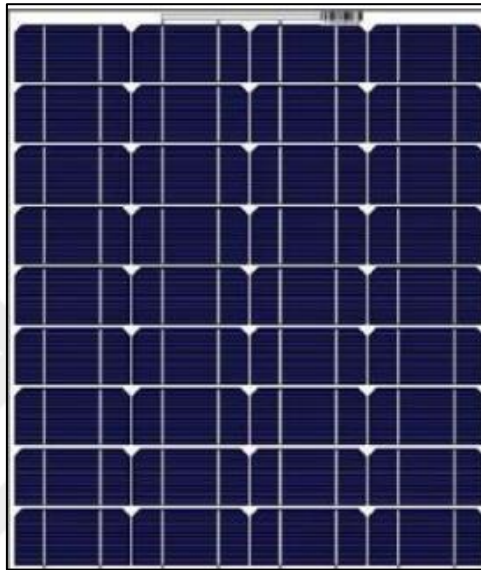


Figure 3.1: Front Side of the Solar PV Module.

Table 3.1: The Detailed Technical Specifications of Solar PV Module.

| Sl. No. | Components | Specification |
|---------|-----------------------------------|-------------------------|
| 1 | Made | INNOVA SOLAR INC |
| 2 | Material | Polycrystalline Silicon |
| 3 | Area per module (m ²) | 0.4087 |
| 4 | Weight per module (kg) | 8 |

3.2.2 Ammeter

An ammeter is an instrument that is used to measure the amount of electric current in a circuit, with the unit of electric current being the ampere (A). The primary function of an ammeter is to measure current, and it must have very low resistance and inductive reactance. This is because it must allow for a low amount of voltage drop across it to accurately measure the current. The technical specifications of the ammeter used in the study are presented in Figure 3.3 provides a front view of the ammeter used.

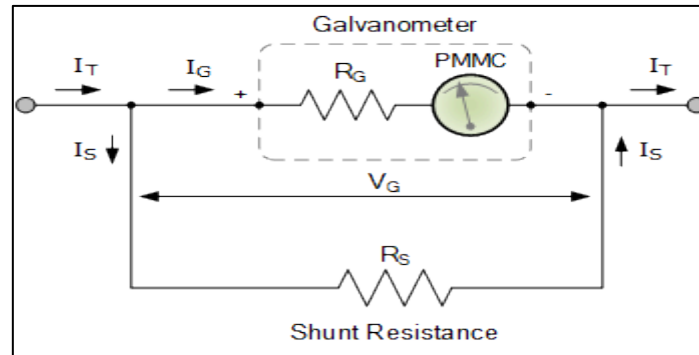


Figure 3.2: Ammeter Used in this Study.

3.2.3 Voltmeter

A voltmeter is an instrument used to measure the electric potential difference between two points, with the unit of potential difference being the volt (V). It works by connecting the two terminals of the voltmeter across the two points of the circuit between which the voltage difference is to be measured. The technical specifications of the voltmeter used in the study are presented in Table 3.3, while Figure 3.3 provides a front view of the voltmeter used. The main function of the voltmeter is to measure the potential difference, with accuracy being ensured by having very high resistance between the two terminals of the voltmeter.

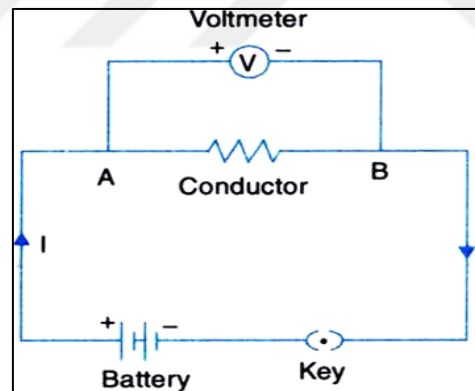


Figure 3.3: Technical Specifications of the Voltmeter.

Table 3.2: The Detailed Technical Specifications of the Voltmeter.

| Sl. No. | Components | Specification |
|---------|------------|-------------------------|
| 1 | Made | Automatic India Limited |
| 2 | Type | DC |
| 3 | Range | (0-60)V |

3.3 BASIC FLAT-PLATE PVT COLLECTOR ENERGY BALANCE EQUATION

A flat-plate PVT collector is a combination of a PV panel and a heat exchanger that transform solar energy into heat and electricity simultaneously. The heat exchanger, called absorber plate, differs from a conventional solar collector in which radiant energy transfers to a fluid. In the PVT collector, heat transfer is dominated by the heat conduction from the PV panel to the fluid, while the radiation is an unimportant heat transfer mode because of the opaque PV panel. And cooling down the upside PV cells is the goal of such heat transfer. Therefore the heat transfer performance of the absorber plate is the key factor for PVT efficiency. The schematic of energy balance of an unglazed, roll-bond PVT collector is shown in Figure 3.6. Its liquid channels are embedded in the thermal absorber plate, different from the traditional sheet-and-tube absorber structure.

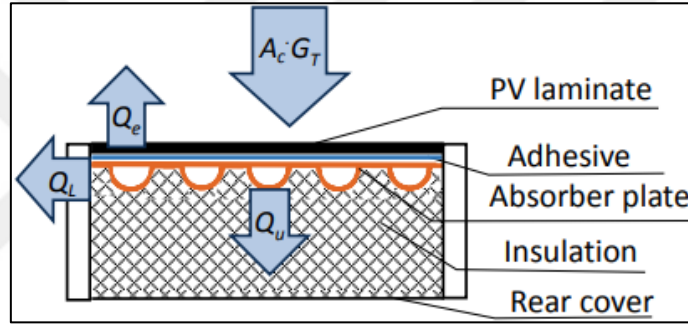


Figure 3.4: Energy Balance and Cross-Section of an Un-Glazed Roll-Bond PVT Collector.

The flat-plate analytic model by [57] is the most widely used, which considers thermal balance, PV yield of the PVT panel. The overall energy balance of a PVT collector with gross area A_c can be expressed as:

$$\rho \delta C_p \frac{dT}{dt} = G_T (\tau \alpha) eff - \frac{Q_e + Q_u + Q_L}{A_c} \quad (3.1)$$

where ρ , δ , C_p are the density (kg/m^3), thickness (m) and specific heat capacity ($\text{kJ/kg} \cdot \text{K}$), respectively, of the whole PVT collector; T is the local temperature of the PVT collector. Adapted from [58], under the steady state heat transfer condition, the overall energy balance of the PVT collector can be depicted as:

$$A_c G_T (\tau \alpha) eff = Q_e + Q_u + Q_L \quad (3.2)$$

The useful heat gain Q_u will be interpreted in next section 3.4, while the effective transmittance-absorptance product $(\tau \alpha) eff$ [59], overall electrical output Q_e , and overall thermal loss rate Q_L can be expressed as:

$$(\tau \alpha) eff = (\tau \alpha)_n IAM \quad (3.3)$$

$$Q_e = A_c G_T (\tau\alpha)_{eff} \cdot \eta p v \quad (3.4)$$

$$Q_L = A_c U_L (T_{abs} - T_a) \quad (3.5)$$

To calculate this, one can use the normal-incidence transmittance-absorptance product $(\tau\alpha)_n$. The equation excludes the electrical output and allows the calculation of the net absorbed radiation S for the plate. By using this equation, we can calculate the amount of radiation that is absorbed by the plate. This information can be useful in a variety of applications, including those related to solar energy and heat transfer. Overall, the equation provides a way to calculate the net absorbed radiation in a fairly straightforward manner, allowing for more accurate predictions and analysis [60] :

$$S = G_T (\tau\alpha)_{eff} (1 - \eta p v) \quad (3.6)$$

The incidence angle modifier (IAM) was introduced to evaluate the effect of off-normal incident radiation, which included the beam, diffuse, and ground-reflected IAM. The IAM for beam radiation at angle θ is expressed as [61]:

$$IAM_b = \frac{(\tau\alpha)_b}{(\tau\alpha)_n} \quad (3.7)$$

For a single cover collector, b_0 is about 0.136 at $\theta < 60^\circ$ [62]. For an uncovered PVT, the default b_0 set to 0.1 in some numerical models, considering that the value of KL_1 of a PV cell glass was less than that of a solar collector and an air gap was eliminated so that reflection losses reduced.

