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A Review of Recent Photovoltaic/Thermal (PV/T) System Development

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Abstract: *Hybrid photovoltaic/thermal systems have become an essential energy technology since they can produce electricity and heat simultaneously, are easy to install in buildings, and work well overall. Conventional photovoltaic (PV) systems waste energy in the form of heat as they turn sunlight into electricity. It has been established that as the temperature of a PV cell goes up, the panels' efficiency goes down. So, this heat can be reduced to improve the performance of PV. The most frequent ways to get rid of heat are through air and water, and the energy can subsequently be used to heat structures. Over the past 50 years, scientists worldwide have tested, simulated, and used numbers to model many PV/T systems. In addition to water and air, other ways to eliminate heat have been looked at. These include refrigerants, PCM, heat pumps, and nanofluids. This article overviews and discusses the research done over the last five years on the different PV/T thermal control systems. The current study looks at the most essential parts of the various techniques, such as how well they perform overall, their parameters and settings, the type of system, the sort of work, where they were developed, and how they are used. Based on this study, it was decided that PV/T systems are a good idea and that further effort should be made to make them look better so that they are more widely used and their efficiency improves.*

Keywords: Photovoltaic, Thermal, Efficiency, Air-Based, And Water-Based

I. INTRODUCTION

Since the 1970s, one of the most important goals has been reducing greenhouse gases (GHG). This has made people more interested in finding other sources of energy that can help us fulfill our future goals for sustainability and safeguarding the environment. Olivier and Peters (2018) summarized the growth of global GHG in 2018, and it shows that emissions went up 1.3% in 2017 but only 0.2% and 0.6%, respectively, in 2015 and 2016. According to the same report, greenhouse gas emissions today are around 55% greater than in 1990. This tremendous amount of GHG comes from the need for electricity. The International Energy Agency says buildings use 33% of the energy worldwide and release 28% of the carbon dioxide (CO2). About 77% of the energy used in buildings comes from heating and cooling. This includes heating and cooling the area, heating and cooling the water, and cooking. (International Energy Agency, 2019). To help reduce emissions, some governments have promised to use less fuel and more efficient technology and renewable energy sources, such as solar power, instead. Solar power can be harnessed to make electricity or heat using photovoltaic modules or thermal collectors. Installing these devices in buildings can assist in cutting down on the amount of energy used to provide electricity, domestic hot water (DHW), and heat. Solar photovoltaic (PV) is a type of power system comprising a series of connected parts that work together to turn the energy from the sun into electricity, use that electricity, store it, or turn it around (Shubbak, 2019). Over the years, this technology has been one of the first to use renewable energy. Solar PV achieved 480 GW of installed capacity worldwide by the end of 2018, making it the second-largest renewable source of electricity behind wind. (IRENA, 2019). Solar thermal collectors are made to gather heat from the sun. They can be used to heat air or water to heat a building. The sun's rays heat up a liquid that enters a hot water tank. The fluid heats the water, and then flows back to the solar collector. Solar collectors are one of the most cost-effective ways to get energy from the sun. Photovoltaic technology and thermal collectors can be integrated into a single device called Photovoltaic/Thermal (PV/T). This device comprises a PV module and a heat exchanger, and it can produce energy and heat. Since a PV panel's efficiency goes down when the cell temperature goes up, eliminating the

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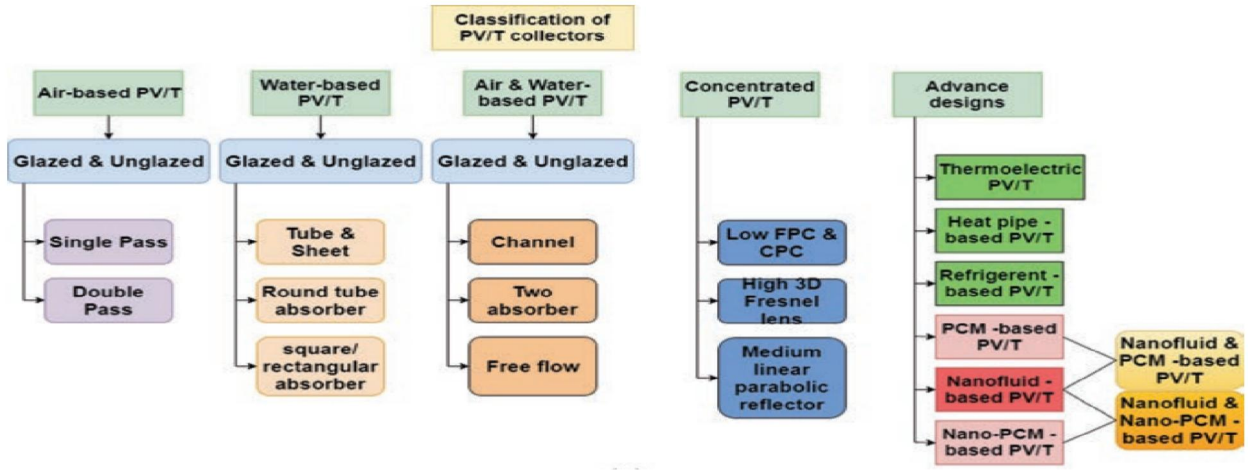
heat from the photovoltaic module by running fluid through the collector keeps the efficiency from decreasing. Combining both technologies solves roof space problems when PV and thermal solar are used separately.

(Dean et al. 2015). Even while non-concentrated and concentrated collectors can be utilized to make a PV/T device, this study will focus on non-concentrating PV/T systems because they are easier to put into buildings. But Singh and Tiwari (2017) and El-Samie et al. (2020) are new studies that have been added. Photovoltaic/thermal devices are an excellent way to use solar energy. Because of this, researchers have been looking at them since the late 1970s, when Kern and Russell (1978) and Florschuetz (1979) studied flat plate, PV/T collectors. At the beginning of the decade, authors like Agrawal and Tiwari (2010), Bhattarai et al. (2012), and Adeli et al. (2012) studied water-based and air-based PV/T systems. These conventional systems were the ones that were reviewed the most in the years that followed. In the last five years, scientists have been working on several configurations of nanofluid, phase change materials (PCM), and heat pump PV/T systems. Recent review papers by Jia, Alva, and Fang (2019), Diwania et al. (2020), and Rukman et al. (2019) give an overview of the different types of PV/T systems listed above. Even though some recent work is mentioned, they all discuss experiments and simulations in the last ten years. This review focuses on the previous five years and is meant to show other researchers what has changed and will change in this technology. The following sections will give a quick appraisal of the state-of-the-art liquid-based, air-based, bi-fluid, refrigerant, heat pump, nanofluids, phase change materials, and concentrated PV/T systems.

II. TYPES OF PV/T SYSTEMS

Over the years, researchers have developed many sorts of PV/T systems. This part looks at some of the most recent changes to the PV/T collector, focusing on how they can be used in buildings as shown in Fig.1.



