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PHOTOVOLTAIC/THERMAL (PV/T) SYSTEM DIRECT CONTACT TYPE: A REVIEW

Ali Kadhim Khudadad[1] **Fouad Alwan Saleh**[1] **Naseer Kaream Kasim**[2]

1) Mechanical Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq
2) Training and Energy Research Office, Ministry of Electricity, Baghdad, Iraq

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Abstract: Hybrid photovoltaic/thermal systems have emerged as a key energy technology as a result of the photovoltaic thermal PV/capacity T's to simultaneously produce electrical and thermal energy. Over the last couple of decades, much attention has been paid to photovoltaic–thermal systems due to their benefits over solar thermal and photovoltaic applications. This paper will concentrate on direct contact systems in order to demonstrate the various electrical and thermal features of photovoltaic–thermal systems. The main objective of researchers and manufacturers is to improve photovoltaic/thermal collector efficiency by employing state-of-the-art materials and design concepts and appropriately integrating them into solar modules and thermal absorbers. Additionally, it is important to lower the cost of these systems and increase their market competitiveness. As well as, PV/T systems are critical for supplying electricity in a clean and ecologically beneficial manner.

Keywords: *Photovoltaic, thermal efficiency, direct contact*

1. **Introduction**

Solar thermal collectors (ST)and photovoltaic modules are combined to create hybrid photovoltaic (PV)/thermal collectors. In other words, the photovoltaic module serves as a heat sink. The photovoltaic module's temperature rises as a result of the bulk of solar radiation it collects being transformed into thermal energy. The efficiency of solar cells is highly temperature dependent. The solar cell material's atomic thermal vibrations increase as the temperature rises, which causes a reduction in conversion efficiency. The electrons' orientation is altered by these vibrations, it interferes with the current passing through the solar cell. By removing heat with the use of an adequate natural or forced fluid (air or water) circulation, the temperature of the solar module can be decreased. A variety of methods are needed to integrate ST collectors and PV modules into a PV/T collector as a whole. [1] The functioning and effectiveness of hybrid system are significantly influenced by how it is incorporated. Solar photovoltaics (PV) is a type of photovoltaic energy conversion system that consists of a series of interconnected components that operate in concert to convert solar energy to electricity, utilize the generated energy, store it, or invert it. [2].

**Corresponding Author*: alikadhim199265@gmail.com

This technology has been a trailblazer in the field of renewable energy for decades. Solar photovoltaic (PV) capacity had surpassed 480 GW globally by the end of 2020, making it the second largest renewable energy source behind wind.[3]

Solar thermal collectors are designed specifically to capture solar energy and may be used to heat either air or water for home heating. The sun's energy heats a liquid, which is subsequently transferred to a hot-water tank. The liquid heats the water, which is subsequently diverted to the collector via the solar collector. Solar collectors are generally recognized as a cost-effective source of renewable energy. They have a life expectancy of 25 to 30 years or more and need minimal maintenance other than antifreeze and pressure control. [4].

Due to the fact that the efficiency of a solar panel decreases as the temperature of the cell increases, transporting heat from the photovoltaic system to the collector through a fluid avoids efficiency loss. Additionally, integrating both technologies alleviate roof space limitations associated with individual photovoltaic and thermal solar systems.

A range of factors, including as the kind of photovoltaic modules used, the absorber thermal design, the usage of glass, the working fluid type and circulation pattern, and the use of a hybrid collector, can be considered when analyzing PV/T systems. [5-23] CPV/T systems, which use concentrated photovoltaic and thermal energy, other factors to consider include the geometry of the reflectors, the material used to make the reflectors, and the technique of integration into the system [24-38]

2. Classification of Photovoltaic Thermal Collectors

Often, thermal and electrical energy requirements are mutually exclusive. A photovoltaic thermal system is a kind of solar cogeneration system that combines a photovoltaic module with a solar thermal collector to produce both energy and heat. The term solar cogeneration' was invented by many scholars, while others used the term 'photo thermo conversion.' The initial impetus for integrating photovoltaic and solar thermal technology was the discovery that photovoltaic efficiency decreases with increasing temperature; this degradation in photovoltaic performance can be partially offset by extracting heat from the module and reusing it for useful heating applications, resulting in hybrid photovoltaic/thermal technology. The main benefit of hybrid photovoltaic/thermal systems is that they generate electricity. several outputs, notably energy and heat, at a slight fee, but at the cost of priceless room. It is also a low-cost, adaptable technology that may be applied to both heating and cooling.[6] .

