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Experimental and Numerical Study of the Thermal Solar Panel Performance using heated tubes: A review

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ABSTRACT

Due to the pollution and unreliability of conventional energy sources, renewable energy sources are growing in popularity. The topic of what will replace fossil fuels as a reliable energy source grows as the world's population grows is raised. Solar energy is one of the most plentiful resources; it can be seen directly as solar irradiance or indirectly as biomass and wind energy. There are a few aspects that need to be distinguished while discussing energy conversion efficiency. Electrical energy and thermal energy are the two different forms of energy that can be generated. Thermal energy is not as useful as electrical energy, mostly because electrical energy can be transformed to labour more easily. Using photovoltaic cells (PV cells) to capture direct sun radiation is the most effective method of producing electricity. This paper focuses on the various approaches or geometries used to produce electricity and their impact on the heat transfer rate. It also introduces the concept of PV cell efficiency enhancement and reviews some of the experimental and numerical works done by researchers on this technique in recent years.

1. Introduction

Solar energy is the renewable energy technology that is expanding the fastest. Growth was 58% on average between 2006 and 2011 [1]. Globally, there was 139 GW of PV capacity at the end of 2014. With 277 GW of PV capacity at the end of 2015, it ranked third in the world for renewable electricity generation by capacity, behind hydropower and wind. The annual market for new capacity increased by 25% from the previous year. There was an increase of over 50 GW, or over 185 million solar panels [2].

Utilising the photovoltaic phenomenon, which William Becquerel originally noticed in 1839, photovoltaic energy is the direct method of converting solar radiation into electricity [3]. When photons shine on semiconductors, this technology produces direct current electrical power. The semiconductors' ability to receive light determines how much electricity they produce. The installation of a novel and more ecologically friendly power supply system is greatly attracted to the photovoltaic system. The semiconductors in solid materials have a high efficiency in converting solar energy into electrical energy, and almost all photovoltaic devices have a P-N junction in a semiconductor across which the photovoltaic voltage is developed.

The photovoltaic effect can be produced in solid, liquid, and gaseous materials. Another name for these gadgets is solar cells. Solar cells are bundled into modules for practical usage, with the number of cells varying based on the application. These modules can be connected in parallel or series, though series is more common in the commercial sector. The module provides a higher voltage than a single cell while shielding the solar cells from the environment. Additionally, modules frequently

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include a structure that facilitates handling and transit. An electronic component known as an inverter usually converts the DC current produced by the module into AC current. This allows the electricity to be used in electrical devices or stored in batteries [4 and 5].

It is possible to transform electrical energy into A heat pipe is a simple, immobile device that can transport large amounts of heat without the need for electricity over long distances and nearly at constant temperature. It is essentially a sealed cylinder tube that is partially filled with water or another saturated fluid. It is divided into three sections: At one end an evaporator section, where heat is taken and the fluid converted into vapor. A condenser section at the other end where the vapour turns into liquid and heat is dumped. In addition, an adiabatic section in between where the fluid liquid and vapour phase flow in opposite direction through the core and complete the cycle with no exchange of heat between the fluid and the medium [6].

2. Literature Review

The decrease in conversion efficiency of PV panels with rising panel temperatures, which is directly related to rising solar intensity and rising ambient temperatures around the panels, is one of the technology's most notable problems. In order to get increased electrical efficiency, the PV module needs to be cooled through some means of removing surplus heat from the cell assembly. The module ought to be integrated with a heat exchange system that uses a fluid stream at either its front or back surface, such as water or air. Water's thermo-physical characteristics make it an effective cooling medium. This kind of device, called a hybrid system since it uses fluid as a coolant, converts solar light into electrical energy while also absorbing heat from the panel to produce thermal energy. This allows the panel to operate at lower temperatures (more efficient) and allows the thermal energy gained to be used for residential purposes in the form of hot water. Over the last several years, a great deal of work has been put into the study of active and passive cooling in an attempt to better absorb the available energy when the sun is at its strongest. This section provides a quick overview of some of the previous research on cooling photovoltaic cells.