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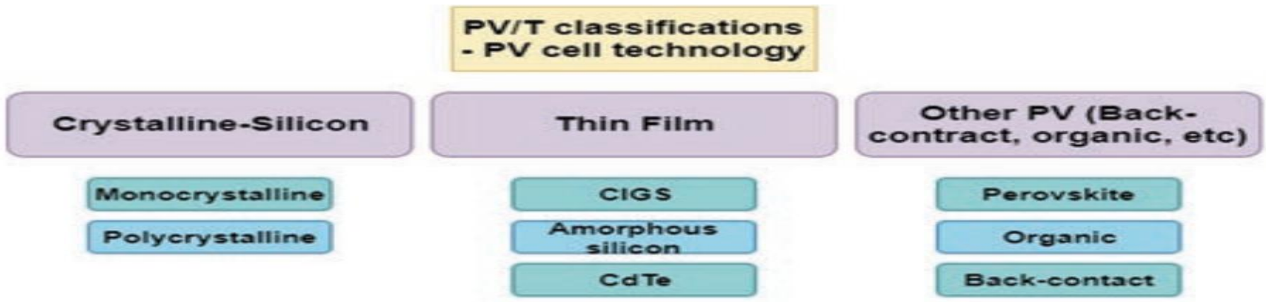

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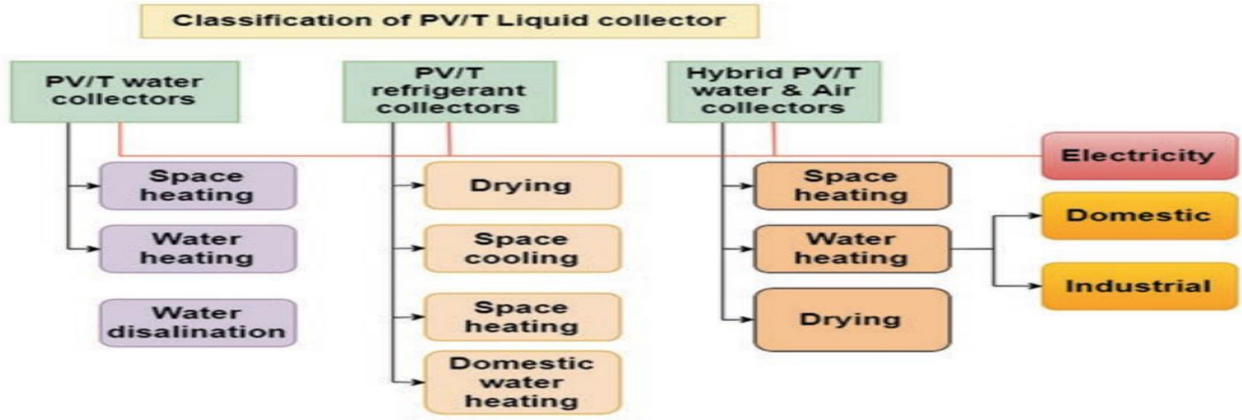

(c)

Fig.1 Classifications of PV/T collectors (a) according to design, (b) according to PV cell technology, (c) according to application.

2.1 Water cooling

Aste, del Pero, and Leonforte (2014) looked at the different parts and configurations of a water-based PV/T and found that this media is more effective since water can hold more heat. This makes it possible to keep the PV temperature stable. Most of the time, researchers have looked at water-based PV/T systems from both a theoretical and an experimental point of view. Most of the time, heated water is used to meet household needs. These studies examined how PV/T may be set up with or without glazing, with or without semitransparent PV modules, partially or entirely covered by PV modules, with or without different coatings, and so on. To simulate a mathematical model in TRNSYS, Aste et al. looked at how well an open PV/T collector worked. (2016). The PV/T comprised an uncovered mc-Si PV module with a roll-bond aluminum absorber, a cylindrical storage tank, a loop for forced water circulation, and a pump. (Figure 2). The test was done over two years in Milan, Italy.

The results showed that the system can have about 15% thermal and 10% electrical efficiency. Shyam et al. (2016) did tests in New Delhi, India, with a PV/T water collector comprising three single-glazed tubes partially covered by semi-transparent PV modules. MATLAB was used to run some simulations with varied sky conditions. The results showed that the total amount of thermal energy used in a year was 3561.9 kWh and that the water in the storage tank could reach 80°C when the sky was clear. He and his colleagues made four experimental PV/T solar systems in 2017 with 0.4, 0.56, 0.7, and 0.82 PV cell coverage. Analyses of the effect of PV cell coverage on the photo thermal properties of a PV/T system showed thermal efficiencies of 58%, 51%, 64%, and 67%, heating 250 L of water to 50°C in 5 hours (matching local demand). It was decided that it is possible to increase the thermal performance of the PV/T solar system by making sure that the PV cells are covered as much as possible. Sainthiya and Beniwal (2019) did tests to see how front surface water cooling affected the performance of a PV/T module in India during the summer and winter. The electrical and thermal efficiency of PV modules with and without water flow in the summer and winter were found using energy balance equations. Every day from 9:00 to 17:00, the required parameters were measured every hour from 9:00 to 17:00. It was found that the difference between the analytical and experimental results was slight, and both showed that water flow on the front side of the PV module dramatically lowered the temperature on the back surface. This makes electricity use 11–14% more efficient in the winter and 9–12% more efficient in the summer. The thermal efficiency was also raised by 22–25% in the winter and 17–22% in the summer. After running a CFD simulation with ANSYS, Misha et al. (2019) looked at an experimental configuration of a PV/T water system in the weather of Melaka, Malaysia. The PV/T system comprised a solar panel connected to two copper absorbers that moved back and forth. (Figure 3). The PV module was linked to a 100-liter water tank attached to the flat plate collector's intake. The outflow of the collector was connected to the heat exchanger, and the cold water was transported to the storage tank. The cold water was piped from the storage tank to the flat plate collector. The average thermal efficiency was 59.6%, and the average electrical efficiency was 11.7%.

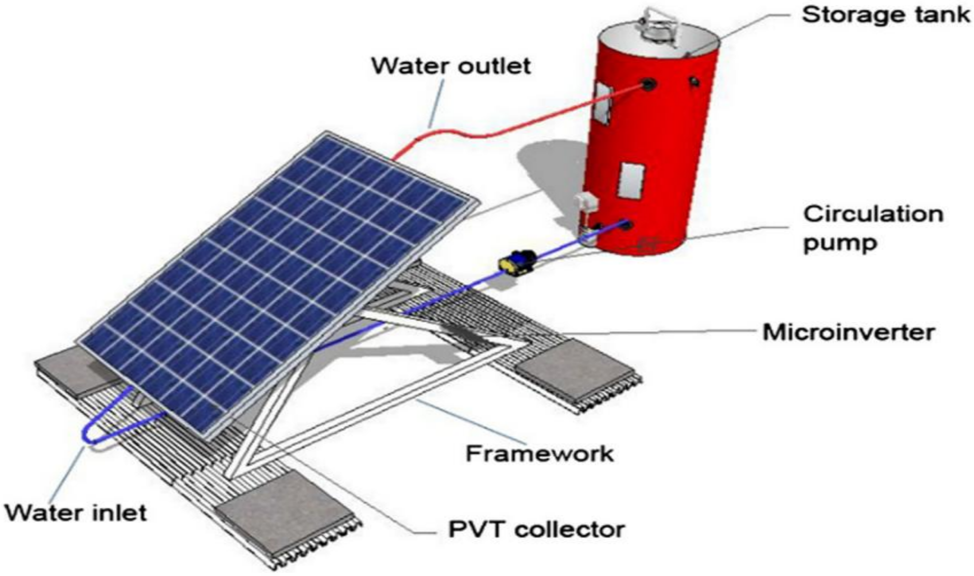

Figure 2: Uncovered PV/T collector configuration (Aste et al. 2016).

