RECENT TENDENCIES IN PV/T SYSTEM PERFORMANCE – A REVIEW

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Abstract: The capacity, performance and ease of photovoltaic/thermal systems in producing at the same time electricity and heat have made this technology one of the most significant in terms of energy, worldwide. In the past years, researchers have focused their work on obtaining new configurations of hybrid PV/T systems that are sustainable, solve problems related to the space on the roof of buildings, lead to reduced emissions of greenhouse gases (GHG) and protect our natural environment by using renewable resources. This paper presents the recent trends of hybrid PV/T systems and their performance. Also, the thermal and electrical efficiencies are indicated for each studied article.

Keywords: photovoltaic, thermal, hybrid systems, performance, efficiency, technology

1. INTRODUCTION

Due to the high intake of fossil fuels around the world, various matters have arisen related to depletion of the ozone layer and environmental pollution, all heading to a global warming. These effects have led to an increase in the demand for energy obtained from renewable sources worldwide [1, 2].

Hybrid photovoltaic/thermal systems have the capacity to produce both electricity and heat at the same time, being easy to integrate into buildings. The generation of energy waste, in the manner of heat through the conversion of solar energy into electricity, leads to a lower performance and efficiency of the panels, their optimization being achieved by removing the excess heat. The achievement of this objective is done using heat, water or air transfer fluid as common media, refrigerants, nanofluids, PCM and heat pumps. The resulting energy in the form of heat can be useful in applications for heating residential homes, buildings, industrial halls, etc. [3].

Over the past fifty years, researchers around the world have been conducting on different types of PV/T systems, both experimental studies and simulations, numerical modeling and heat removal methods. At the same time, a number of important points of the techniques are researched and highlighted: the type of system, the general efficiency, the parameters and configurations, the applications in which they are used, the country where they were developed [3].

The photovoltaic/thermal assembly can be classified according to different parameters of the system such as: the design of the absorbent plate and the fluid flow systems, the natural circulation, the forced circulation, the passage (single-pass, double-passing), the number of channels, etc. [4].

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Using an optimal design for these hybrid PV/T systems, that produce both electricity and heat, which is 100 % from renewable sources, can be supplied to the buildings and thus the international objectives regarding the large-scale deployment of renewable energy in the built environment can be met.

This review is based on the search of the words "PV/T" in the database of "Web of Science". The search resulted in a total of 33000 published articles. The period of 2020-2022, chosen for this article, results in a number of 6623 published articles. A new search of the keyword "performance" for the chosen period, between 2020-2022, resulted in a number of 1770 articles published as follows: 753 published in 2020; 800 in 2021 and 217 for the first five months of 2022. All 1770 articles have been studied individually and a number of 22 articles have been selected to be presented in this paper, articles in which studies on increasing the performance of hybrid PV/T systems are presented. The graph with the number of written publications for the chosen period is shown in Figure 1 [5].

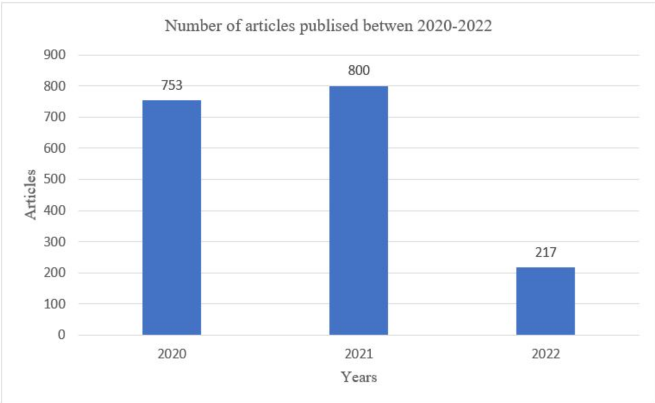


Fig. 1. Number of articles published between 2020-2022.

Figure 2 shows the annual percentage of the total number of papers published over the whole selected period (1770) following the search of the keyword "performance". It can be noted that in 2020 the percentage is 42.54 %; in 2021 it is 45.19 % and in 2022 for the first five months (January-May) it is 12.25 % [5].