2.1 Experimental Studies

A passive technique based on thermosyphons was presented by Akbarzadeh and **Wadowski (1996)** [7], and it can successfully cool the photovoltaic cells in situations with intense light. An east-west trough solar concentrator prototype was made using a thermosyphon cooling mechanism for the PV cells and a reflecting surface profile. The device was successfully tested. Two heat exchangers connected by pipe make up the system that is being suggested here for cooling the back of the solar cells. The evaporator has photovoltaic cells attached to it, and convective air cooling occurs naturally over the higher condenser. The working fluid type for a thermosyphon is determined by the necessary temperature range. Fluids like R-11, R-22, and water are appropriate for temperatures between 20 and 100 degrees Celsius. PV performance decreased by 50% when the experiment's solar cells reached a temperature of 85°C. This indicates that the solar cells' performance has been significantly enhanced by the suggested cooling mechanism. Given that the system was intended to operate at a concentration of 20 sun, the output that was achieved in the experiment should have been twice as high. The concentrating surface's imperfect reflectivity and the cooling system's limited ability to drop the cell's surface temperature to 46oC are the reasons for this lower performance. Solar cells function at this temperature.

Many suggestions have been made by **Krauter** (2004) [8] to reduce solar radiation reflection, which often reduces the electrical yield of photovoltaic modules by 8 to 15%. However, most have drawbacks, such as weak antireflective coatings and costly, dust-collecting, and challenging to clean structured surfaces. Water, on the other hand, is an inefficient medium between glass (1.5) and air (1.0), with a refractive index of 1.3. Water not only maintains a clean surface but also reduces reflection by 2-3.6%, drops cell temperatures to 22°C, and generates an electrical surplus of 10.3%; a net advantage of 8–9% can be obtained even after subtracting the electricity needed to run the pump (Fig. 1). A big tank beneath the photovoltaic module was pumped with about two litres of water per minute into a tiny tank above the module. A 1 mm-thick water flow was produced by the 12 nozzles arranged along the top of the solar module and dispersed over the surface of the cell.

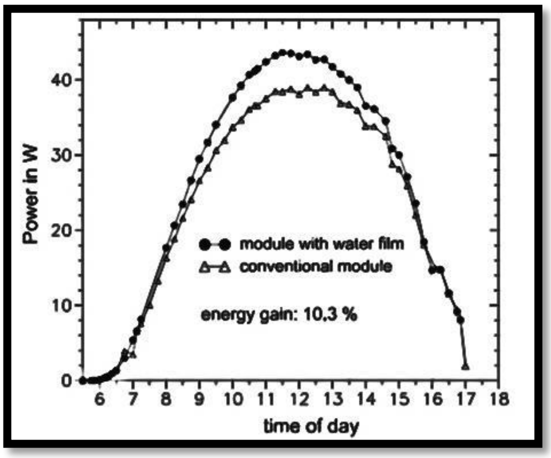

Figure 1. Comparison of output power of the PV-modules during 21st of March 99.

Tonui et al. (2007) [9] investigated photovoltaic/thermal (PV/T) SC that extract heat through forced or spontaneous air circulation. This study explains how to add fins to the air duct's back wall or hang a thin, flat metallic sheet in the centre of an air-cooled PV/T SC to improve heat transmission. A comparison is made with a regular PV/T air system, and the steady state thermal efficiency of the modified systems. The channel back wall, PV rear surface and outlet air temperature profiles are presented to demonstrate how the modifications have enhanced the electrical and system's thermal efficiency. The REF system serves as a datum system and depicts the standard single-pass air duct that is fastened behind the PV module. The TMS sheet twice the heat extraction surface and forms a sort of double-pass structure. On the other hand, the FIN system comprises of fins that have rectangular cross sections (P) that are anchored on the back wall of the air duct and for reasons of convenience, the fins are aligned parallel to the direction of air movement. The FIN system has the highest thermal efficiency across all flow rates, followed by the TMS system and the REF system. Therefore, the changes result in increased heat output for useful uses by improving thermal efficiency.