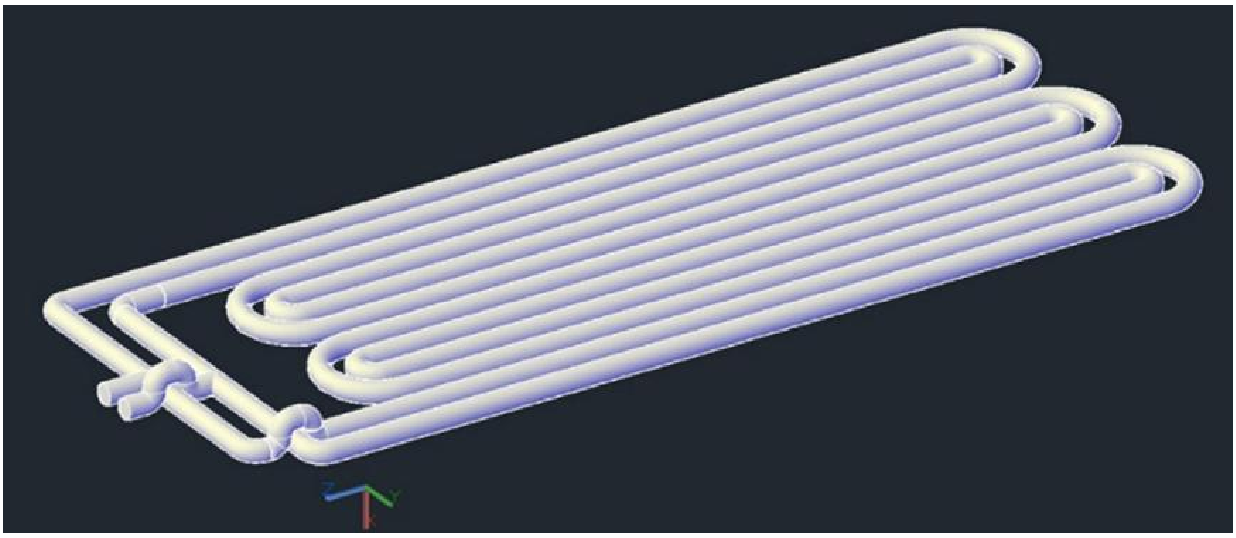

Figure 3: Dual oscillating absorber designed by Misha et al. (2019).

When there isn't much contact between the cooling channel and the PV module, heat also doesn't move. Ma et al. looked at an iron scrap-filled tube-plate PV/T system because of this. (2020). By adding a filling medium, the heat exchange effect of the system was increased since there was more heat transfer between the backplane of the PV plate and the fluid in the tube. The filler material makes the module better at transferring heat. Thus it can be used as a construction material. In this example, iron scraps were chosen as the filler material since they were cheap, could be made from other metals, and had a high thermal conductivity. This experiment used a layer of conductive cement to stick a commercial monocrystalline module and an absorbent plate together. The heat-collecting module, which was packed with scrap iron, was put under it. Figure 4 combines the PV/T system and the iron scrap bed. The filled tube plate had an average electrical efficiency of 15.5% and a thermal efficiency of 65.7%.

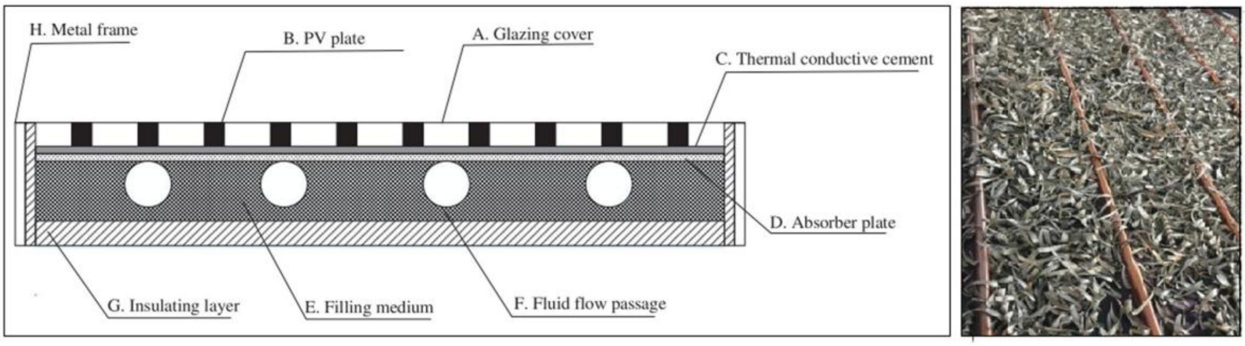

Figure 4: Cross section of the PV/T system and iron scrap filling (Ma et al. 2020).

2.2 Refrigerant cooling

Refrigerant-based PV/T has a high heat transfer rate and good thermal properties. It can be utilized in icy places without concern about freezing, depending on the refrigerant. The collectors can be made as heat pipe-based PV/T systems, where the direct expansion evaporation coils are put under the PV module, and the refrigerant evaporates as it goes through. So, the rings are part of the heat pump that deals with evaporation. The water might evaporate at depths like 0–20 °C. So, the temperature of the PV module would go down. The heat pump's compressor raises the pressure of the vapor made by the module and sends it to where it will be used to heat.

Tsai [52] constructed a mathematical model of a refrigerant-based PV/T-assisted heat pump water heater (HPWH) system and used MATLAB/Simulink software to simulate the performance of the PV/T. Data from experiments done outside were compared to numerical research results. The collector was set up at a tilt angle of 23.5°. The authors employed a model-based control strategy to get the electricity from the PV to flow into the HPWH system. We can see how accurate the model is by comparing the numerical and experimental results. The scientists say that the model-based prediction control strategy enabled the PV to power the HPWH system's compressor. In the end, it was observed that the PV/T efficiency and COP of PVTAHPWH were 86% and 7.09, respectively. The average electrical efficiency was 12.37%, and the average thermal efficiency was 73.90%.