The diffuse radiation and the ground reflected radiation were treated as having equivalent angles of beam radiation respectively [63]. They were given by:

$$\theta_d = 59.68 - 0.1388\beta + 0.001497\beta^2 \quad (3.8)$$

$$\theta_g = 90.0 - 0.5788\beta + 0.002693\beta^2 \quad (3.9)$$

3.3.1 The Model and the Performance of the PVT Collector with Parallel-Channels Absorber

The traditional solar collector and PVT collector commonly adopted parallel-channel absorber plates. Considering the PVT collector with parallel channels as shown in Figure 3.7, the temperature distribution of its thermal absorber plate can be solved on the basis of its energy balance equation, then the energy yield of PVT module is obtained.

The steady state model for PVT module has the following assumptions [64]:

- Heat transfer in cell layer and insulation layer are considered as one dimension, i.e. Z-direction, since cell thickness is very small and the thermal resistance of the insulation is very large relative to those of the absorber
- Temperature gradients across the absorber thickness (Z-direction in Figure 3.7) are neglected due to the thickness δ is very small relative to its length and width (X-direction and Y-direction in Figure 3.7).

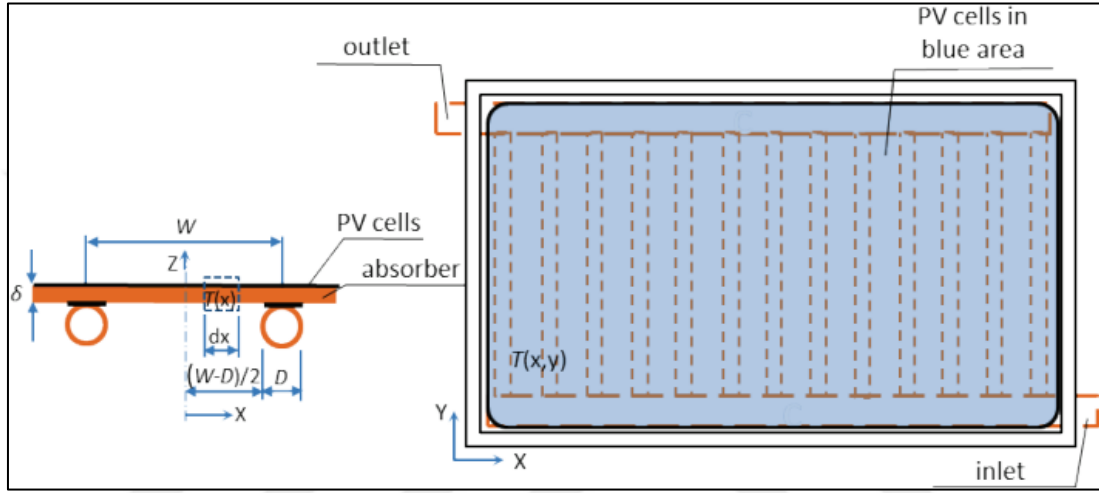


Figure 3.5: The Temperature Distribution of the PVT Collector with Parallel-Channels Absorber

- Temperature gradients across X-direction (vertical to the flow direction) can be treated independently of those across Y-direction (the flow direction).
- The down header can provide uniform flow to channels and both headers will be neglected in heat transfer analysis due to small area relative to the whole absorber.

The local energy balance equations of the element dx in Figure 3.7 are described as:

$$\begin{cases} \rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} + \frac{1}{\delta x_1} [U_L(T_a - T) + S] \\ k \left(\frac{\partial T}{\partial x} \right) |_{x = \frac{(W-D)}{2}} = \pi D D_{hfi} (T_f - T_{bond}) \\ k \left(\frac{\partial T}{\partial x} \right) |_{x = 0} = 0 \end{cases} \quad (3.10)$$

Under the steady state condition, the local energy balance equations of the element dx in Figure 3.7 are described as:

$$\begin{cases} \frac{d^2 T}{dx^2} = \frac{1}{k\delta} [U_L(T - T_a) - S] \\ \frac{dT}{dx} |_{x = 0} = 0 \\ T |_{x = \frac{(W-D)}{2}} = T_{bond} \end{cases} \quad (3.11)$$

The local energy balance equation of the element dy along the pipe direction is [65]:

$$\dot{m} C_p \frac{dT}{dy} = nWF'[S - U_L(T - T_a)] \quad (3.12)$$

where k thermal conductivity of the absorber, $W/m \cdot K$ n number of parallel channels on the absorber plate.

In this problem, the absorber plate section between two parallel channels is treated as a straight fin, and the temperature distribution of the absorber is calculated using differential equations (3.8) and (3.9). The usable intensity gain of the Photovoltaic-Warm (PVT) authority might be figured utilizing this temperature dissemination. Equations similar to those utilized for sun oriented warm authorities are utilized to process the blade effectiveness F , gatherer productivity factor F' , and intensity expulsion factor FR . Utilizing these attributes, one might work out the PVT authority's general productivity, which portrays its ability to change over sun based energy into commonsense intensity creation. By and large, this section offers a rundown of the numerical strategy to evaluating the exhibition of a PVT gatherer, as well as featuring the likenesses in the situations utilized for PVT and sunlight based warm gatherers.

3.3.2 Overall Heat Loss Coefficient

The overall heat loss is the energy losses from the absorber to the ambient, including energy losses through the top, bottom and edge of the PVT collector though the latter two parts are minor. In view of this, the overall loss coefficient U_L is the sum of the top, bottom, and edge loss coefficients [66], shown in the thermal network of Fig. 3.3(a) and expressed as:

$$U_L = U_t + U_b + U_e \quad (3.13)$$

Some models assume that the top and bottom surfaces of the collector have the same ambient temperature, represented by T_a . Meanwhile, other models use a different ambient temperature, represented by T_{bbb} , for the back of the collector, as shown in Figure 3.8(a). This decision ultimately depends on the specific design of the PVT collector and the assumptions made by the model. By carefully selecting the ambient temperature values, heat transfer models can more accurately predict the performance of the collector and provide valuable insight for improving their design and functionality. Overall, this paragraph highlights the importance of carefully selecting ambient temperature values in PVT collector models to ensure accurate predictions of their performance.