The study done by **William et al. [10]** revealed that there is need to cool the solar cell because the efficiency of CPV is directly proportional to the cell temperature. It was also shown that the heat pipe cooling system actively cooled the high heat flux waste heat for the CPV cell without using any external power by natural convection. A rear plate holds the solar cell in place. A Fresnel lens roughly concentrates the incoming solar radiation 500 times. When the focused flux hits the solar cell, energy is generated. The saddle allows the waste thermal energy to exit the cell and enter the heat pipe. The heat pipe transfers the heat to a set of fins where natural convection removes it. There was only a 40^{o}C temperature rise from the cell to the ambient due to the heat pipe heat sink's 40 W/cm^2 heat flux, which rejected heat to the environment by natural convection. However, if natural convection from the back plate was to be used the temperature differential between the cell and ambient would be well over 110 ^{o}C.

Experimental research on the micro heat pipe configuration for air-cooling and water-cooling solar panels was conducted by **Tang et al.** (2010) [11]. The authors came to the conclusion that lowering the cell's temperature can significantly raise the solar panel's photoelectric conversion efficiency. When utilising water cooling, the temperature decreased by 8 ^{o}C and the output power increased by 13.9%; when comparing air cooling to a standard solar panel, the temperature decreased by 4.7 ^{o}C and the output power increased by 8.4%.

Souliotis et al. (2010) [12] investigated the architecture and operation of thermosyphon hybrid PV/T solar systems. Well-known solar systems that generate both heat and power include thermosyphon solar water heaters and photovoltaic cells. Photovoltaic modules can produce heat that PV/T systems can use to heat water or air. The silicon photovoltaic modules that make up the PVT/WATER models under study are combined with a metallic sheet that serves as the heat extraction unit and has pipes for water circulation. To prevent water from coming into direct touch with the solar back surface, water is flowing through the pipes. The back side of the PV module is in thermal contact with this heat exchanger device. To reduce heat loss to the surrounding air, the entire device is thermally insulated at the rear and the edges. It is advantageous that solar modules' working temperature is lowered because it maintains a sufficient level of electrical efficiency. From the experimental results of the outdoor experiments, it can be concluded that for the hot water, electricity and thermosyphon type of PV/T systems for domestic use are acceptable.

In order to solve the problem of uneven cooling of solar photovoltaic panel cells and to conveniently manage the working temperature of solar photovoltaic cells, **Ying et al.** (2011) [13] devised and described a heat pipes photovoltaic thermal hybrid system (PV/T). This was accomplished by selecting a wick heat pipe to isothermally absorb the extra heat produced by solar photovoltaic cells. To predict the heat pipe PV/T system's overall thermal-electrical conversion performances, a theoretical model was constructed. The model evaluated the heat transfer process in solar module panels and included the effectiveness number of transfer unit (ε–NTU) approach in heat exchanger design. The ingredients of this theory include understanding the organisms in relation to the first and the second laws of thermodynamics, an experimental investigation of changing associated parameters, as inlet water temperature, water mass flow, packing factor of photovoltaic cell, heat loss coefficient etc., were performed. The overall thermal, electrical, and energy efficiency of the heat pipe PV/T hybrid system might be 63.65%, 8.45%, and 10.26%, respectively. under the working conditions described in this research, according to the consequences. Less than 2.5^{o}C is the working temperature range that the solar cell on the absorber plate can change. The heat pipe PV/T hybrid system is feasible, competitive, and shows promise compared to other traditional systems. Combining the two technologies has allowed for the development of solar photovoltaic systems, which provide higher efficiency and expanded solar energy utilization.