Ji et al. [53] showed a new PV/T-solar-assisted heat pump (PV/T-SAHP) with a specific design of a direct expansion evaporator with PV cells utilized as lamination (thus, PV evaporator) and a thermal absorber. In Fig. 5, you can see how the system is set up. A dynamic model of the system was made with the help of the distributed model approach. Solar irradiance and temperature variables are placed into the model, and the regional distributions of refrigerant conditions emerge. Figure 6 shows the things that go into the model. Experiments were also done to compare the measured data with the anticipated data and prove that the model was correct. The tests were done to see how the weather is in China. Based on the findings of the tests, the heat gain is more than 2500 W from 11 a.m. to 1 p.m. When measured and anticipated values are compared, the results are the same, with a difference of less than 8% between predicted and measured output electricity and PV efficiency. Ultimately, it was determined that the PV and thermal efficiencies were higher than 12% and 50%, respectively. Zhao et al. [54] produced a new PV/e roof module that may be used as a roof part to make electricity and cool a heat pump system. The model comprises flat-plate glazing, photovoltaic cells, a copper plate, an evaporation coil, insulation, and hose connectors for the intake and output. The study looks at the proposed hybrid system's energy profile and how the temperature changes between its layers. Using computer software, a mathematical model shows how energy is transferred, changed, and set up. Experiments from another research project were used to confirm the model. The authors looked into things including the type of glazing, the type of solar cell (monocrystalline or polycrystalline), and how the system works in the UK. The prototype of the system is made up of 10 PV/e modules and a 5 kW heat pump.

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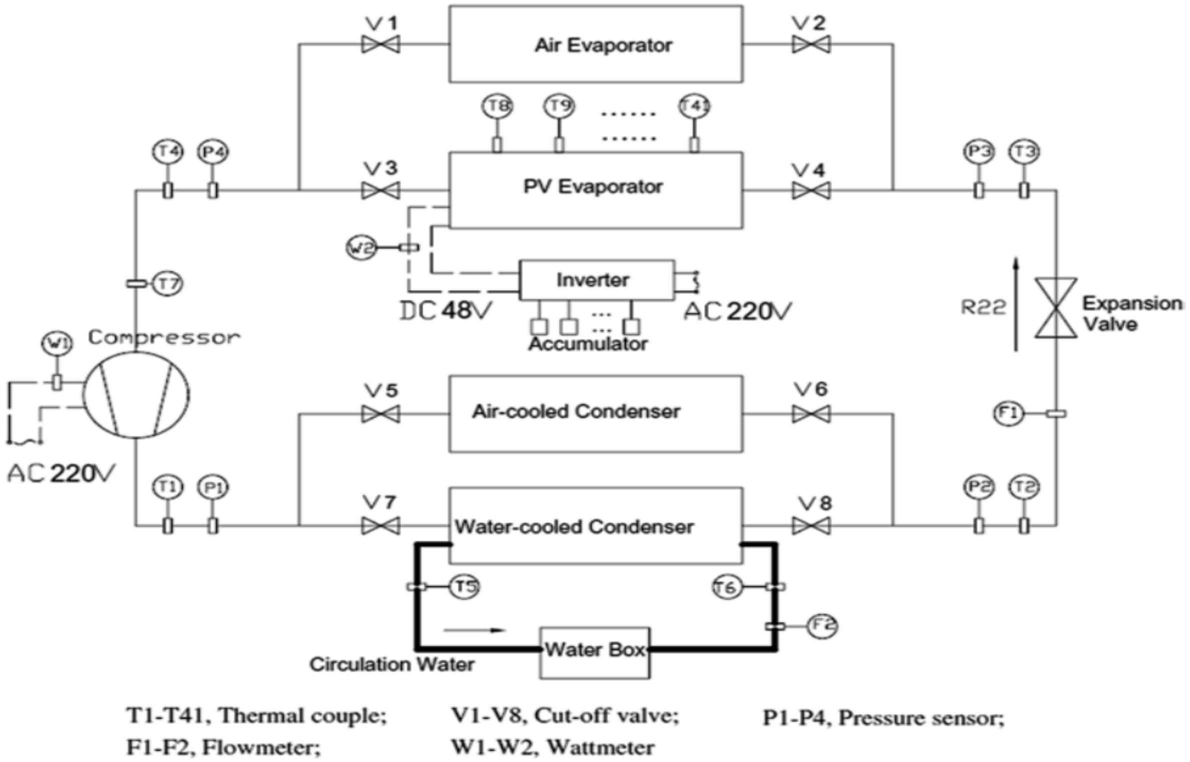

Fig. 5 Schematic diagram of the PV-SAHP experimental setup

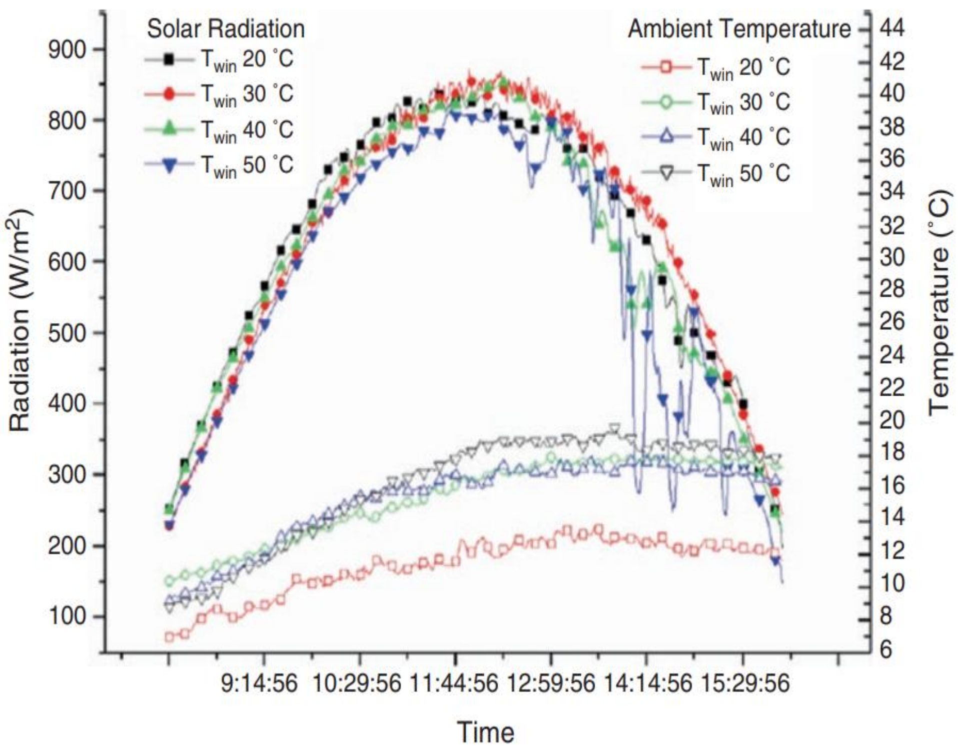

Fig. 6 Daily variation of solar irradiance (referred to as solar radiation) and ambient temperature during the experiment period [53]