2.1. Classification Based on Geometry shape

PV/T collectors might be in the shape of a concentrator or a flat plate. Additionally, a unique arrangement known as building integrated PV/T uses the building's structure to define its geometry.

2.1.1 Flat / Plate PV/T

The well-known flat plate thermal collectors are similar to flat plate photovoltaic/thermal collectors. The addition of a solar panel to the iron absorber plate is the sole significant change.

As schematically shown in Figure 1, a PV/T collector typically comprises of a photovoltaic module attached to the back of an absorber plate (a heat extraction device). As seen in the section above, PV modules have a peak efficiency of 11–23% when converting solar energy to electricity. The absorber plate has two purposes. to capture the thermal energy produced, which would otherwise be lost to the atmosphere as heat, and to cool the photovoltaic module, both of which will improve its electrical performance. For applications needing low temperatures, like providing hot water for a home, this accumulated heat could be employed.

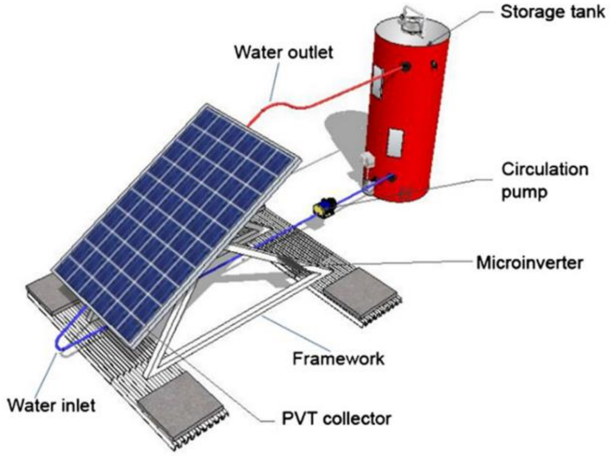


Figure 1. PV/T system collector [39]

Flat-plate PV-T collectors are the most common kind of PV-T collector due to their ease of construction [40]. This design is mostly for home uses like space heating and hot water delivery. As opposed to commercial solar water heaters, Household sun water heaters often connect flat-plate collectors in parallel and work automatically via the thermosiphon process, unlike commercial solar water heaters, which employ a series of flat-plate collectors and need a pump to fix water flow. (2011) Erdil, Ilkan, and Egelioglu Generally, the side faces and bottoms are insulated, and a glass cover helps prevent heat loss. The flat-plate PV/T collector cross section is illustrated in Figure 2 The collector collects solar cell waste heat and transfers it to a heat transfer fluid, which is often air or water.

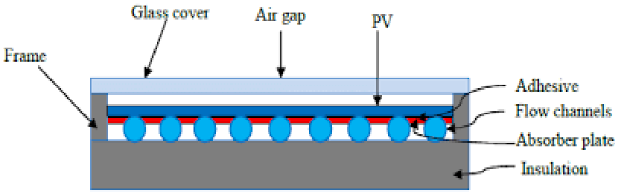


Figure 2. cross section of a typical flat-plate PV/T [42]

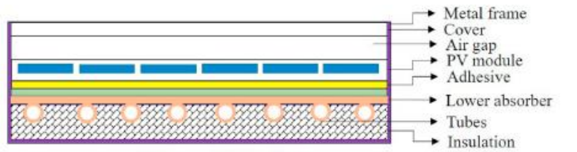
Flat-plate photovoltaic/thermal systems can collect both direct and diffuse irradiation. Flat-plate photovoltaic/thermal systems are relatively inexpensive due to their simplicity of design. This section discusses many significant research efforts on flat plate PV/T.