A critical review of photovoltaic–thermal solar collectors for air heating was conducted by **Kumar and Rosen** (2011) [14]. They covered recent developments and a study of (PV/T) technology, mostly as it relates to air heaters. The findings demonstrated that combined photovoltaic and thermal collectors offer more useful energy per unit collector area than do separate systems, and that using a photovoltaic/thermal air heater to preheat air for a variety of uses, such as drying and space heating, is currently or could be feasible in the future. PV/T collectors reject the heat from photovoltaic panels in order to simultaneously convert solar energy into electricity and heat. When combined, the efficiencies of individual solar thermal and photovoltaic collectors are less than the total efficiency of a PV/T collector. While photovoltaic/thermal collectors show promise, further study is clearly needed to increase efficiency, lower costs, and tackle a number of collector-related technical design issues.

Teo et al. (2012) [15] investigated the PV module's active cooling mechanism. Absorption of solar radiation causes a large increase in cell operating temperature, which has an unfavourable effect on PV panel cells' electrical efficiency. The system was designed, developed, and the hybrid PV/T solar system was tested experimentally. In order to achieve active cooling of the solar cells, a parallel array of ducts with an exhaust manifold and an intake for even distribution of the airflow was mounted at the back of the PV panel. We performed trials in the presence and absence of active cooling. A linear tendency was observed in the relationship between temperature and efficiency. The module's temperature was high without active cooling, resulting in an efficiency of only 8–9% for solar cells. On the other hand, the temperature dropped dramatically when the module was operated with active cooling, which increased the solar cells' efficiency by 12% to 14%.

In one experiment, **Loredana and Octavian** (2013) [16] used a monocrystalline solar panel that was continuously cooled by a layer of water that evaporated over the panel's surface. This system's benefits go beyond simply keeping the PV panel cool. It also reduces heat loss due to radiation reflectivity (water's refractive index is 1.3, which is in between glass's 1.5 and air's 1.0), and it can remove deposits like dust or dry that have been left on the PV panel's surface. This cooling system's benefit is that it lowers the temperature of the solar panels while also improving electrical efficiency by minimising reflection loss. The photovoltaic panel's front water cooling system increases the power efficiency by 9.5%.

In his work, **Alami (2013) [17]** investigated the effectiveness of a simple passive evaporation method in controlling the temperature increase which occurs in PV modules due to radiation absorption. This method consists in coating the back of the solar module with synthetic clay and letting a layer of water to evaporate thus, the photovoltaic temperature**.** The output voltage and power increased by a maximum of 19.4% and 19.1%, respectively, in the results, indicating the technical feasibility of the proposed method. Clay is an inexpensive, silent, highly effective, and environmentally beneficial combination.

The water immersion approach was investigated by **Abdulgafar et al.** (2014) [18] in order to increase the solar panel's efficiency. The solar cells' cooling is an important consideration, particularly when building concentrated PV systems. This study examined the cooling of a PV panel by the use of water immersion. This project's goal was to maximize a solar panel's efficiency by immersing it in distillate water at various depths. An investigation of polycrystalline silicon panels was conducted. As the water depth increased, there was a noticeable rise in efficiency. The results were reviewed; at a water depth of 6 cm, thermal drift decreased and solar photovoltaic panel efficiency increased by roughly 22%.

In an experiment, **Ebrahimi et al.** (2015) [19] cooled solar panel cells using natural vaporisation. This study set out to investigate a novel approach to PV cell cooling that makes use of natural vapour as a coolant. A solar cell's performance was evaluated in a sun simulator. Natural vapour enters the PV cell vertically from the rear at variable mass flow rates and distributions. Additionally, an analysis was conducted on the impact of natural vapour temperature on cooling efficiency. The findings demonstrated a sharp drop in solar cell temperature with increasing natural vapour mass flow rate. More specifically, the solar cell's temperature decreased by about 7 to 16 degrees Celsius when the flow rate reached 1.6 to 5 gr.min−1. Electrical efficiency increased as a result, from 12.12% to 22.9%. When low natural vapour temperature, high natural vapour flow rate, and ideal distribution conditions are met, solar panel cells work at their best.