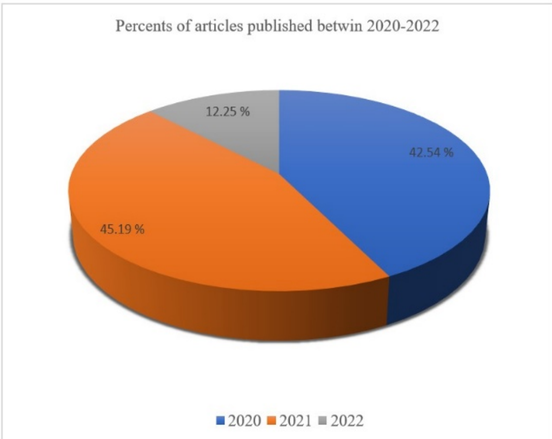


Fig. 2. Percent of articles published between 2020-2022.

In Figure 3 we observe a classification of the different methods and techniques to augment the performance of the hybrid PV/T systems studied, which increase their yield and efficiency [5].

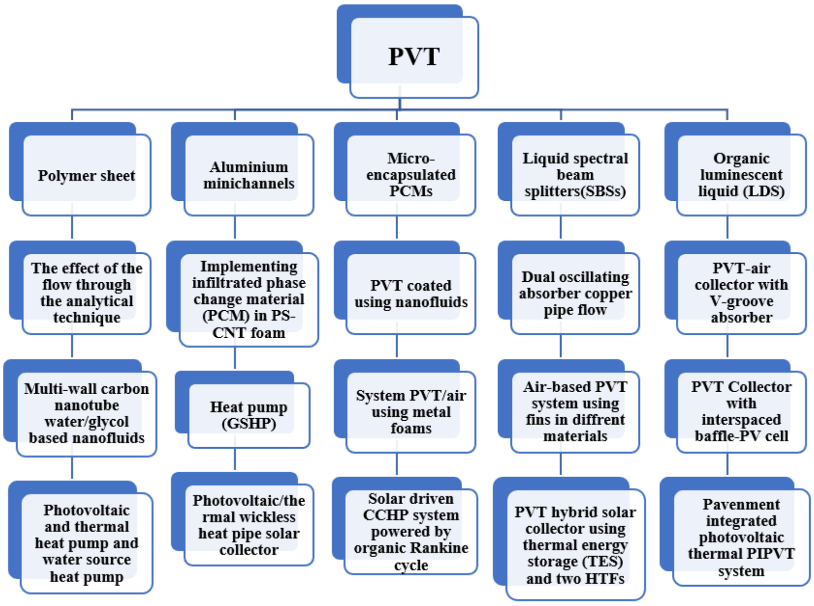


Fig. 3. Methods to augment the performance and efficiency of the PV/T hybrid systems.

2. STUDIES AND METHODS USED TO ENHANCE THE EFFICIENCY OF HYBRID PV/ SYSTEMS

Rohan Kulkarni and the research team have made a comparison between a normal PV equipment and a manufactured PV/T hybrid system. The PV panel used for this work is polycrystalline, model YL300P-35b, and was used in the construction of the new PV/T hybrid module for comparison consisting of five layers, one of them being a polymer sheet. Temperature measurement sensors LM-35 and DS18B20; current measurements sensor ACS712 and irradiation measurement sensor BH1750 were used. The electrical parameters along with other necessary data were recorded using an ArduinoMEGA2560. As a result of the experiences of electrical and thermal efficiency evaluation, an improvement in the performance of the PV/T panel in comparison to the normal one can be observed. The value of this electrical efficiency is 2.17 % better than that of the normal solar panel [6].

To reduce the costs of PV/T modules, the team formed by Bennett Widyolar and his collaborators, developed a prototype solar collector with solar cells build out of silicon Sun Power, with a low price and highly thermally efficient mini-channel from aluminum. Thus, the traditional packaging materials and the heat exchange materials were replaced with sheets and tubes. As a result of the experiments carried out on the new type of collector, researchers obtained an electrical efficiency of 12.3 % and a thermal efficiency of 57.4 % for the ambient temperature [7].