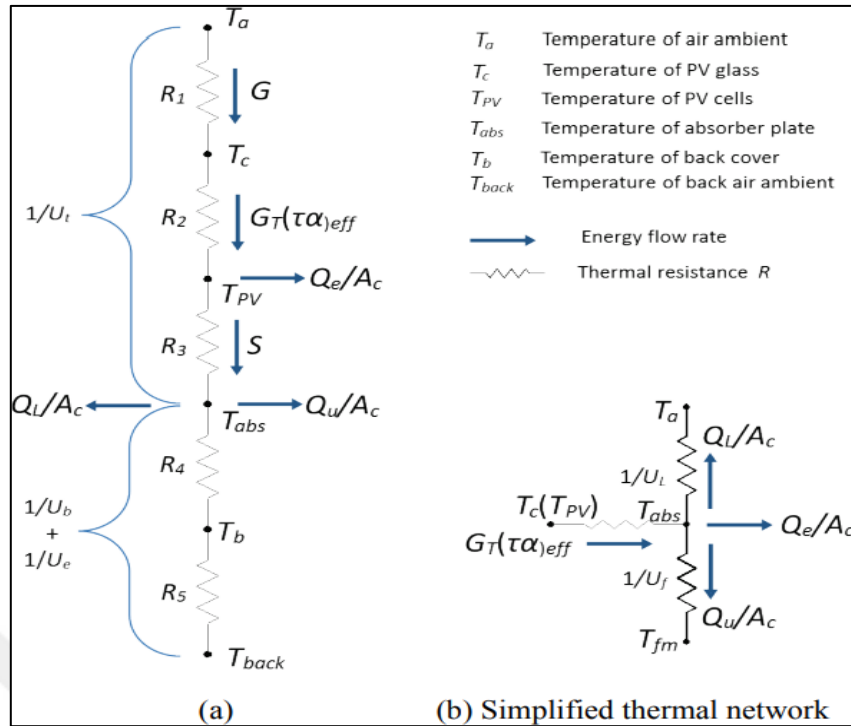


Figure 3.6: Thermal Network for an Un-Glazed Roll-Bond PVT Collector.

PV glass cover is laminated to solar cells through a layer of 0.45 mm thick Ethylene-vinyl acetate (EVA), whose thermal conductivity is 0.35 W/m·K, indicating the small thermal resistance of R_2 . Thus, some thermal models set the approximation of $T_c = T_{PV}$, for example, TYPE 560 model of TRNSYS. Essentially, the warm obstruction between PV cells and safeguard (R_3) can be overlooked, as in the TRNSYS TYPE 50 model. Figure 3.8(b) portrays a primarily worked on warm organization with zero temperature inclinations all through the PV overlay and safeguard thickness: $T_c = T_{PV} = T_{abs}$. The tests in Part 4 show minor changes between these temperatures.

3.4 EXPERIMENTAL SETUP AND WORKING PRINCIPLE

3.4.1 Water Tank Model Module

The paragraph describes a device known as a solar PVT water collector, which is designed to convert solar energy into both electrical and thermal energy simultaneously. Figure 3.9 provides a schematic layout and highlights the major working components of this device. The collector consists of two main parts: the electrical and the thermal sections. These parts work independently but in tandem to produce both electrical and thermal energy from the same input of solar radiation. This device is a hybrid system that combines the advantages of both a photovoltaic cell and thermal collector to create an efficient and effective way to

harness and utilize solar energy. By using this device, one can generate both electricity and heat by directly harnessing the energy from the sun, reducing the dependence on traditional energy sources and promoting energy sustainability. Overall, this paragraph provides an overview of the technology used in a solar PV/T water collector and its potential benefits for renewable energy production.

To test the change rate, interface the module's two terminals, signified by +ve and - ve in the text, to an electrical circuit that contains a voltmeter, an ammeter, and a rheostat. Daylight falls on the highest point of the polycrystalline sunlight based PV module, which has a power rating of 40 Watts and an area of 0.4087 square meters. The specialized prerequisites of the sunlight based PV module decide the size of any PV framework. The exhibition of the PV module is impacted by its working temperature, which can be measured using a temperature gun as shown in Figure 3.9. By accurately measuring the conversion rate and temperature of the module, one can optimize its performance and improve the overall efficiency of the solar energy system. Overall, this paragraph provides an overview of the technical specifications and testing methods used for solar PV modules and highlights the importance of accurate measurement and analysis for efficient and effective solar energy production.

The water storage tank is a vertical cylinder. The hot water from the PVT collector enters the tank from the top of it, the outlet of the tank to the PVT collector is at the bottom of it, and the cold water is also replenished from the bottom of the tank. The flow rate is very small in the tank due to the relatively large cross-section of the tank. Sometimes the pump is switched off and the circulation flow rate is zero, so there is a temperature stratification in the depth direction of the tank, the upper part is hot and the lower part is cold. The electric auxiliary heater and the thermostat are placed on the uppermost layer of the water tank, and the domestic hot water outlet is also placed on the uppermost layer of it.

The model in TRNSYS [67] can be considered to comprise of N ($N = 15$) completely blended equivalent volume sections for a reasonable energy stockpiling tank with warm definition. The worth of N , as outlined in Figure 3.9, decides the level of delineation. Assuming N is equivalent to one, the liquid in the capacity tank is altogether blended and there is no definition impact.

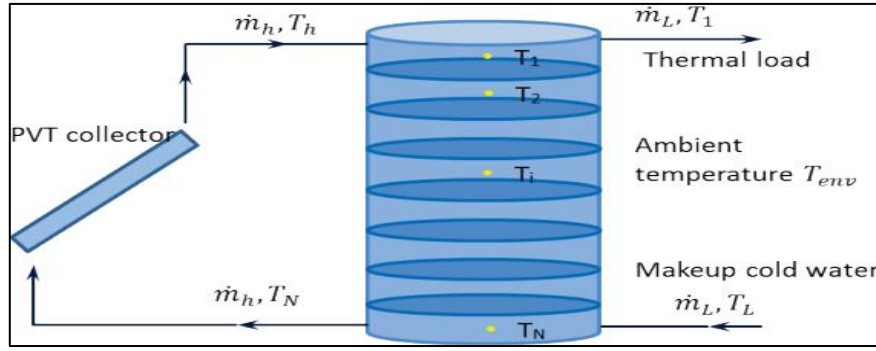


Figure 3.7: Model of Stratified Storage Tank.

The energy input to the water tank includes the useful heat gain Q_u from the heat source (PVT collectors), and the heating amount Q_{AUX} of the auxiliary heater. The energy output to the water tank includes the heat load Q_{DHW} (e.g. domestic hot water), and the heat loss Q_{env} to the environment. If the energy change inside the water tank is ΔE , the energy balance equation of the water tank is:

$$\Delta E = Q_u + Q_{AUX} - Q_{DHW} - Q_{env} \quad (3.14)$$

The auxiliary heaters are activated when the temperature of the node where the thermostat is located is below a certain threshold ($T_{SSS} - \Delta T_{dd}$). The heater will also stay on if it was already on during the previous interval and the thermostat temperature is still below T_{SSS} . The temperature deadband ΔT_{dd} controls when the heater is activated.

3.4.2 Parallel Connected Solar PV/T Water Collector Module

This experiment entails two flat plates, completely covered in photovoltaic/thermal water collectors, connected in series, as depicted in Figure 3.11. Along with the collectors, an ammeter (capable of reading from 0 to 10 Amperes), a voltmeter (ranging from 0 to 120 Volts), a rheostat (having a resistance of 250 Ohms and 1.8 Amperes) and a storage tank (with a capacity of 100 liters and equipped with an inlet and an outlet) are also present. This trial's PV module is contained polycrystalline silicon cells connected in series. Each gatherer has an inlet and an outlet. The intensity move liquid enters through the channel and escapes through the power source due to the thermosyphon impact. The power source of PV/T-1 is connected in series with the admission of PV/T-2, raising the temperature at the power source over that of a solitary independent PV/T framework. A series-associated PV/T module has an evaluated power and voltage of 80 watts and 44.4 volts, with a general size of 0.8174 m². PV/T-1 and PV/T-2 are both raised in a North-South direction and leaned at

a 20° point from the level plane, confronting southwards. Two Mixtec computerized thermometers are utilized to recognize the intensity move liquid's entry and outlet temperatures, while a HTC instrument non-contact type temperature sensor is used to quantify the surface temperature of the PV modules.