2.3 Nanofluid Cooling

Nanofluids are fluids with particles the size of a nanometer, called nanoparticles. Most of the time, these nanofluids are made of metals, oxides, carbides, or nanotubes made of carbon. They have better thermal conductivity and convective heat transfer coefficients than the base fluid. Nanofluids are a new technology used in PV/T systems to improve thermal management and increase overall energy production. Rejeb et al. (2016) looked at the performance of a monocrystalline silicon PV unit illustrated in Figure 7, employing nanoparticles of $Al_2 O_3$ and Cu at varying concentrations (0.1, 0.2, and 0.4 wt%) and ethylene glycol and water as base fluids. The numerical model was made using the FORTRAN programming language. Experiments were done to mimic the weather in Mashhad, Iran, from 9:30 to 15:30 on the last day of September. It has been seen that as the number of nanoparticles increases, the specific heat of the nanofluid goes down. The results showed that CuO/H_2O at 0.4 wt% had the best thermal performance (76.88%) and electrical efficiency (13.5%).Hamdan et al. (2017) did experiments to see if controlling the temperature with nanofluids may increase the performance of PV. One of the modules was used as a baseline. The second module utilized water to cool it down, while the third module employed nanofluids. The main idea behind using nanofluids is that they will remove more heat from the PV because they are better at transferring heat than water. Because the solar cell is cooled more efficiently, it will produce more power. There were different amounts of Al_2O_3 and CuO utilized. Al_2O_3 and CuO cooled best when their concentrations were 0.4% and 0.6%, respectively. For cooling with water, Al_2O_3, and CuO, the increase in electrical efficiency was found to be 11%, 20%, and 23%, respectively. The results showed that using nanofluids to control the temperature of a PV module will make it work better electrically. Samylingam et al. (2020) used COMSOL to study the thermal performance of a PV/T system with a heat transfer fluid made of MXene ($Ti_3 C_2$) suspended in pure olein palm oil (OPO). It was seen that this nanofluid increases thermal efficiency, enhances heat transmission, and lowers the temperature of the PV. Six different amounts of MXene-OPO were employed for the study: 0.01%, 0.03%, 0.05, 0.08, 0.1, and 0.2 wt%. The calculations revealed that a concentration of 0.2 wt% with a flow rate of 0.07 kg/s has the best thermal and electrical performance (79.13% and 13.8%, respectively) in the 25–70°C. It was also noticed that this concentration made the viscosity less, meaning less pumping power was needed. Rubbi et al. (2020) made a nanofluid out of particles made of soybean oil (SO) and MXene ($Ti_3 C_2$). With concentrations of 0.025, 0.075, and 0.125 wt%, the numerical study was done in COMSOL. This study found that a 0.125 wt% attention of MXene-SO is superior to the 0.2 wt% concentration of MXene-OPO that Samylingam et al. looked at. (2020). Compared to MXene-OPO, MXene-SO was 12.11 percent better at removing heat. This was because MXene nanoparticles and soybean oil as a base fluid were better at moving heat than palm oil. At a mass flow rate of 0.07 kg/s, it was found that the thermal efficiency could be as high as 84.25%, while the electrical efficiency was only 14.20%. (Figure 8).

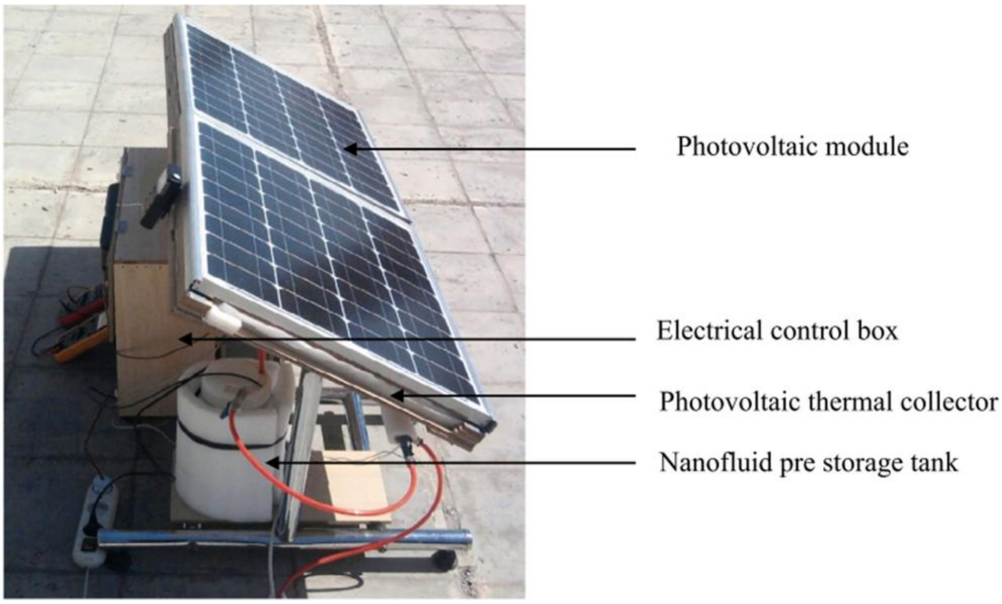

Figure 7: Experimental setup of the PV/T system studied by Rejeb et al. (2016).

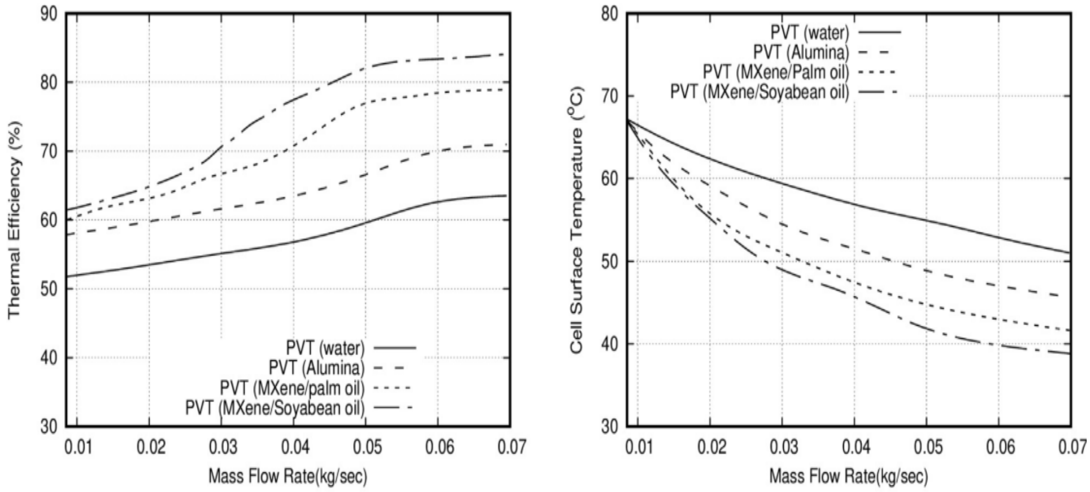

Figure 8: Performance evaluation of the thermal and electrical efficiency of a PV/T system studied by Rubbi et al. (2020).