[43] examined single glazed flat-plate photovoltaic/thermal water collectors' thermal and electrical performance numerically and experimentally. The scientists discovered thermal and electrical efficiency of 79 and 8.8 percent, respectively, at zero decreased temperature.

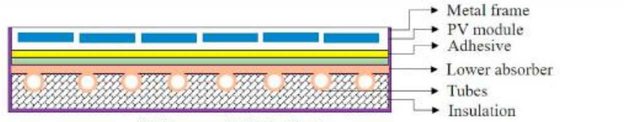
Roll-bond flat plate collectors and glazed PVT water collectors using thin film photovoltaic technology (top amorphous layer, bottom microcrystalline layer) were studied. The study used a single collector that was entirely covered and found that PVT technology offers greater overall efficiency than solar modules. [44]

Using a few changes to the input parameters, TRNSYS models for parallel-tube PVT collectors were easily adapted to a harp-channel roll-bond PVT collector. They could also be applied to a grid-channel PVT collector with a property parameter derived from test data. Additionally, the two PVT-DHW systems' annual energy output was simulated. [14]

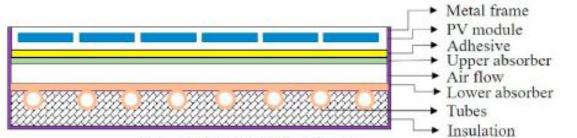
In light of extensive literature research and taking into account the many differences in the electrical and thermal efficiency of the PV/T collector, the impacts of operating media, structural designs, and environmental conditions on the performance of flat plate PV/T collectors were studied. The results showed that a water-type PV/T collector was generally more effective than an air-type PV/T collector., because of the higher specific heat capacity of water, but with a more intricate design. Because dispersion nanoparticles in a base fluid have a high thermal conductivity and the nanofluid is colloidally stable, it has a higher overall efficiency than other PV/T collectors. The architecture of the absorber, its placement in relation to the fluid, and whether or not the glass cover was used all had an impact on the PV/T collector's overall performance. Additionally, the major meteorological factors affecting performance were solar radiation and ambient temperature, which varied according to the geographical location of the installation. Future research will focus on the advancement of sophisticated photovoltaic/thermal technologies, which will allow for the integration of photovoltaic collectors into residential and public structures. [16] figure 3 show different structure of PV/T collector



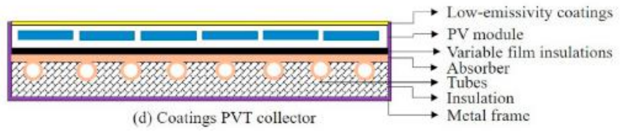
(a) Covered PVT collector



(b) Uncovered PVT collector



(c) Dual-absorber PVT collector



(d) Coatings PVT collector

Figure 3. Different structures of PV/T collectors

2.1.2. Concentrator PV/T

In comparison to flat-plate collectors, concentrated photovoltaic/thermal systems (CPV/T) generate higher temperatures. CPV/T is a development of concentrator photovoltaic (PV) technology, which concentrates sunlight onto a small number of extremely effective solar cells using Fresnel lenses and mirrors. While these solar cells produce extremely high temperatures and need specialized cooling, the heat that the coolant removes can be utilised in thermal applications that demand reasonably high temperatures. This approach shows promise since CPV/T only requires a small area of solar cells and because reflectors cost substantially less than solar cells. To capture the most solar energy possible and maintain a constant focus on the Sun throughout the day, a tracking device is required. While CPV/T operates successfully in bright, clear skies, performance is significantly impacted by dusty circumstances.

[45] conducted a computational and experimental research towards the construction of an integrated photovoltaic/thermal system using static tiny solar concentrators. According to the authors, the greatest thermal efficiency was 37.2 percent in September with a water exit temperature of 56.9C.