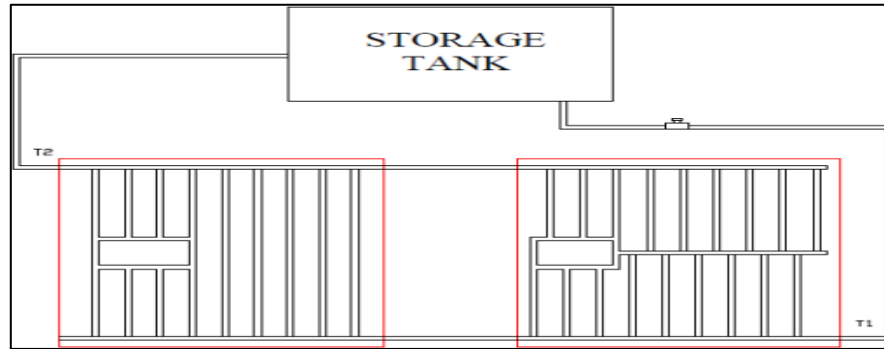


Figure 3.8: PV/T Fluid Flow Pattern.

3.4.3 Solar Fraction

The solar fraction is the ratio of solar heat gain to total heat energy demand or heat load, which indicates the percentage of solar energy that can meet the total heat demand. Taking domestic hot water (DHW) as an example, when the hot water load is Q_{DHW} and the auxiliary heating amount is Q_{AUX} , the solar fraction is defined as:

$$f_{sol} = 1 - \frac{Q_{AUX}}{Q_{DHW}} \quad (3.15)$$

Here f_{sol} is not directly expressed as the ratio of Q_u to Q_{DHW} , which mainly accounts for heat losses of the entire system, especially the heat loss of the hot water tank, which has always occurred no matter during the consumption or non-consumption period. Therefore, the solar fraction is mainly indicative of the performance of solar thermal systems, rather than the performance of solar collectors or PVT components.

The solar fraction of a solar thermal system increases with the area of the collectors. For a pure solar thermal system, this value usually ranges from 40% to 90% [68][70]. In other words, the remaining 60% to 10% of the energy demand is provided by the auxiliary heater, which can meet all the thermal demand in summer and part of the demand in winter. The higher the f_{sol} , for example, when it is above 60%, the more heat can be provided by solar energy in winter, but in summer, the solar energy would be oversupplied. Such system configuration may not be cost-effective, and may also cause some technical problems such

as overheating. Especially for PVT systems, too high solar fraction will have a negative impact, because the heat surplus in summer will increase the cells' temperature and affect the electrical efficiency of the PV cells. Therefore, pointed out that the optimal range of solar fraction of the PVT-DHW system was 40~60%, which is lower than the optimal range of solar collector system 40%~90%.

3.4.4 Heat Transfer Models of PVT Coupled to the Roof

The building integrated PVT (BIPVT) includes roof-integrated PVT, and façade-integrated PVT. Each of them comes in two forms: one is directly using PVT modules to replace the external envelope, called a real BIPVT system, the other is to mount PVT modules on the existing envelope to form a building-applied photovoltaic thermal (BAPVT) system. In this study, the BAPVT system consists of the PVT collectors, an airflow gap between the PVT and the roof, fixed brackets, an air inlet, an air outlet, and the roof, as well as the thermal and electrical load systems. The thermal load system includes a water circulation loop and a storage tank, while the electrical load system is a stand-alone system including a battery, a regulator, and even an inverter.

The PVT roof has changed the heat gain mode of the building by avoiding exposure of the roof to solar irradiation directly, which effectively reduce the building's heating and cooling load at the same time improving solar energy utilization compared to side-by-side solar applications.

The schematic diagram of the PVT-roof is shown in Figure 3.12. The ordinate direction is perpendicular to the PVT panel and the roof surface. The abscissa direction is the airflow direction in the gap. The origin of coordinates is set at the airflow inlet. The size of PVT panel is L (length) \times W (width), and the depth of air gap is D .

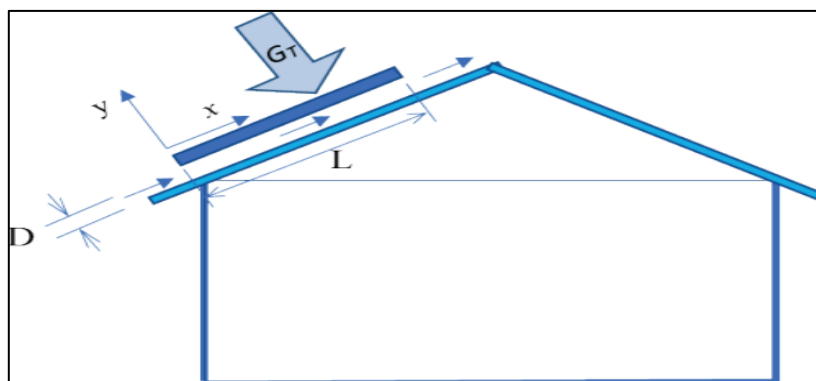


Figure 3.9: The Schematic Diagram of the Roof Mounted with PVT Panels.

The irradiance on the tilt PVT is GT , apart from the output of electricity Q_e and heat Q_u transferred to the water loop, most of the rest is converted into thermal energy, lost from the surface and bottom of the PVT panel to the ambient. The heat loss from the bottom of the PVT collector directly affects the temperature and speed of the airflow in the gap, and then affects the heat gain of the roof and the indoor thermal environment. At night, the heat transfer direction between the PVT and the roof is opposite, the heat release from the roof to the air flow channel depends on the temperature of the back surface of the PVT T_b and the convective heat loss of the airflow in the channel. In addition, when the PVT water flow is stagnant, $Q_u = 0$, the heat transfer direction between the PVT and the roof depends on the T_b and the airflow state in the channel. The temperature of the back side of the PVT T_b can be derived from the average water temperature in the absorber plate, even under the non-circulating condition.

3.5 SUMMARY

This chapter gives theoretical models for the PVT module and PVT system, as well as the BAPVT system --- PVT-roof. The theoretical core of this research focuses on the performance evaluation of the PVT modules and systems, and their parameters' expressions as well, which lays the foundations for further experimental and simulation studies.

The conclusions of this chapter are as follows:

- a. Based on the energy balance law of flat-plate solar thermal collectors, the energy balance equation of PVT modules has been developed, and the expressions of various energy terms have been analyzed and derived.
- b. The analytical solution of the temperature distribution of the harp-channel absorber of the PVT collectors has been derived. Then, according to the heat transfer network of the PVT collectors, the components of the overall heat transfer coefficient have been analyzed, and the important performance parameters F' and UL have been obtained, the useful heat gain Q_u and the thermal efficiency η_{th} obtained as well. This lays the foundations for subsequent numerical study on PVT modules with non-parallel channel absorbers in Chapter 4.