2.4 Studies on Air-Based PV/T

The fluid that moves around or does the work with these collectors is air. It works best for hot air applications, like drying, etc. The main benefit of utilizing air instead of water is that it is cheaper, less likely to freeze or boil, and less likely to cause harm if it leaks. The problem with these collectors is that their thermal performance could be better than water-based or other liquid-based PV/T systems. This is because air has a lessened heat capacity; thus, less heat is transferred when it moves through the tubes or pipes. Also, the air is not very dense, so it has a far more enormous transmission volume than liquid or water-based forms. Since more capacity is needed, the pipes or tubes would be more significant, which means they wouldn't work well in compact spaces and wouldn't look good either. Even with these problems, it is still a good choice for systems that need to heat air and have reduced prices. Ahn et al. [35] showed an air-type PV/T collector to help a heat recovery ventilation (HRV) system. The PV/T is used to heat the air before it enters the HRV system instead of letting outside air in. The authors say that combining the two technologies should improve ventilation. Experiments were done on the system in a building using a 1 kW array of four air-based PV/T collectors positioned at it has a 30° tilt and faces south. To show the difference between a traditional HRV system and a PV/T-assisted HRV system, the authors devised OA mode and PV/T mode. In OA mode, outside air is fed directly into the HRV, while in PV/T mode, the air from the PV/T outlet is fed into the HRV. The study's results suggest that the heat transfer efficiency of the HRV system was 80%. The authors say that the heat transfer efficiency was enhanced by about 20%. Also, the thermal and electrical efficiency of the PV/T collector was 23% and 15%, respectively. So, the study concludes that putting an air-based PV/T collector into an HRV system makes it work better. Hu et al. [36] developed an ETFE (ethylene tetrafluoroethylene) cushion roof-integrated PV/T system that uses air as its working fluid and then tested it in the lab. Figure 9 demonstrates the way the system is set up. The tests were done. They were made over 8 months, and each day has about 6–7 hours of work. It was determined that the system worked smoothly and steadily. Also, the performance test was done over 4 days, including both summer and winter. The authors stress how important it is to choose days with clear skies. The process for the experiment was broken up into three primary phases. First, connect the batteries to the PV module and blow on the solar controller.

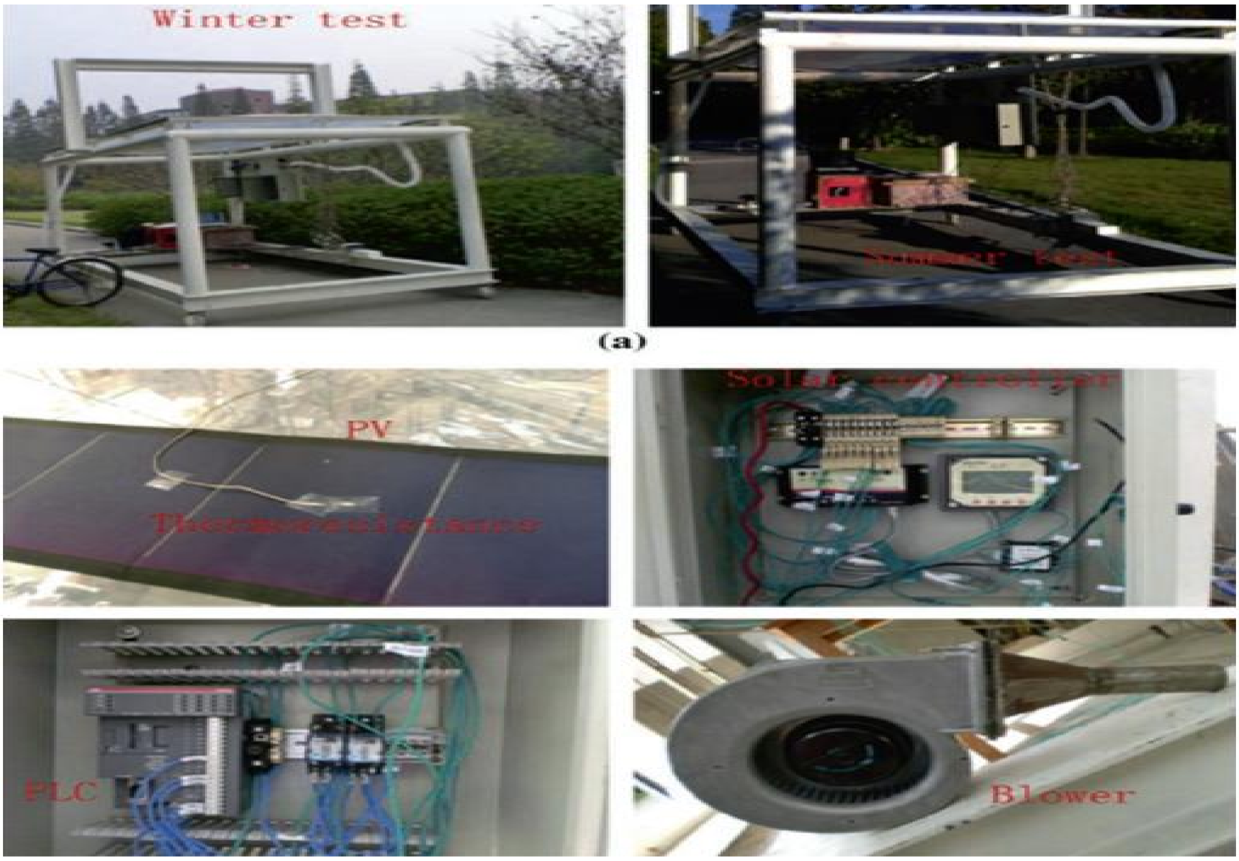

Fig. 9 Photographs from the experiments (a) test mockup (b) equipment [36]

2.5 Studies on Air- and Water-Based PV/T

Through distinct channels (called "dual channels") or pipelines, air and water could be used at the same time. Another way is to run the collector in either water- or air-only mode, depending on the time of year. The air-based and water-based PV/T collectors are handy since they have a higher cooling rate and can heat air and/or water. The biggest problem with this kind of system is that it is hard to understand and has extra costs and space because it has more than one pipe or channel. Also, more money must be spent on pumps (for the water) and blowers/fans for the active parts. (For the air). Su et al. [49] studied PV/T collectors with two channels so that different fluids might be used. Figure 10 shows the collector. Comparing the use of (1) air-air, (2) air-water, (3) water-water, and (4) water-air-based PV/T in terms of electrical and thermal properties helped find the best fluid combination. Such as how much power is made, how hot the fluid comes out, how efficient it is, etc. This was proven by making a collector with a glass cover (top layer), flow passage (for either air or water), solar cells, backplane, flow passage (for either air or water), shell, and flow passage (for either air or water). (Lower outer layer). The study makes a mathematical model of the system and then runs simulations based on that model. The simulation's results are checked against experimental and numerical work from another study. The survey results demonstrate that employing the PV/T cooled by water helps heat water better. For air-water, the temperature of the water was the greatest, while the air-air-cooled PV/T made the hottest air. According to the research, the influence of mass flow rate on the overall efficiency of the water-water-cooled PV/T is that it increases the efficiency value. The authors also showed that increasing the height difference between the upper and lower pipes makes the system more efficient. With a mass flow rate of 0.15 kg/s and a height ratio of 3:1, the water-water-cooled PV/T has an electrical efficiency of 7.8% and a total efficiency of 83.4%. Figure 11 shows the thermal power for each arrangement of the working fluid. Jarimi et al. [48] did a 2D steady-state thermal modeling of a new PV/T collector that utilized air and water as working fluids. The collector mainly comprises a finned air collector and water-based tubes and sheets. The water will flow through pipes and stand between the lines (at the top part) and the fins. (lower area). The standard operating condition (NOCT), given by the manufacturer, is used to validate the thermal model without working fluids. But for the cooled model, the results are confirmed by research done in the past, and the collector model is then simulated. Under irradiance levels of 500 W/m2 to 800 W/m2, the average temperature of the PV cells was anticipated to be 20, 16, and 14 °C for water and air, only water and only air, respectively. Theoretically and in the literature, these results show that air has the most negligible cooling impact, followed by water, and then using both air and water simultaneously. It was revealed that the PC cells work better when kept at a low temperature. So, it was thought that the overall energy efficiency would be 40% greater because the thermal component would cover the whole area of PV. The authors say it is helpful to use the hot air and water to pre-heat the water for fish breeding and other uses like drying clothes and getting hot water.