A schematic illustration of CPV/T is shown in Figure 4. To maximize solar insolation utilization over the entire spectrum, a more advanced CPV/T design known as Spectral Beam Splitting CPV/T was developed.[9]

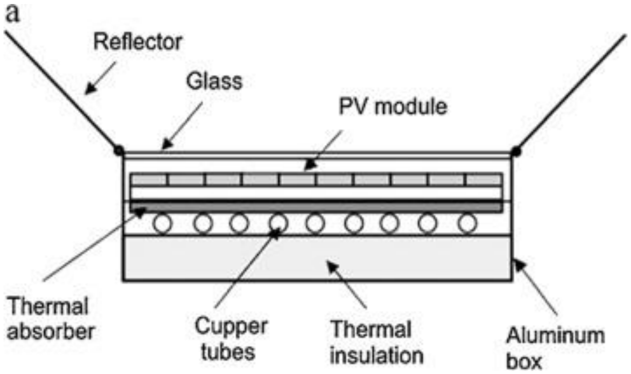


Figure 4. Schematic of a concentrator PV/T

[46] The relevance of this study is that it presents a small size, single axis solar tracking system that is suited for building integration, investigates its probable integration into a building, and analyzes the suggested solutions' power generating capabilities in depth. Data gathered from experimental tests on a prototype consisting of four semi-parabolic mirrors were used to infer these features. The presentation of a brand-new research direction targeted at improving the functionality, system design, and installation of a prefabricated modular façade component constitutes the original contribution. The recommended PVT low concentrated solar gadget is very simple to control and integrate into structures.

2.2. Integrated PV/T

Energy use in homes and businesses is rising daily, especially in urban areas with an industrial economy. In recent years, PV/T has grown in importance as an integral part of the building envelope. Considering that building integrated photovoltaic/thermal (BIPV/T) systems are one of the best methods to help buildings achieve their net-zero energy goals.

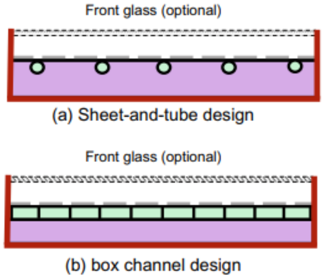
To attain a high air output temperature, [47] carried out a theoretical (numerical) analysis of BIPV/T systems with an air collector and wire mesh. The findings show that utilizing a wire net increases performance for air fluxes smaller than 0.03 kg/s and that the improvement in heat transfer depends on the design of the wire mesh. Utilizing wire mesh resulted in a gain in efficiency of 8.5% and an increase in output air temperature of 4°C to 11°C.

[48] a full -scale solar simulator was used to evaluate the characteristics of an open loop bi-inlet BIPV/T air system. According to experimental tests, the twin inlet collector increases thermal efficiency in comparison to a single inlet device by 5%. The scientists also found that adopting BIPV/T systems with semi-transparent photovoltaic modules rather than clear ones increased thermal efficiency by 7.6 percent.

[49]A vibration-sedimentation method was used to manufacture an aluminum/high-density polyethylene (HDPE) functionally graded material (FGM) panel integrated with aluminum water tubes. PV efficiency achieves 14.51 percent and 15.82 percent under solar irradiation of 800 and 1000 W/m2, respectively, and the output electricity energy is 32.96 W and 44.91 W. Additionally, when there is no water flow, the PV efficiency increases by 21.1 and 24.0 percent for those two solar irradiances, respectively.