4. RESULTS & DISCUSSION

4.1 PERFORMANCE EXPERIMENT OF PVT MODULES

The proposed PVT system was tailored for a family use. At the first stage, a small scale experimental system, or a prototype system, was developed for performance monitoring experiments. The model framework is comprised of a PVT module made in Segment 4.1, a 220 L water tank, and a few control and check valves associated by polypropylene irregular (PP-R) pipe as an open circle framework. However, theoretical calculations and practical experience have predicted that the conditions of natural circulation are generally difficult to be met, so a bypass pipe with a small pump is connected in parallel on the water system, as shown in Figure 4.1.

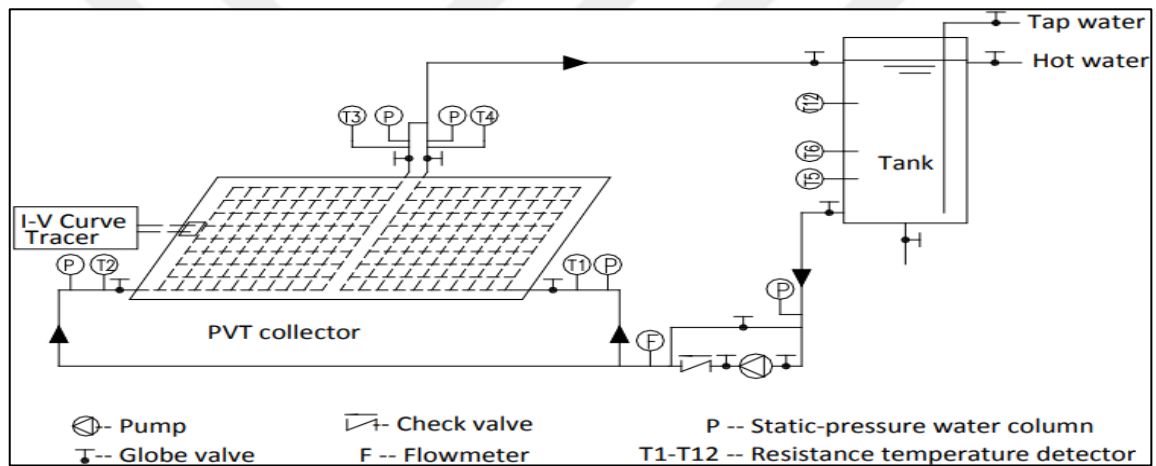


Figure 4.1: Schematic of the PVT 2 Experimental System.

For the two roll-bond absorber plates developed in this study, two PVT modules of the same size were fabricated respectively, the hybrid module with Absorber 1 is PVT 1, with Absorber 2 is PVT 2. Thus, two experimental systems were also developed correspondingly. PVT 1 test rig and PVT 2 test rig are identical configuration except for the different absorber plates adopted, shown in Figure 4.1.

4.2 EXPERIMENTAL RESULTS AND DISCUSSION

The impacts of shadow on photovoltaic execution, the stagnation temperature of PVT modules, the basic radiation level, and the strain drop of PVT safeguards at different flowrates were completely explored. Moreover, the standard performance test of PVT collectors had also been carried out according to the EN12975 standard in few days when the steady state test conditions were met.

This section analyzes the characteristics of the various components of the PVT collectors, including the effect of shadow on the PV efficiency, the stagnation temperature and the two properties associated with the thermal absorbers: critical radiation level and internal hydraulic pressure drop.

4.2.1 PV Efficiency Sensitivity to Shadows

When the PVT panel is shaded by surrounding stuff such as trees, wing walls, it is equivalent to be under the diffuse radiation. This shading has a great influence on the photovoltaic output under the sunny conditions with the strong solar radiation. In the earlier experiments, the PVT absorber was not infilled with water, the comparison test on the shading influence was carried out on the premise that the PV sandwiches of the two PVT modules are identical and have the same electrical efficiency (STC) that have been tested at the factory. During the experiment, the surface of PVT 1 was shaded by the eaves several meters away, specifically from the partial to whole area shaded; while the adjacent PVT 2 was completely exposed in total radiation [71][72].

The suitable experimental condition should be under strong irradiance. So the period within one hour before and after the local solar noon was selected. The longitude of Chengdu is 104.02°E , but its time zone falls in the longitude 120°E . Therefore, the local solar noon of Chengdu is at around 13:05. Figure 4.2 shows the PV electrical output and efficiency of the two modules around a solar noon, except for the data from 12:37 to 12:50 because the irradiance was fluctuating within the ten minutes. In the figure, one grid means one piece of mc-Si cells' area, that is 1/36 of the total area of each PVT panel.

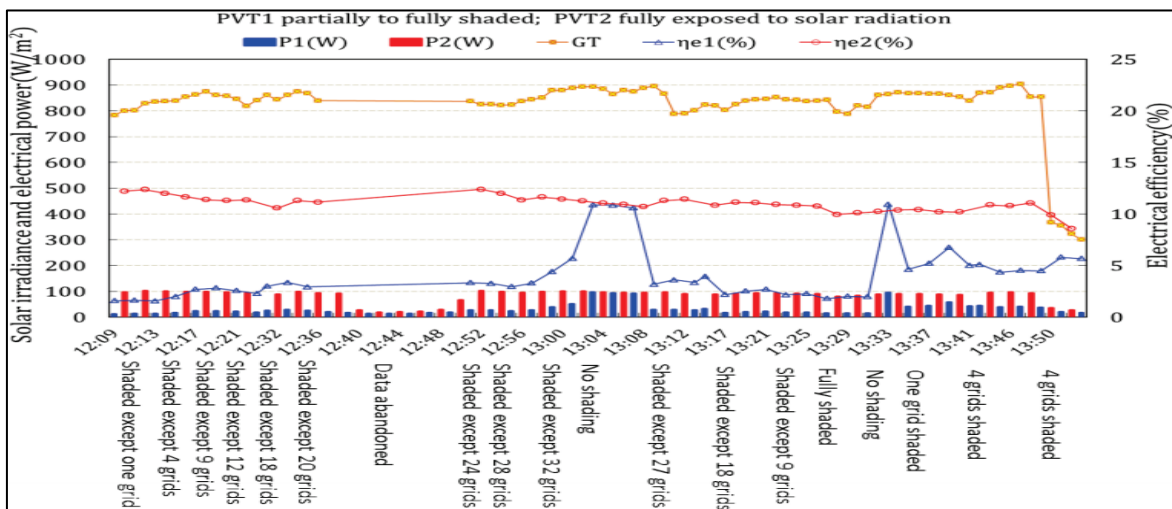


Figure 4.2: Photovoltaic Performance Comparison of PVTs with and Without Shading.

It can be seen that the electrical efficiencies (red points) of the unshaded PVT 2 are relatively stable ranged from 11% to 12.5%, while the efficiencies of PVT 1 (blue points) can be basically classified into three grades:

- a. η_{el} is around 11%, which occurred in two periods when fully exposed to solar radiation, and was almost identical to the efficiency of PVT 2 at the same moment.
- b. $\eta_{el} = 5\% \pm 1\%$, occurring when 1/36 to 4/36 (i.e. 2.7% to 11%) of the PVT surface was shaded. That is, a small area of shading will reduce the electrical efficiency to half that of the unshaded PVT.
- c. $\eta_{el} = 1.5\% \sim 3\%$ which occurred after the shading area exceeded 11% and further increased until 100% shaded. At this time, the electrical output was about 10 to 20 W/m², which was equivalent to the power output of the mc-Si PV cells in a heavy cloudy day, that is the situation which could be observed in experiments during the cloudy day.