Ibrahim et al. (2015) [20] designed and built a thermosyphon solar PV/T water heating system in Sokoto, North-West Nigeria, where the average air temperature is between 30 and 45 degrees Celsius. The panel gets heated to between 30 and 80 degrees Celsius. A little percentage of the incident solar radiation was converted into electrical power by the photovoltaic surface, which gathered solar energy. The solar cells used the remainder mostly to generate waste heat. A wavering flow heat exchanger was affixed to the back of the photovoltaic panel by solidifying it to a copper sheet in order to remove heat from it. The system was later expanded to include a cold and hot water tank. This allows water to pass from the cold water tank to the heat exchanger, where it heats up and then enters a hot water storage tank via the thermosyphon rule. 63.2^{o}C, 957 W/m^2, 509.5 W, 140 W, and solar insolation were the maximum fluid output temperatures, thermal, and electrical outputs, respectively. In areas with abundant and stable sunlight, this solar water heating device finds practical usage and serves as a renewable energy source.

A study to look into how weather affects solar panel production performance was given by **Al-Showany** (2016) [21]. Two identical 75-watt photovoltaic modules were used in the studies, which were conducted in Kirkuk City, Iraq during the summer under identical meteorological circumstances. One of them served as a standard photovoltaic panel reference module, and the other panel was utilised for all necessary experiments. The solar module was cooled by water circulation, and the impact of dust residue and hot weather on photovoltaic performance was measured using very delicate soil, respectively**.** The findings indicated that while the cooling process contributed to an 11.8% increase in voltage generation across the solar panel, the FF (fill factor) and photovoltaic efficiency had opposite effects with rising temperatures. However, over the course of three months, the natural dirtiness deposition on the front of the panel caused a decrease in voltage output of roughly 3.8% when compared to clean solar panels and 13.8% when compared to panels that were cooled by water.

In an experimental research by **Ammar and Duaa** (2020) [22], the straightforward passive cooling technique of extending the PV's surfaces with fins was used to minimize the device temperature. The impacts of adding varying numbers of longitudinal aluminium fins to a PV panel's bottom surface were investigated in real-world weather scenarios for Baghdad, Iraq. The findings indicate that lowering PV temperature before solar noon will be more successful when using the passive cooling approach under natural convection than after solar noon. With 10 aluminium fins, the highest power improvement of around 2.5 W happened during solar noon. The PV panel with fin cooling had a peak efficiency value of approximately 15.3%, while the PV panel without fins had a value of 14%.

By combining both active and passive cooling systems, **Ephraim et al.** (2021) [23] improved the electrical output of a PV module through experimental study. An aluminum fin heat sink and an ultrasonic humidifier were used to cool the panel by supplying it with moisture for dissipating the heat load. There is the used of the ultrasonic humidifier at the back of the PV module to generate a humid atmosphere. The study's cooling method was able to lower the panel's average temperature by 14.61 °C. The electrical efficiency of the module increased by 6.8% because of this lowering. The cooled panel recorded 12.23 W of power, whereas the reference module recorded 10.87 W on average.

2.2 Numerical Studies

Chow et al (2006) [24] investigated a different method of cooling solar panels. The extruded aluminium alloy box-structure modules that made up the full flat-box absorber were joined to provide a smooth, flat top surface. This 1.64 m^2 aperture collector held a 100 litre thermally insulated water storage tank. Cell conversion efficiency of 14.5% for polycrystalline silicon solar cells operating under typical conditions was employed. The test results showed that a high final hot water temperature in the collector system could be reached after just one day of exposure. A numerical model was also created for this photovoltaic-thermosyphon collector system, and its accuracy was verified by comparing it with data that was gathered. The collector system's energy efficiency was then investigated twice: once using reduced-temperature analysis, and again considering its application in China's "hot summer and cold winter" climate zone.