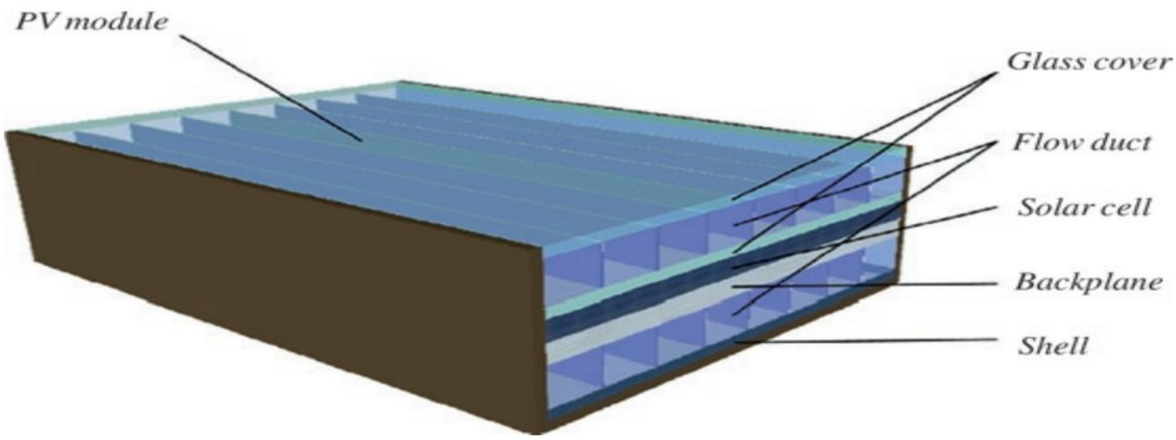

Fig. 10 The schematic diagram of the PV/T collector with dual channels [49]

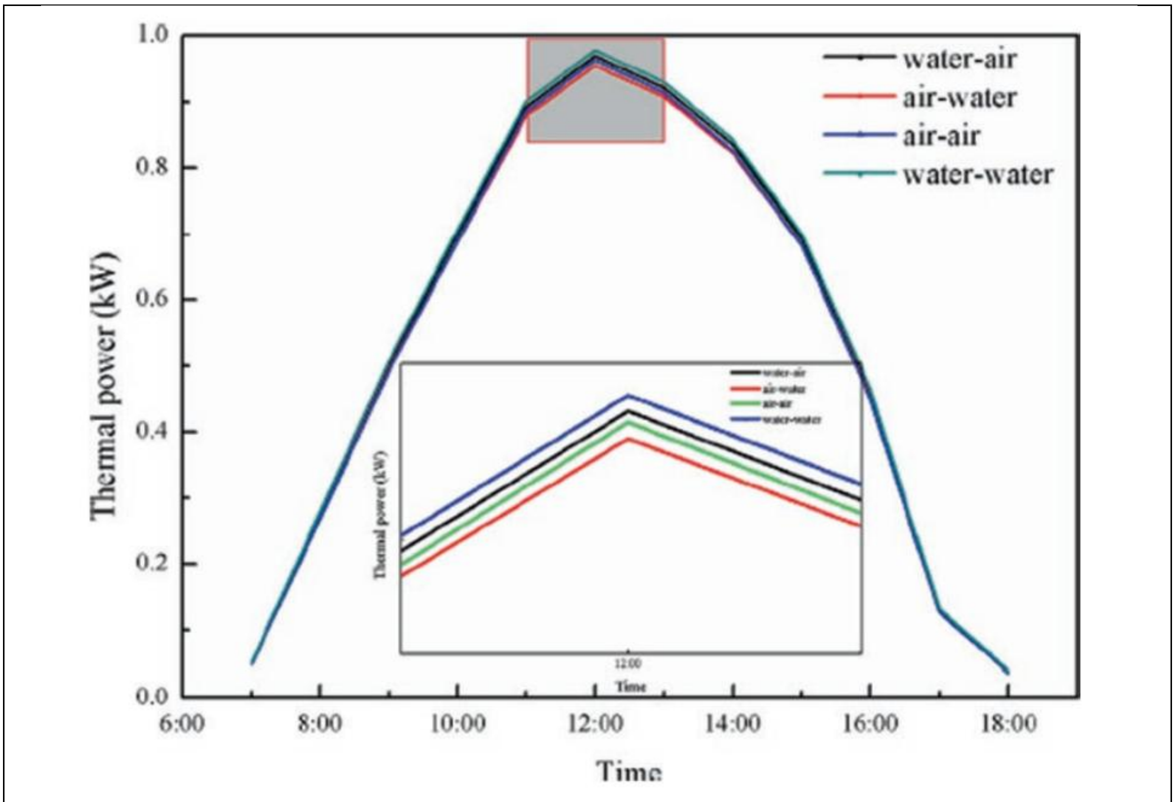

Fig. 11 The hourly variation of thermal power corresponding to different working fluid configurations [49]

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2.6 Concentrated PV/T Systems

Using reflectors, these systems focus the sun's light on a PV receiver. CPV/Ts can sometimes get as much sunlight as 100 suns, and they need more Some of the complicated parts are dual-axis tracking and PV cells with more than one junction. A cooling fluid usually moves in a closed loop between the PV receivers and a heat exchanger. As long as there is a significant demand for heat, CPV/T systems can have an overall efficiency of up to 80%, collected as electricity and heat. PV/T collectors are helpful because they use reflector material, which is less expensive than PV panels. This means that pricey PV panels may be replaced with less expensive reflector material, which lowers the overall cost of the system. Due to the high temperatures, which might damage PV cells, it is essential to have stable cooling. Some CPV/T designs have an extra power-making cycle, like the Rankine cycle, that uses additional thermal energy. Singh and Tiwari (2017) examined how well basin-type solar stills worked when combined with N identical partially covered CPV/T systems. The influence of water depth was taken into account. Solar distillation is a way to extract water from the sun. Using heat energy, you may make drinkable water out of salt water. Figure 12 illustrates a diagram of how the system works. It can be seen that 25% of the N identical CPC water collectors have PV/T on them. The single slope active solar still featured a 2 m × 1 m basin manufactured of glass-reinforced plastic with a clear glass cover. The inside surfaces were painted black to absorb as much sunlight as possible. The best mass flow rate was 0.04 m/s, while the best water depth in a single-slope basin was 0.70 m, and 0.31 m in a double-slope basin. El-Samie et al. (2020) used finite volume CFD to predict the optical, thermal, and electrical performance of the low CPV/T collector, and the results were confirmed using the Monte Carlo method. Way of tracing rays. The authors examined different coolants and heat sink designs (U-type and Z-type). (water, ethylene glycol, and Therminol VP-1). It was observed that changes in irradiance significantly affect electric performance, but that high thermal efficiency of 48–51% may be reached at any time of day. The temperature of the PV cell was observed to drop more with the Z-type heat sink than with the U-type. The water-cooling system was the most efficient, with an average thermal efficiency of 48.8% and an average electrical efficiency of 7.1%.