4.2.2 PVT Cooling Effect

The exploratory assessment distinguished various framework defects. The information accumulated uncovered a low warm proficiency of the modules as well as a surprising way of behaving of the evaporator. The coefficient of execution (COP), pace of vanishing (Q_{eva}), and pace of buildup (Q_{cond}) were all lower than anticipated, and the evaporator outlet temperature ($T_{ref,e}$) was recorded at a startlingly low - 12°C, while the water-glycol mix was exclusively at 5°C.

The issue with the solar collectors, leading to the detachment of the sheet tube heat exchanger, has been addressed by replacing the modules with newer ones. After cleaning the evaporator, the performance did not improve, indicating that the heat pump was a prototype, and the heat exchangers may require a redesign for water-source mode. Additionally, simply exchanging the air-source evaporator with a brazed-plate heat exchanger identical to the condenser may not be the best solution. Furthermore, it is important to inspect the thermostatic valve, as the lack of performance might be attributed to a wrong calibration.

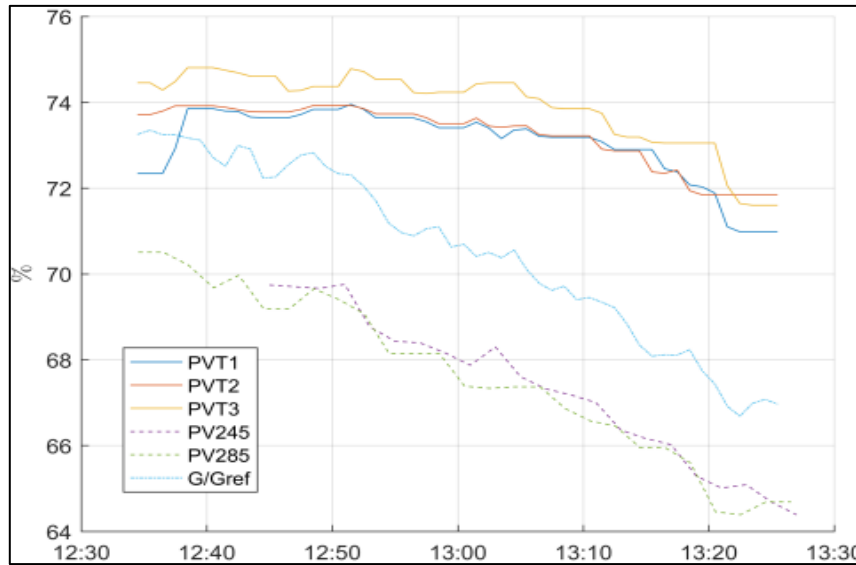


Figure 4.3: Comparison Between PVT and PV Electric Power Production with Respect to Nominal Values on November, 30th

In order to determine the effectiveness of PVT collectors, a comparison with conventional PV modules was conducted. Upon analysis, it was found that PVT collectors provide a 5 percentage point improvement in performance in comparison to the traditional methods. This improvement is attributed to the water-glycol mixture which flows through the roll-bond heat exchanger, and is maintained at temperatures within the range of 8-15°C.

4.2.3 Stagnation Temperature

If the temperature of solar cells exceeds 135 °C, it will highly increase the risk of EVA delamination to damage the structure of the PV laminate. Even if it does not reach 135 °C, the dual function of long-term high temperature and ultraviolet light will make the transparency of EVA adhesive decrease, which tends to reduce the transmittance and shorten the life-span of the PV laminate. The hybrid PVT module may cause the higher PV temperature than that of the PV module under the same environmental conditions, especially under stagnation condition. The stagnation temperature is the temperature reached by the PV cell when the fluid in the absorber plate of the PVT module is stagnant. Controlling the stagnation temperature is beneficial to slow down the performance degradation of the PV module. [73] established a numerical model in 2002 to calculate the maximum temperature of PV cells under the stagnation condition. The occurrence of the maximum stagnation temperature is lagged behind the moment of maximum irradiance, so the dynamic model is more accurate than the static model, and the lag time is related to the heat capacity of the

PVT component. The stagnation temperature of the glazed PVT module is also higher than that of the unglazed, because the heat loss of the former is small. In addition, the mounted slope of the PVT module also affects its stagnation temperature.

The occurrence chance of the yearly maximum stagnation temperature mainly depends on three conditions: the highest ambient temperature, the maximum irradiance, and zero incident angle of the PVT surface. The first two conditions are uncontrollable and do not necessarily occur at the same time. The third can be artificially given. The test site is located 30.67 north latitude, the slope of the unglazed PVT modules was 33°, the azimuth was zero, so the minimum incident angle appeared around the vernal equinox and the autumn equinox, while in hottest season, at the end of July and early August, the minimum incident angle for the PVT modules was approximately 20°. and the incident angle is larger than the minimum incident angle of the day (solar noon) when the maximum ambient temperature is reached, this moment obviously lags behind the solar noon. These conditions made the maximum stagnation temperature recorded in this experiment relatively not high.

The maximum ambient temperature of the experimental site during the year was about 36-38 °C, the recorded maximum stagnation temperature of the PVT modules was about 69 °C. If the water flowed in a natural circulation mode, with flowrate generally below 0.2 L/min·m² (which could be observed at the inlet of the water tank, but could not be monitored by the flowrate sensor), the highest PV temperature dropped back below 60 °C. If forced circulation with flowrate of 1.2 L/min·m² was implemented, the PV temperature dropped to 50 °C or less. Furthermore, on the off chance that the illumination was consistent, the temperature dissemination was somewhat uniform, with a temperature contrast of 3-5 °C. Figure 4.4 shows the temperature change of the PVT surface; the infrared photos were gathered on June 16, 2017, while the encompassing temperature was 26-27 °C and the admission water temperature was 21 °C.

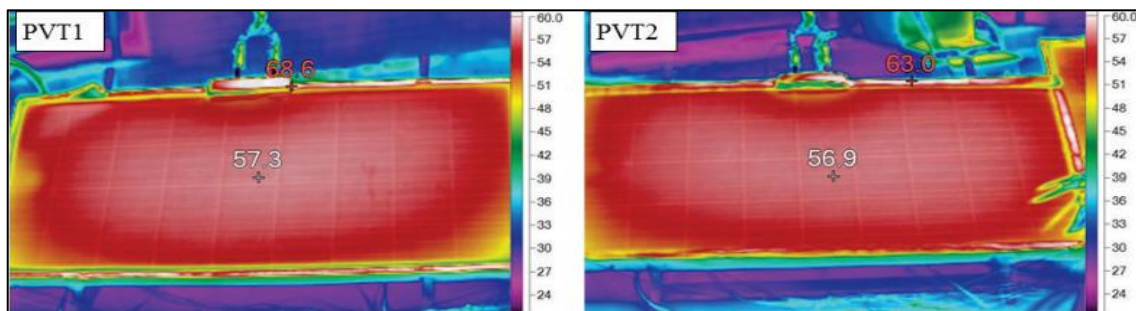


Figure 4.4: Temperature Distribution Under Stagnation Conditions.

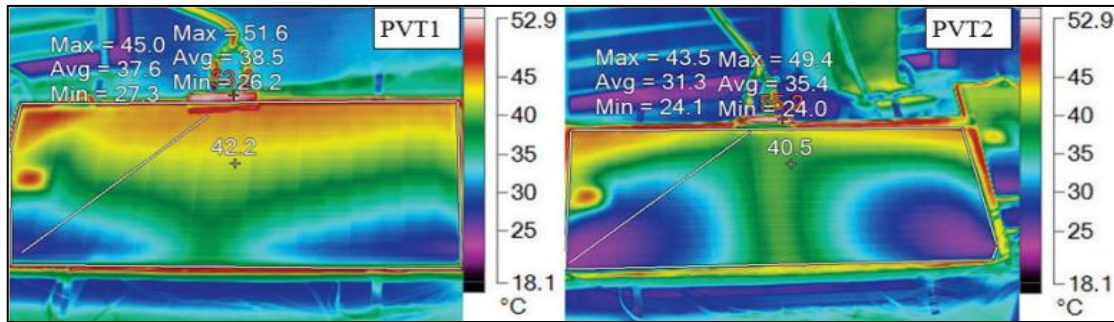


Figure 4.5: Temperature Distribution after 15-Minute Natural Circulation Since Stagnation.