In the study conducted by Zaiguo Fu and Yongwei Li together with the other team members, they designed and experimented with a PV/T system that has as a PCM (phase change material) microencapsulated, an MPCM suspension as cooling medium and liquid paraffin for encapsulation. As a result of indoor and outdoor experiments, electrical and thermal efficiencies were compared using MPCM slurry (water mixture with fine particles of suspended mineral substances), or water, under different conditions. The result was an increase in thermal efficiency by 13.5 % and in average electrical efficiency by 0.8 %. The MPCM suspension, with a low concentration, can improve the PV/T solar system's performance [8].

James Walshe, Pauraic Mc Carron and Sarah Mc Cormack studied for hybrid PV/T applications the qualities of new organic-based fluids like fluorescent, optical and thermal. The combination of a PV/T hybrid system with liquid SBS (liquid spectral beam dividers) leads to an improvement in control for electrical and thermal components regarding the solar spectrum, efficiency and economic viability. The study may be an alternative by using newly advanced fluids including organic imidazo [4.5-f] and organometallic as phenanthroline derivatives [1.10] (heterocyclic organic compound) for PV/T-SBS systems. The results showed a 63 % increase in optical efficiency, resulting in an improvement over PV technology of 18-20 % and an augment in the economic value of the captured energy by up to 61 % [9].

The work treated by Gowtham Mohan, Levi Reyes Premer and Behnam Roshanzadeh, refers to a hybrid solar photovoltaic/thermal collector that simultaneously produces electricity and domestic hot water (ACM) that has a positive influence on environmental oppression through low carbon emissions. In order to enhance the thermal efficiency, this research relies on the encapsulation of the glass tube in a vacuum, thus achieving a minimization of convection losses in the system. Following the tests that were simulated in ANSYS 18.1, the result showed an increase in thermal performance for the proposed system and a thermal efficiency with a value between 64-67 % at different solar irradiances. The electrical efficiency had values in 14.2-16.7 % interval [10].

The performances of a flat water-based PV/T system are studied by a team consisting of Emmanuel Ramde, David Quansah and Saeed Abdul-Ganiyu, through the effect that mass flow has on performance in a tropical environment. Also, they studied the electrical and thermal performances for different mass flow rates with values between 0.025kg/s and 0.083kg/s. At an increase in the mass flow rate above the value of 0.082 kg/s there were no important changes in the temperature of the module. The system assessed showed, at a mass flow rate of 0.033kg/s and regardless of irradiation, a constant exergy efficiency of 12.75 %, a thermal efficiency of 38.8-43.1 % and an energy saving efficiency over 50 % [11].

To investigate the electrical and thermal performance, Rouhollah Ahmadi, Farhad Monadinia and Mahdi Maleki, conducted experimental studies of active and passive cooling for a PV/T system observing their impact in a solar simulator. For these experiments they used a passive PCM cooling system infiltrated into a heat-conducting foam, a special PS-CNT foam. Two cooling methods are used to carry out tests and determine electrical and thermal efficiencies, one active and one passive. The gathered data showed that the PCM cooling system can lower the cell temperature by a value of up to 6.8% and increment electrical efficiency by 14 % [12].

Mohamed Hissouf and his collaborators examined the effect on the PV/T performance of alumina (Al_2O_3) and copper (Cu) nanofluids dispersion in clean water. In order to obtain satisfactory results, the mathematical model according to the balance equations was established and a numerical model was verified and validated, comparing the data from the current study with information obtained in previous researches. Comparing the two nanofluids, research has shown that the use of Cu-water, a better performance of the equipment is observed than using the nanofluid that has Al_2O_3 in its composition. If copper nanoparticles are used in a 2 % volume fraction it will increase the thermal capacity of the hybrid system. The thermal and electrical capacity of the water nanofluid has been improved with values of 4.1 % and 1.9 % respectively. An increase in maximum thermal and electrical power of the system tested could be observed after 14 hours [13].

The study developed by Amira Lateef Abdullah together with a group of researchers of a PV/T system based on water refers to a new flow of copper pipes that have a double absorbent. The data and studies obtained experimentally were introduced in MATLAB and discussed. A comparison of the outcomes between the new double oscillating absorbent of the PV/T system and the simple PV system is made. The tests carried out resulted in a series of data on the maximum electrical efficiency that reached a value of 11.5 %, the maximum thermal efficiency obtained was at a value of 58.64 % and the total efficiency equal to 66.87 % [14].