A computer analysis was conducted by **Hughes et al.** (2011) [25] to increase **t**he efficiency of solar panels. The rate of heat dissipation was calculated by modelling the heat transport from a typical solar panel using computational fluid dynamics (CFD). The distinct climatic conditions of the UAE were accurately reproduced through the use of a case study of a recently constructed green building in Dubai. The purpose of a finned heat pipe arrangement to cool solar panels is to lower their operating temperatures. Low-cost methods are taken into consideration to both decrease and increase the power output of the panels by reducing heat production that would otherwise be lost, as shown in Fig. (2). This paper examined the CFD-analyzed a finned heat pipe performance mounted on the back of a solar panel. The authors suggested and examined ways to increase heat dissipation, which would increase the photovoltaic panel's performance efficiency. The arrangement was constructed as an experimental testing prototype in order to show the CFD modelling and proof of concept.

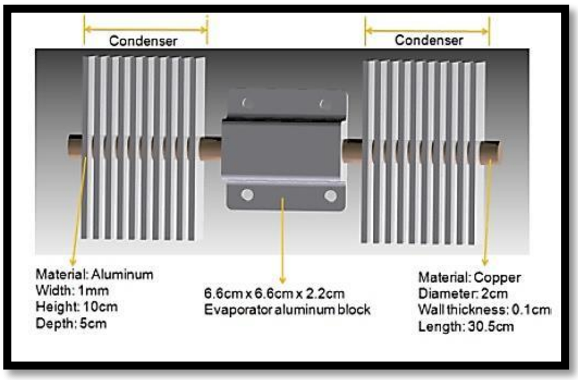

Figure 2. Fin arrangement on heat pipe.

Bahaidarah et al. (2013) [26] investigated a hybrid water-cooled system's performance. The Engineering Equation Solver (EES) programme was used to create a numerical model that is both thermal and electrical in nature. The model forecasts a range of temperature and electrical characteristics that impact its functionality. The cooling effect of mounting a heat exchanger (cooling panel) on the rear side of the module was studied. It was observed that the results of the numerical model are in reasonable good agreement with the experimental data of the climate of Dhahran, in Saudi Arabia. The module temperature dramatically decreased to roughly 20% with active water cooling, increasing the PV panel efficiency by 9%.

Cecilia et al. (2013) [27] conducted a study to look at several techniques for improving the contact between a solar panel and a thermal plate. The goal was to cool the PV panel using water with the intention of connecting it to a heat pump. They thought that a system like this could result in a greater energy efficiency. Both computational and experimental methods were used to construct the analysis, which tested several configurations under various operating environments. The photovoltaic panel was equipped with two aluminium tubes that were cooled by water and fixed to its rear, with aluminium plates situated there as well. Polyurethane foam, polyurethane panel, and plain wood structure (ribs) were the three types of rear side insulation that were used. The best performance was determined to be provided by the wood ribs because they aid in adhering the thermal plate to the PV panel. The impact of changing the thermal plates' and solar panel's contact resistance was also tested through simulation and the results showed that the conductive paste enhances the performance of the PV panel. The findings demonstrated intriguing potential for retrofitting current PV panels with relatively easy fixes, including fastening the thermal plate to the solar panel's back with wooden ribs.

A novel cooling technique was proposed and studied numerically by **Najafi and Woodbury** (2013) [28] using the Peltier effect. This method entailed fixing of a thermoelectric cooling module at the back of a single photovoltaic cell. It has been assumed that the PV cell produces the energy needed to run the thermoelectric cooling module. In order to ascertain the system's temperatures, the thermoelectric cooling module's power consumption, and the additional photovoltaic power produced by the cooling of the solar cells, a comprehensive model was constructed and solved using MATLAB. The results demonstrated that thermoelectric cooling modules might effectively keep the temperature of PV cells low by using a fair amount of electricity.