4.3 EXPERIMENTAL RESULTS AND DISCUSSION OF THE PERFORMANCE OF PVT COLLECTORS

Performance tests were operated for 3-7 days in every month from June, 2017 to May, 2022, under clear, cloudy and overcast weather conditions, actually including several heavy haze days. Steady-state standard efficiency of PVT was tested under certain conditions according to some standardized measurement procedure. Under other conditions, the transient thermal and electrical efficiencies could be calculated by test data on the time-step basis.

Since the slope of the two PVT panels was 33° , very close to the latitude of the experimental site of 31° , the time when the incident angle was close to the normal direction, which is one of the steady-state test conditions, occurred near the spring equinox or the autumn equinox. The thermal performance test standards demanded that only four days of weather conditions should be suitable for the steady-state test throughout the duration of the experiment. These four days were September 21, 2017, March 1, 22, and April 16, 2022. Figure 4.6 illustrates the transient thermal efficiencies of the test around solar noon on March 22, 2022.

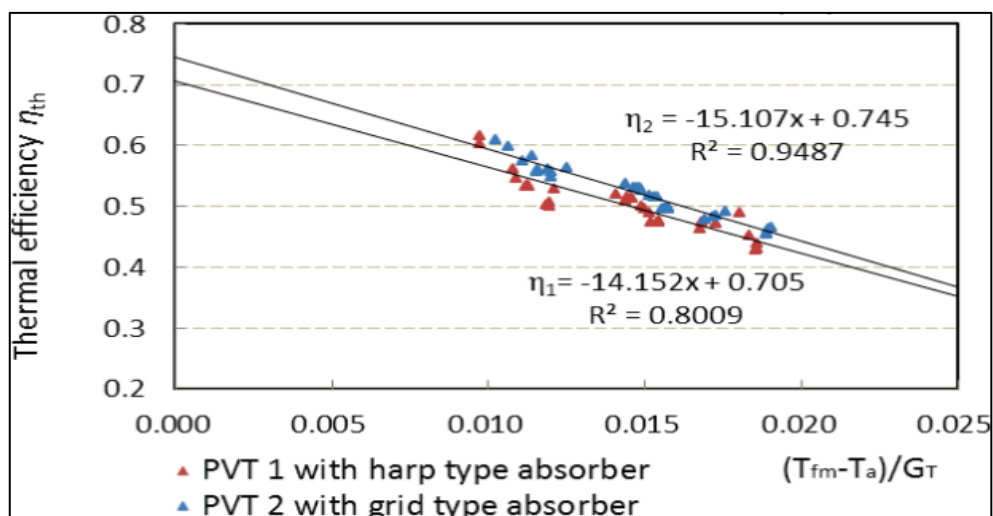


Figure 4.6: Thermal Efficiency of Two PVT Collectors are Compared.

The PVT systems were tested with an angle of incidence ranging from 2.3° to 17.6° and a variation of no more than $\pm 2\%$ in the incident angle modifier. Sun oriented irradiance was recorded at 91030 W/m^2 with a diffuse irradiance extent of under 20%. The temperature was held at $22.61.0^\circ \text{C}$, while the breeze speed was controlled somewhere in the range of 1.0 and 3.0 m/s. Both PVT frameworks' feedback water temperatures were painstakingly controlled inside $30\text{-}45^\circ \text{C}$, with a 0.2°C variety from the essential qualities, and the stream rates were set at $1.20.01 \text{ L/minm}^2$.

4.4 TRANSIENT PERFORMANCE

Apart from the steady-state standard tests, the usual monitoring results further illustrate the performance differences between the two PVT modules. The following example are the experimental results of a typical sunny day and a cloudy day.

Utilizing April sixteenth, 2022 for instance, the typical warm efficiencies of PVT 1 and PVT 2 were 27.5% and 28.9%, individually, with normal electrical efficiencies of 11.2% and 11.6%, proposing that PVT 2 has higher warm and electrical characteristics than PVT 1. Their examination result was reliable with the recently detailed results. The solar irradiance on the PVT plane and transient efficiency per minute are shown in Figure 4.7.

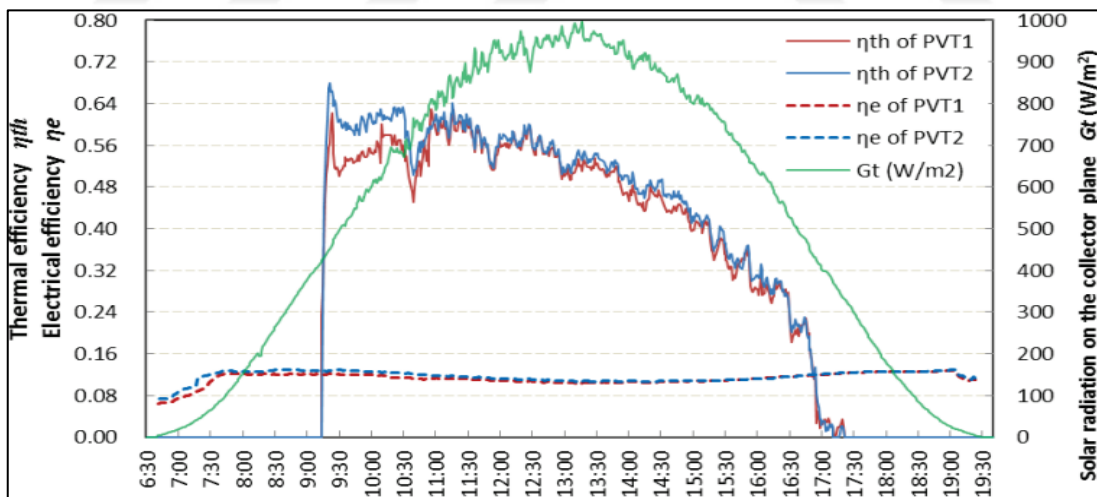


Figure 4.7: On a Clear Day, the Thermal and PV Efficiency of Two PVT Collectors.

It is worth noting that before the pump was switched on at 9:18 am, both PVT collectors were in heat storage process, so the heat gain of the water was high within a few minutes after the pump was started, and the thermal efficiency is also very high. The instantaneous thermal efficiency at the first 3 minutes could be beyond 100%. And the heat storage amount is related to water volume of the absorber of the PVT module, in other words, to the effective

specific heat capacity of the PVT module. It was after 6-8 minutes operation by the pump in PVT 1 system, 8-10 minutes operation by the pump in PVT 2 system, that the impact of heat storage was eliminated and the genuine transient thermal performance was appeared.

In addition, it can be seen that the electrical efficiency indicated by the dashed line is slightly lower at noon, but highest at 1 hour after sunrise and 1 hour before sunset, which is the same situation for both PVT collectors. This was mainly due to the impact of PV cells temperature on electrical power and efficiency. Of course, the actual power output was still the highest at noon. The closer to sunrise or sunset, the lower the electrical efficiency, suggesting that the low irradiance became the dominant factor, see Equation (3.4), and cells temperature retreated to the secondary factor. However, since the actual power output was very small at this time, the experimental data showed $< 5\text{W/m}^2$, so the error caused by ignoring the low irradiance correction factor can be neglected.