The research team's paper consisting of Rajeev Kumar, Sanjay Agrawal, Anwar Siddiqui, and Sourav Diwania examined the capacity of an air PV/T collector that has a V-channel absorbent in real-world climate conditions of India. In order to settle and solve the energy balance equation and the temperature equations, a matrix reversal method was developed. After obtaining the experimental results, a comparison was made between them and the theoretical results that were obtained by modeling. Thermal efficiency valued in the interval of 41.78-41.57 %; electrical efficiency had a range of 10.39-10.26 % and overall efficiency in the 52.21-51.81 % interval [15].

The investigation of the effect of the PV/T/PCM system by adding paraffin wax (PCM medium) as a passive coolant and MWCNT (multi-walled carbon nanotube) as an active coolant to the base fluid has been investigated by the team consisting of Ali Naghdbishi, Mohammad Eftekhari and Ghasem Akbari. The energy and exergy performances were evaluated and compared with the results attained from a PV module that does not have a thermal collector. By dispersing in the base fluid nanoparticles of MWCNT, an increase in energy efficiency is achieved, both thermal efficiencies up to 23.58% and electric efficiency by 4.21 %. An improvement in exergy thermal efficiency can also be noted [16].

The work of the research team consisting of Saffa Riffat, Siddig Omer, Yuanlong Cui, Theo Elmer and Tugba Gurler presents an innovative heat pump system (GSHP) that contains a hybrid PV/T system for shelters. This system consists of: an innovative type of heat exchanger; solar heat exchanger made of polyethylene with thin tube and a vertical one that is on the ground that uses the heat that is stored in the soil. The result shows a 15.02MWh production of heat energy annually by the heat pump, with a seasonal performance coefficient of 3.73 per year. This PV/T-GSHP heating system can be a solution for a high consumption of fossil fuels in agriculture and can bring major savings, depending on the control of the system [17].

In order to improve and increase the electrical and thermal efficiencies of PV/T collectors, Milad Tahmasbi and the team used porous metal foams to cool the cells. Then, different outcomes of parameters like: the thickness of the porous layer; heat flow from the sun and Reynolds number are numerically investigated. The most important part of the results is focused on the influence of the porous environment on this system from a hydrodynamic and thermodynamic point of view, the speed profile and pressure drop. Utilizing porous media leads to an increase in thermal efficiency between 10-40 % and electrical efficiency between 3-4 %. If the thickness is more than half the height of the channel the results showed a negative effect [18].

Ahmet Numan Özakın and Ferhat Kaya experimentally used fins that were made of brass, aluminum and copper materials, in different materials and configurations, to study the exergy, electrical and thermal efficiencies of a PV/T system. For this experimental work they used monocrystalline panels as well as polycrystalline and realized a comparison between panels equipped with fins and panels without fins. The results showed that using fins achieve higher efficiency values compared to their lack in the system. For each material from which the fins are made, research was made by the Taguchi method, with their ideal number, which should be used to achieve superior electrical and thermal efficiencies. The final conclusion was that in order to have maximum efficiencies the main factor is the material from which these fins are built, then the air speed and the last factor the temperature of the panel. The ideal number of fins is 27 for brass and 55 for aluminum and copper [19].

The study of this article was conducted by Jin-Hee Kim, Fred Edmond Boafo, Ji-Suk Yu and Jong-Gwon Ahn with the aim of enhancing the thermal performance of a PV/T by designing a collector with curved deflectors (absorbent). To increase heat efficiency the PV cells were arranged interspatial and curved deflectors were placed in the collection space. The results showed a thermal efficiency with a value of 37.1 % and 6.4 % for the electric one. The error between the experimental obtained results and the numerical ones was a good one with values of 0.24 % and 4 % for electrical and thermal efficiencies. The heat gains annually analyzed using the TRNSYS program was 644kWh [20].

The work of Peiyuan Mi, Liangdong Ma and Jili Zhang analyzes the shortcomings of common hot water systems that have multiple heat sources and fixes these gaps by introducing a new system with multiple heat sources that is based on water source heat pump and PV/T heat pump Subsequently, they researched to integrate and optimize this system through ideas that were put into practice increasing performance and energy efficiency. After optimizing the system, the production of hot water supply increased from 80 tons to 146 tons with a decrease in the cost of delivery, increased COP from 3 to 7.1 and high energy efficiency [21].