Rahimi (2014) [29] looked into a number of ways to combine solar and wind power as a renewable energy source for more effectively producing electricity. A conic wind-collecting tunnel served as the model for the laboratory-scale cooling device that was designed and built to cool a solar cell. The wind captured from the conic tunnel was used for two purposes: it was used to power a turbine that was supposed to produce electricity and was also thought of as a cooling fluid for solar cells. The study's main focus was on the suggested cooling device's enormous potential impact on photovoltaic cell performance. The collected results showed that the combined electrical energy generation from the solar cell and turbine boosted the total output power by 36%. The observed results were explained by a CFD modelling based on the MRF approach. By examining the flow distributions in the two modes (with and without the turbine), the impact of the turbine blade was ascertained, focusing on the air flow pattern that was redirected beneath the solar cell under investigation.

A number of water-and air-cooled photovoltaic cooling systems were investigated by **Natale et al.** (2014) [30]. Various parts of construction were examined, including the use of a metal sheet to separate the cooling system from the photovoltaic module, variations in the materials and pitches of the cooling ducts for the water system, and also, more number of ducts for air system. Regarding the water system, the analysis demonstrated that metallic ducts with greater thermal conductivity are required as plastic cooling ducts, while offering significant construction advantages, have poor thermal efficiency. Energy assessments were carried out using the software TRNSYS in order to assess the annual performances simulation code. Five water ducts, solar cooling systems, and the finest specified air and water cooling solutions were all taken into account. According to the simulation results, the performance of the air and water systems was comparable, with mean annual efficiency of 12.65% and 12.58%, respectively, and energy production of 269.53 and 270.93 kWh. Both showed increased percentage efficiency and greater energy production results. A further enhancement may be implemented, namely concerning the ventilation system, in the event that the system was employed in a structure that included integrated solar energy systems. An air or water cooling system added to a typical PV system improved its performance by about 5% a year.

Qureshi (2015) [31] attempted to provide a brief overview of the different cooling techniques and how they affected the PV systems' performance when exposed to increased light. The outcome demonstrated that the system's overall performance increased when it became water cooled. Several researchers have calculated data pertaining to air and water cooled systems; the effects of these systems' various cooling mechanisms and their thermal performance are compiled in table (1).

Study as to the benefits associated with the cooling of solar modules with a rectangular channel form filled with water for the thermal collector were conducted by **Mutombo** (2016) [32]. The behaviour of thermosyphon hybrid photovoltaic thermal (PV/T) under various climatic conditions was investigated in this work. The module's heat was taken from the solar cells using water convection in thermal collector tubes. By using the thermosyphon concept, water was circulated. PV/T behaviour was examined for various environmental characteristics, a numerical model was created, and a simulation of the Durban weather for specific days was done. According to the simulation's findings, the storage tank's water temperature had increased to 37.1 °C. and the PV/T module's overall efficiency was 38.7% as opposed to a conventional PV module's 14.6%. This gives South Africa's hybrid photovoltaic thermal technology marketers a lot of comfort, especially in the summer months.

Samiya et al. (2019) [33] simulated the applicability of heat pipe based passive cooling for solar photovoltaic panel in the building named Eco house of the Higher Colleges of Technology, Oman through CFD. A baseline model consisting of 20 water-filled heat pipes with a 20 mm diameter and a 992 mm length has been assembled and fixed to a 1956 mm by 992 mm solar panel. The results have demonstrated that the integration of heat pipes into PV panels can result in a temperature reduction of up to 9 ^{o}C, using the source temperature of 64.5 ^{o}C (337.65 K). The optimal separation was found to be 50 mm in this investigation, which is 2.5 times the diameter of the heat pipe. Additionally, it acts as a demonstration of the viability of using heat pipe technology to passively cool solar panels in hot climates, (see Fig. (3)).