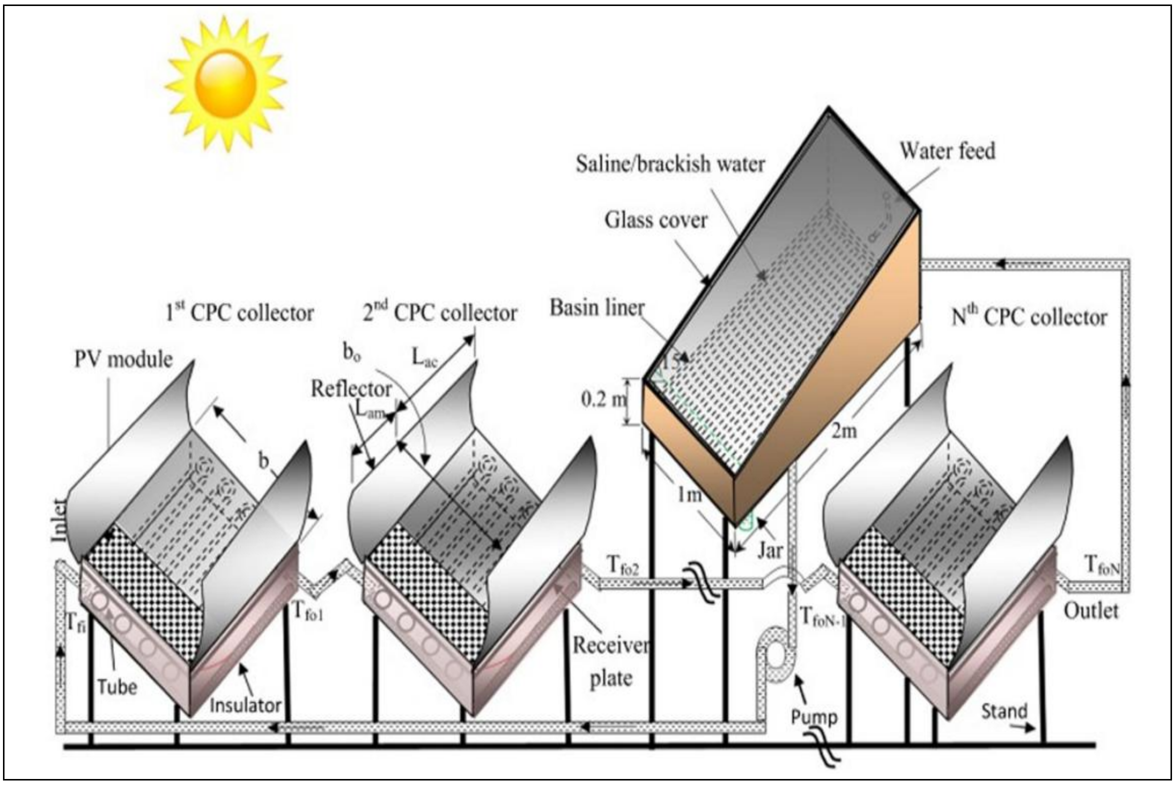

Figure 12 Diagram of a single slope active solar still partially covered by CPV/T (Singh and Tiwari 2017).

III. CONCLUSION

Compared to standard solar modules, PV/T systems are more efficient in both heat and electricity. You can get more energy overall if you put PV/T collectors on your roof instead of individual photovoltaic modules and solar thermal collectors. In the scientific literature, indoor studies with PV/T collectors show higher efficiency than outdoor experiments. Refrigerant-based, air- and water-based, and water-based PV/T systems have the highest total efficiencies. Air-based PV/T systems have the lowest real efficiencies. Most of the time, electrical, thermal, and overall efficiency increases as solar irradiance increases. But even when there is a lot of sunlight, the collector's efficiency will go down if the heat transfer isn't enough to lower the temperature of the PV module or if something else goes wrong in the process. Then, a rise in solar irradiation will likely have the opposite effect. When the mass flow rate increases, heat transfer between the PV module and solar thermal collector usually improves overall. This means the electrical, thermal, and total PV/T efficiencies improve. Nanofluids have more excellent thermo physical capabilities for transferring heat than pure water or regular fluids. The thermal conductivity of the nanofluid goes up as the volume percentage of nanoparticles goes up. This means the overall heat transfer between the PV module and thermal absorber also increases. There are two ways to compare the performance of different PV/T systems: on an equal Reynolds numbers basis or an equal pumping power basis. When nanoparticles are mixed into phase change material (PCM), the PCM's thermal conductivity increases, and its recovery time decreases. The performance of the nanofluid and nano-PCM-based PV/T system is better than that of the traditional PV and nanofluid-based PV/T system.

IV. RECOMMENDATIONS

Photovoltaic-thermal (PV/T) collectors need a global standard for designing, testing, assessing, and installing them because there is yet to be an agreement on how long trials should last, how testing should be done, and what range of mass flow rates should be To do further long-term studies on PV/T collectors to find out things like how long the PV module will last. Since thermal stress causes PV modules to break down and PV/Ts help reduces this stress, it is best to evaluate a PV module's power yield, energy, and efficiency over lengthy periods. To learn how different geometries and base fluids work with the same geometries to understand more about how PV/T designs parameters affect performance. Most of the research written about is of natural systems that can be used immediately and have active parts. Most people must discuss controlling or connecting these parts to a thermal load. Types of valves, connecting parts and their materials, and the controller (if there is one) should also be discussed regarding how much power they need and how they are made. In the realm of PV/T, most studies don't look at pressure drop and pumping power requirements. It's best to work using metrics to aid a complete system evaluation. In indirect systems, you should also talk about the sort of heat exchanger and how effectively it works. This is because it can help people see how hot the water is before they use it, and it can also help other researchers find the best type of water for their studies, which will improve the field. To learn more about how improved nanofluids can improve the way the PV/T collector transfers heat. This will contain things like magnetic nanofluid and Boehmite nanofluid. To determine how stable nanofluids are over time when utilized as working fluids in PV/T systems.To figure out how many cycles of melting and hardening nano-PCM can handle.To determine if the advanced type of PV/T systems in the literature are possible and their life cycle costs. Even though they are pretty effective, you must look at their expenses and how they affect the environment.

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