In the study described by Taoufik Brahim and Abdelmajid Jemni, a new hot water heating system with solar photovoltaic heat pipes is experimented with using acetone as a working fluid. The realized model is based on the thermal equilibrium mechanism simulating the capacity of the PV/T/WHP system. The electrical and thermal efficiencies of the panel can be influenced by the following parameters: radiation, wind speed, water inlet temperature, collector surface and limits of the heat pipe operation. All these parameters were studied using a mathematical model. The study provided a framework to be able to evaluate such systems and to obtain the performance offered by its flexibility. The electrical thermal efficiency of the PV/T/WHP module according to the results was 12.52 %, the thermal efficiency at a value of 43.75 % and the overall efficiency of 56.27 % [22].

The poly-generation system powered by two solar sources (CCHP) is proposed by Ahmad Zarei and the research team using water as a working agent and serially configured thermal and parabolic photovoltaic traps (PV/T/PTC). This system has a refrigeration cycle used for two-level cooling and a recovery RCO (Rankine organic) cycle. With the help of thermodynamic laws, parameters such as the water flow of the PV/T-PTC circuit, solar irradiation and the effect of the RCO cycle working fluid are analyzed. Using refrigerants R123, R600, R245fa, R600a can be seen from the results that they have a high energy efficiency. For the R123 refrigerant, the best results were obtained: exergy efficiency of 10.70 % and energy efficiency of 70.78 % [23].

Navakrishnan S. and its team of researchers studied a system to improve the production of electricity and heat of a PV/T system, utilizing a solar collector with thermal storage (TES) with two HTFs. The exterior measurements were made between February and July to be able to establish the thermal and electrical response variations. The water has a natural circulation regime with a flow rate of 0.00833kg/s and the air circulates through the channel with a flow rate of 0.0069kg/s with the help of a blower. The equipment is provided with two inputs and outputs of water this improving the temperature distribution of the panel. Following this study, it can be said that this collector with hybrid cooling causes a decreasing in the temperature of the PV/T collector of a maximum of 7.5°C, this leading to an improvement in the conversion of electricity. The maximum thermal efficiency has a value of 69.25 % and the global recovery efficiency 84.40 % at a constant flow of water and air in February. In July, a 22% higher, than the case of a conventional system, electrical efficiency of 15.2 % is achieved. The maximum thermal efficiency has a value of 70.8 %, and the total one, a value of 85.7 %. The efficiency of this hybrid system in producing electricity, hot water and hot air at the same time has been demonstrated [24].

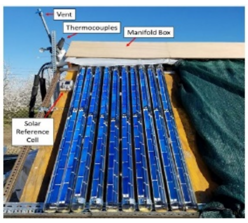
The team consisting of Senji Li and Wenbo Gu together with other researchers advanced a 2D numerical model to demonstrate the performance of a PIPV/T system that has a water tank with 50-liter capacity and two PIPV/T modules. The performance of this system, considering the mathematical model, is analyzed using simulations in three typical atmospheric conditions in five different regions. The results showed an overall energy efficiency of 33.10 % for sunny days, 34.74 % for semi-cloudy days and 18.60 % for cloudy days. From the results we understand that the photovoltaic/thermal system has good functionality on sunny and semi-cloudy days. It can also be said that the PIPV/T system has the highest overall annual exergy and energy efficiencies of 14.17 % and 37.89 % respectively [25].