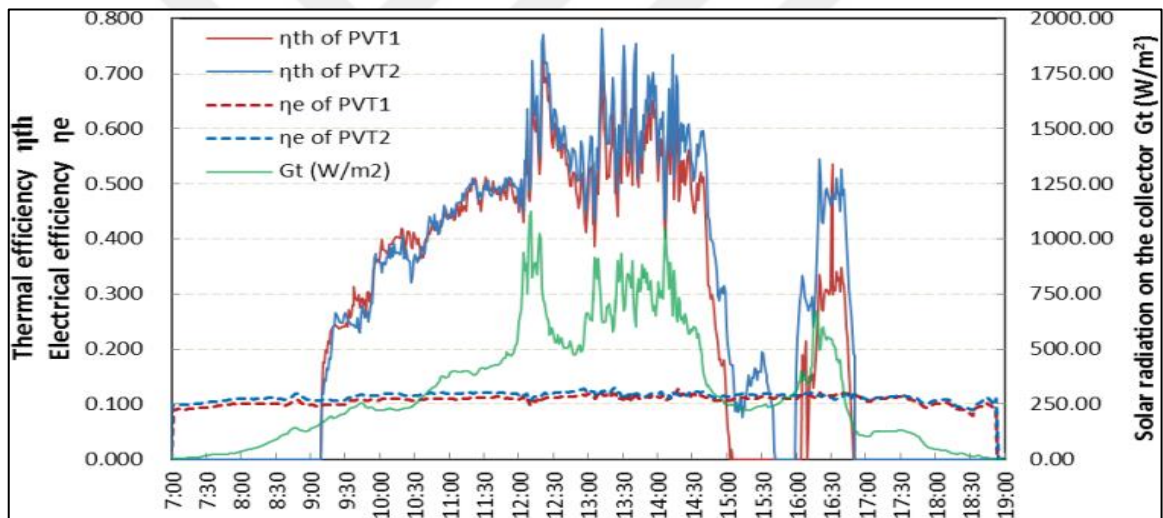


Figure 4.8: On a Gloomy Day, the Thermal and PV Efficiencies of Two PVT Collectors.

The thermal efficiency curves went up and down with the fluctuating solar irradiance in Figure 4.8, but existing about 10-minute lag, resulted from the heat capacity property of the PVT modules. The electrical efficiency curves were not as smooth as them in Figure 4.8. But there were not obvious low values around noon, which might be the results of lower temperature of absorber and PV cells compared with that at the same time in a clear day. The data record also shows the maximum water temperatures of PVT 1 outlet and PVT 2 outlet reached $41\text{ }^{\circ}\text{C}$ and $42\text{ }^{\circ}\text{C}$ around 14:30. It can be deduced the temperature of PV cells mostly below $40\text{ }^{\circ}\text{C}$ due to moderate insolation condition and fairly large flow rates around noon.

The performance of two PVT modules has been found to degrade in past year's intermittent or continuous experiment. In earlier experiments, for example, such as the sunny day of June and July of 2017, the highest instantaneous thermal efficiency of PVT 1 could reach more than 78%, of PVT 2 could reach more than 85%. The nominal thermal efficiency values in the steady-state test could also reach 76% and 81% respectively. Preceding 2022, the electrical proficiency was ordinarily somewhere in the range of 11.0% and 15.0%; in any case, information from Walk 2022 showed the PV effectiveness changing somewhere in the range of 10.2% and 13.0%. The reason for the decrease in thermal and electrical efficiency may be the issue of the PV laminate, the PV cells attenuated or the transmittance of the EVA adhesive dropped. And another possible cause is the scale deposit in flow channels of the absorber plate to lead to convective heat transfer worse.

4.5 CONCLUSION

In this chapter, the detail of the experimental test rigs and procedure were described, followed by the processing and analysis of a series of experimental data. It focused on the comparative study on hydraulic and heat transfer property of the absorbers with two kinds of flow channels, which revealed the performance difference between the two PVT modules.

The conclusions of this chapter are as follows:

- a. The proposed aluminum roll-bond absorber was characterized as diverse flow-channel configurations, highly efficient heat transfer, and convenient manufacturing. An innovative connection method was adopted to combine the absorber with the commercial, semi-finished PV panel, which further reduced the heat transfer resistance between the absorber and the PV laminate, and enhanced heat transfer coefficient compared to conventional bonding methods.
- b. The monitored maximum stagnation temperature was no more than 70 °C, which was beneficial to prolong the life span of PV cells. The relatively low stagnation temperature lies in three causes that: firstly, the PVT module was unglazed; secondly, the slope of PVT plane was slightly larger than the local latitude; thirdly, the azimuth was zero. The latter two factors made the incident angle of the PVT panel was beyond 20° in the hottest season.

5. CONCLUSION AND FUTURE WORKS

5.1 CONCLUSION

This study takes a gander at the presentation of a sun powered helped heat siphon that utilizes photovoltaic-warm gatherers to give family boiling water and warming. To recognize the best course of action, a few framework designs with changed heat siphon limit and number of sunlight based gatherers are explored and displayed. By understanding the behavior of the system under different configurations, the most efficient setup can be identified.

The results of the experiments conducted indicated a positive effect of using a cold water-glycol mixture to flow through the PVT modules when it comes to generating electric power. On a winter day with clear skies and a temperature ranging from 5 to 8°C, the electric power generated by the PVT system was 5 percentage points higher than that of the conventional PV modules. Thus, for the purpose of simulation, a mathematical model of the system was devised, taking into consideration the heat exchange properties of commercial heat pumps instead of prototypes. An essential black-box consistent state model was utilized to execute a yearly reproduction inside reasonable computational assets. The warm exhibition of the sun powered modules was displayed utilizing the maker's misfortune coefficients, while the blower conduct was addressed utilizing polynomial conditions drawn from the specialized information sheets.

The outcomes show that the framework's productivity is exceptionally dependent on how much sun powered energy accessible. Utilizing sun based energy, the intensity siphon might warm the functioning liquid to temperatures higher than the surrounding temperature, bringing about a more prominent coefficient of execution (COP) than air-source heat siphons. At the point when sunlight based radiation is lacking, the framework can't make nuclear energy. Yearly reproductions observed that the most reduced plan was just adequate for home heated water conveyance, accepting boundless stockpiling limit and no warm misfortunes. The greatest plan might satisfy half of the all out yearly warm interest. During the mid-season, both the transitional and enormous intensity siphon frameworks had the option to satisfy request, while only the largest (Case C) heat pump system was able to meet a significant portion of the demand during winter.

5.2 FUTURE WORKS

The economic analysis indicated that the largest configuration achieved its break-even point in its useful life. The largest cost advantage of this setup is attributed to the PVT technology which had a considerable impact on the Net Present Value. As the number of PVT installed increases, the NPV also increases, indicating that the higher initial investment cost is offset by additional revenue. When comparing the configuration with PVT to a configuration with conventional modules, it was found that the annual thermal energy supplied to the load was slightly less while the PV collectors covered the electric consumption of the heat pump. However the conventional module framework was initially more affordable than the PVT gatherer framework, the financial examination found that the lower power age emphatically brought down net incomes, coming about in a less fortunate NPV than any remaining setups.

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