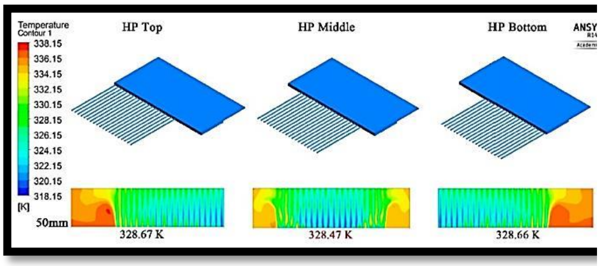

Figure 3. Single sided condenser flow direction HPHE model, distance between tubes = 50 mm, on PV panel.

Sathe et al. (2021)[34] looked at the impact of changing the PV-PCM system's inclination angle. The inclination angle is varied from 15° to 90° at 1000 W/m^2 of incoming solar radiation, all the while keeping the PCM thickness at 30 mm. It has been noted that PCMs can be utilised with PV thermal management systems with success. The PV PCM system's increased inclination angle raises the temperature of the PV surface and shortens the time needed for PCM to melt.

Ahmad and Fatih [35] conducted numerically independent photovoltaic system using PVSYST program. The size of a PV panel and the type of inverter used was decided based on simulation data to meet the load demand Sizing which depends greatly on the location of the site. The performance of the system, losses and detailed configuration diagrams have been generated. PVSYST software data and watt-hour demand have been combined to size and conceptually simulate a PV system. 700 W HJT panels and 675 W si-mono are all modeled for this investigation. The system requires 19 m^2 to install 6 parallel panels, 1 series panel, and 6 total panels. The SV and SF of the PVSYST software are 72% and 93% for the system that uses 700 W HJT solar panels, respectively.

Table 1: Thermal performance of various PVT systems [36].

No.	The variations of the air cooling modes of different systems configurations	Passive Cooling System with Air Based Design ηRth	Air-based photovoltaic system with active cooling ηRth	Different Systems Setting Up Water Cooling Modes	Passive Cooling Water-Based PV System (ηRth)	Active Cooling Water Based PV System (ηRth)	Different System Configurations for Dual Cooling Modes	η*Rth*
1	REF PV/T	16%	25%	Water channel Above PV	33.5% (Thermosyphon effect)	65%	The water heat exchanger is situated above the air channel and below the PV panel.	55%
2	TMS PV/T	18%	28%	Water channel Below PV	-----	66%	water heat exchanger is situated in the chamber where the air is circulated	<55 %
3	Fins PV/T	20%	30%	Sheet and tube design	---------	58%	water heat exchanger is located at the lower side of the air channel	<55 %
4	Air flow over the absorber	----------	Least	Box channel design	----------	54%	PVT/dual-TMS	39%
5	Air flow under the absorber	----------	Better	Spiral Flow Design	-----------	50.12%	PVT/dual-FIN	42%
6	Air flow through the single pass	----------	Excellent (However, more power is needed to provide optimal airflow)	Serpentine Flow Design	---------	32.35%	PVT/dual-TMS/RIB type	44%
7	Air flow through the double pass	---------	Better than all three	---------	---------	---------	---------	------
8	TMS PV/T Glazed	31.6–36.2%,	---------	---------	---------	---------	---------	------
9	TMS PV/T Unglazed	12.2–24.8%	---------	---------	---------	---------	---------	------

3. Conclusions

From the previous sections, most of the reported studies used the different methods to cooling PV panel and enhancing the electrical efficiency. The outcome demonstrated that the system's overall performance rose as it became water cooled. However, the literature on the subject of employing thermosyphon heat pipes to cool solar panels is lacking. According to the previous studies, The ensuing conclusions can be drawn:

1- When comparing the results of all experiments with the conventional panel, the results of cooling photovoltaic panels with heat pipes are acceptable.

2- The effect of temperature is very evident on the voltages more than on the current.

3- The outer wall temperature distribution of evaporator is uniform.

4- Outlet water temperature from water box (heat exchanger) increases with panel temperature increase and with flow rate decrease.

5- Average temperature for conventional panel is 70-more than 80 ^{o}C.

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