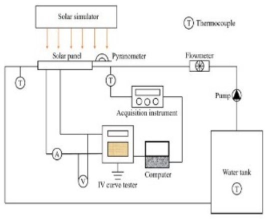
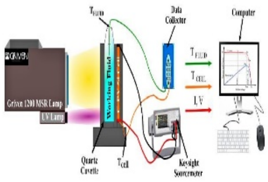
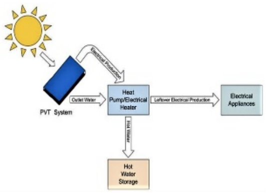
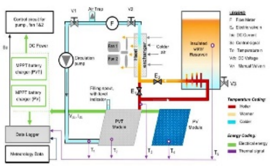
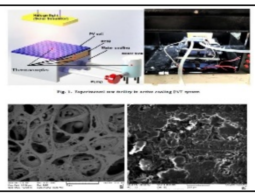
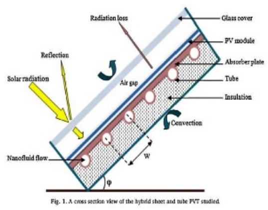
Hossein Afzali Gorouh together with a research team developed a zero-dimensional thermal model to study a new PV/T collector of low concentration (CPV/T), developed using heat transfer equations and energy balance. It has been tested, approved and validated within the relation to the results obtained experimentally. A number of factors on performance have been investigated, such as: the impact of removing the glass cover; the effect of the input HTF temperature; the consequence of the mass flow rate. The maximum thermal efficiency obtained was 69.6 % and the electrical efficiency of 6.1 % [26].

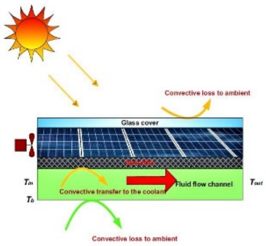
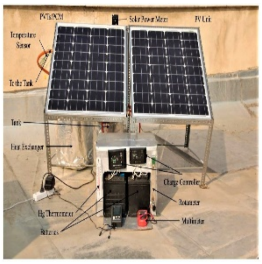
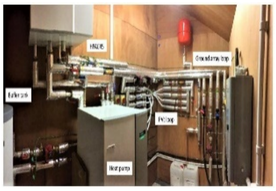
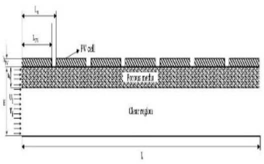
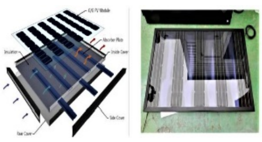
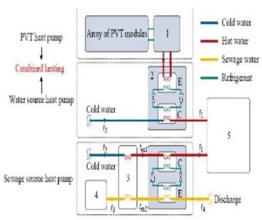
The team consisting of Seyed Reza, Ali Navegi and Evgeny Solomin studied the performance and influence of the corrugated tape inserts for a PV/T system, research that was based on the modeling of the system in 3D and the dynamics of fluids. The effect of inserting with corrugated tape was examined, on various tube numbers (range 5-25), in a given total mass flow rate. The results indicated that the integrated PV/T/Al_2O_3-water-based nanofluid system with corrugated tape insert has an improvement in electrical efficiency by 3.5 % and thermal efficiency by 12.06 % compared to the typical system [27].

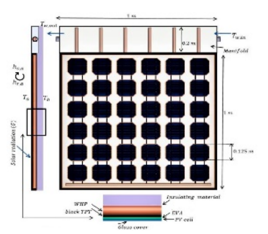
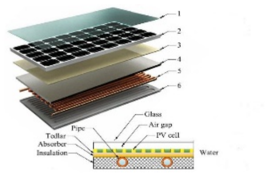
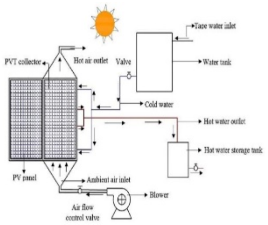
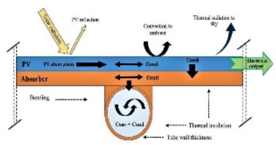
Table 1 represent a detailed description of the research papers presented above, performance and efficiencies improvement methods, the measured parameters, the technologies used as well as an overview of each hybrid PV/T system analyzed.

Table 1. Methods to increase the performances and efficiencies of the hybrid PV/T systems.

No.	System type/ Reference	Image of the system	Technology	Measured parameters	Efficiency
1.	Polymer sheet. [6]		Deploying at the back of the PV of a polymer sheet.	Current measurements; Panel temperature; Outlet water temperature.	Electrical efficiency: with 2.17% higher; Overall efficiency: 58.42% (thermal + electrical).
2.	Aluminum mini-channels. [7]		Non-imaging optics and aluminum mini-channels.	Solar irradiance; Ambient temperature; PV/T water temperature.	Electrical efficiency: 12.3%; Thermal efficiency: 57.4%; A 15% cost savings.

3.	Micro-encapsulated PCMs. [8]		MPCM (Microencapsulated phase change material).	The physical and thermal parameters of working fluid MPCM slurry, tap water; Temperature; Flow rate.	The maximum thermal efficiency and the electrical efficiency increase by 13.5% and 0.8%.
4.	Liquid spectral beam splitters (SBSs). [9]		Liquid spectral beam splitters (SBSs).	Temperature; Optical transmittance; Fluid temperature; Current density; Current, voltage.	Optical efficiencies of 63%; Economic value of the energy increased with 61%.
5.	Advanced PV/T for domestic hot water. [10]		Through vacuum glass tube encapsulation.	Water Temperature; Mass flow; Different mass flows of water; Solar heat fluxes.	Thermal efficiency: 64-67%; Electrical efficiency: 14.2-16.7%.
6.	The effect of the flow through the analytical technique. [11]		Mass flow rate effects.	The fluid inlet temperature; The flow rate; Ambient temperature; Voltage, current.	Thermal efficiency: 38.8-43.1%; Exergy efficiency: 12.75%.
7.	PS-CNT foam with infiltrated phase change material (PCM). [12]		PS-CNT foam with Infiltrated phase change material PCM.	Solar irradiance; PCM temperature; Water flowrate; PV cell temperature.	Energy efficiencies: 13-14% in passive cooling; 66.8–82.6% in active cooling.
8.	PV/T coated using nanofluids. [13]		Collector improvement using nanofluids.	Heat transfer and Temperature coefficients; Solar radiation and ambient temperature; Photovoltaic cell temperature.	Electrical performance is improved by 1.9% and 1.2%; Thermal efficiency is increased by 4.1% for Cu-water; 2.7% for Al_2O_3-water.
9.	Theoretical study for a new PV/T system containing dual oscillating absorber made out of copper pipe. [14]		Dual oscillating absorber copper pipe flow.	Solar irradiance; Mass flow of the fluid; Ambient temperature; Temperatures of the various parts of the system.	Thermal efficiency: 63.39% and 58.43% in the theoretical model; Electrical efficiency: 11.45%.

10.	Air collector PV/T with V-groove absorbent. [15]		Collector with V-groove absorbent.	Ambient temperature; Wind speed; Solar irradiance, Voltage and current, Upper surface temperature.	Electrical efficiency: 10.39-10.26%; Thermal efficiency: 41.78-41.57%, Overall efficiencies: 52.17-51.81%.
11.	Multi-wall based nanofluids like carbon nanotube water/glycol. [16]		Multi-wall carbon nanotube.	Total incident radiation; The flow rate; Temperature of the PV; Collector inlet/outlet temperature; Current and voltage.	Thermal and electrical efficiency rise of up 23.52%, 4.22%.
12.	Heat pump (GSHP). [17]		PV/T-GSHP heating system.	The indoor temperature; Circulating water temperature; Air speed.	Total thermal output: 15.02 MWh; COP: 2.5-5.17; Extra electricity generated 8.74 MWh.
13.	System PV/T/air using metal foams. [18]		Using metal foams.	Ambient temperature; Photovoltaic cell temperature; Fluid outlet temperature; Mass flow.	Thermal efficiency rises of 85%; Electrical efficiency rises of 3%.
14.	Air-based PV/T system utilizing fins in different materials. [19]		Different materials using fins.	The inlet and outlet air temperature; Fan air velocity.	Electrical efficiency rises of: 32-45%; Thermal efficiency rises of 61-75%; Exergy efficiency increased 46-64%.
15.	PV/T Collector with interspaced baffle-PV cell. [20]		PV/T Collector with Interspaced Baffle-PV Cell; With curved baffles.	Temperature, humidity, and air flow; Solar irradiance.	Thermal efficiency: 37.1%; Electrical efficiency: 6.4%.
16.	PV/T heat pump and water source heat pump. [21]		System with multiple heat-sources.	Initial temperature; Hot water temperature; Discharge temperature; Compressor power.	Economic performance of the system is improved by 49%; Production of the system is increased by 80%.

17.	PV/T wickless heat pipe solar collector PV/T/WHP. [22]		Wickless heat pipe solar collector.	Irradiation; Ambient, and water inlet temperature, Water speed.	Electrical efficiency: 12.52%; Thermal efficiency: 43.75%; Overall efficiency: 56.27%.
18.	CCHP system solar driven and powered by organic Rankine cycle. [23]		CCHP system supplied by Rankine organic cycle.	Inlet water mass flow rate; PV/T inlet temperature; Inlet water temperature.	Energy efficiency: 70.78%; Exergy efficiency: 10.70%.
19.	Hybrid PV/T solar collector using two HTFs and thermal energy storage (TES). [24]		Heat transfer tubes with TES; TES and two HTFs.	Photovoltaic cell temperature; Air temperature, wind speed and solar radiation; Water temperatures.	Thermal efficiency: 69.25%; Overall efficiencies: 84.40%. Electrical efficiencies in interval of 12.84%-15.71%.
20.	Pavement integrated photovoltaic thermal PIPV/T system. [25]		Pavement integrated, (PIPV/T).	Optical parameters and thermophysical parameters; Temperature of PIPV/T.	Overall energy: 37.89%; Exergy efficiency: 14.17%.
21.	Novel CPV/T collector with parabolic concentrator. [26]		Concentrating photovoltaic thermal collector (CPV/T).	Mass flow rate and Inlet/outlet temperature of HTF; Solar radiation; Ambient temperature; Electrical power.	Thermal efficiency: 69.6%; Electrical efficiency: 6.1%.
22.	Wavy-strip PV/T system.		Wavy-strip insert without and with nanofluid.	Mass flow rate; Solar radiation; Ambient temperature; PV/T module temperature.	Electrical and Thermal efficiencies increase with values between 6.92 and 8.64% respectively 2.01 and 2.45%.

4. CONCLUSIONS

Depending on solar irradiation, PV and PV/T systems can produce adequate amounts of electricity and heat. At the same time, they can generate energy excess, which is achieved when there are sunny days. This overdue energy can be stored and used during periods when it is needed (peak periods). In temperate climates these hybrid systems need in winter the help of an auxiliary system. With a significant optimization they can be adapted to the buildings taking into account a number of factors such as: the existing location, the demand profile, the heating system existing in that place and last but not least the price of energy. The condition of reliability of these PV/T systems is conditioned by their economic and technical competitiveness, all of which relate to other alternatives that compete with the existing market. Most systems were able to attain a maximum thermal efficiency of 60 % for air-cooled PV/T and slightly superior for the PV/T based on water-cooling, 69 %.

Liquid collectors have good functionality, higher efficiencies and acceptable design. Constructions of duct plates can lead to an increase in heat transport volume, provided if these channels are thin. A heat pump can be integrated into a glass-free PV/T water collector and thus become a promising development for the future. In air-based PV/T systems, the energy capacity is lower than in the liquid one, but it can be improved and optimized through the construction of new models of absorbent plates and fin configurations. In the case of the water-based photovoltaic/thermal hybrid system, it can be seen that its structure is more complex, through the design added by the heat exchanger. They have a higher cost but also a higher thermal and electrical efficiencies in analogy with the air-based ones. PV/T systems based on the tick have satisfactory results due to the fact that both fluids are in the same system, they produce simultaneously hot air, hot water and electricity. The hybrid system based on nanofluids achieves good results and can improve performance by adding this nanofluid as a coolant but also as an optical filter in the same system. By modifying parameters such as size, shape and concentration, better properties can also be achieved.

Using phase-changing materials for thermal performances of PV/T it can be observed that PCM is efficient only when its heat is ethylized with useful purposes requiring its integration of the hybrid system. An integrated PV/T system is a sustainable application but it is indicated to carry out more simulation researches to achieve the optimal construction configuration. The researchers are still conducting studies for hybrid photovoltaic/thermal systems in order to augment the design architecture, system parameters, electrical and thermal efficiencies. Because these systems have a huge potential to accomplish the heat and electricity needs of the entire world, they may be the future of renewable energy.

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