2.3. Classification Based on Contact Type

Two classifications based on fluid contact which is water with the last layer of photovoltaic cell as show in figure 5



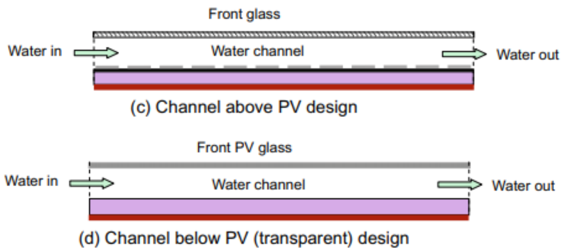


Figure 5. Cross-section views of some liquid-type PV/T collector designs [50]

3. Indirect Contact Sheet-And-Tube PV/T Collectors

The easiest method of constructing a PVT-collector is to depend solely on well-established accessible74000000000000000000000000000 000000000000000000000000000000000 technology by integrating a conventional solar panel directly into a thermal collector. Circular, rectangular, or square tubes may be used. The sheet-and-tube PVT collector seen in Fig.5a was evaluated against other types of PV/T-water collectors and discovered that the sheet-and-tube idea was somewhat less effective than the other collectors. Researchers have explored the use of numerous glasses covers on sheet-and-tube photovoltaic/thermal collectors in order to improve their performance. However, it was shown that employing more than two glass coverings significantly reduces electrical efficiency.

The combined photovoltaic thermal (PV/T) water cooling system is evaluated experimentally for its electrical and thermal performance in a hot climate region. When compared to the performance of the PV module without a cooling system, the maximum and average overall efficiency of the PV/T module are 68.7 percent.[51]

4. Direct contact PV/T collectors

The type (b) collector is a flat box design with rectangular water channels in place of riser tubes, commonly known as channel flow.

Fluid flow is directed beneath the front glazing and above the PV encapsulation, which is incorporated into the front glass.

Type (d) In type (d), the water flow is below the integrated photovoltaic front glass.

Because the coolant in type (b) travels over the PV, fluid choice becomes an issue. If the fluid's and the PV's absorption spectra are similar, the solar cells' capacity to absorb incoming light may be hampered. Although it is simple to construct, there could be a problem with wide channels if a glass plate of the right thickness is required to withstand the water pressure, which increases the risk of a brittle construction.

A design with four configurations—unglazed with tedlar, glazed with tedlar, unglazed without tedlar, and glazed without tedlar—was quantitatively assessed by Type c and D [52]. The energy balance of each additional layer of the photovoltaic/thermal system was used by the same authors to evaluate the performance of the same systems (Tiwari & Sodha, 2006a). The predicted daily thermal efficiency (58%) was found to be in good agreement with the reported experimental value (61.3%) by the authors.

[53]conducted numerical analysis on nine different water-type photovoltaic/thermal collector systems and categorized them into four groups. The thermal and electrical conversion efficiencies of the four groups at zero decreased temperature are presented below. I The efficiencies of sheet and tube type photovoltaic/thermal collectors with no, one, or two glass covers are 52 percent, 58 percent, and 58 percent, respectively; 9.7 percent, 8.9

percent, and 8.1 percent. (ii) The percentages of PV/T collectors with channels above opaque PV, below transparent PV, and below transparent PV are 65 percent, 60 percent, and 63 percent, respectively; 8.4 percent, 9 percent, and 9 percent. (iii) A free flow PV/T collector has a thermal efficiency of 64% and an electrical efficiency of 8.6%. (iv) The insulated type two-absorbers PV/T collector is predicted to have a thermal efficiency of 66 percent and an electrical efficiency of 8.5 percent, whereas the non-insulated type has a thermal efficiency of 65 percent and an electrical efficiency of 8.4 percent, respectively.

[54] examined several configurations of water-cooled photovoltaic/thermal systems at varying mass flow rates and sun irradiation levels. They suggested three distinct novel absorber channel designs: the web flow absorber, the direct flow absorber, and the spiral flow absorber. Increases in mass flow rate resulted in a drop in PV temperature and an improvement in electrical efficiency. Additionally, increasing the amount of solar light raised the temperature of the photovoltaic cells and their produced electrical efficiency. They stated that the direct flow and spiral flow absorbers behaved similarly; the direct flow absorber achieves better thermal efficiencies, while the spiral flow absorber achieves higher electrical efficiencies. At 800 W/m2, the spiral flow absorber had the highest overall performance, with efficiencies of 68.4 percent, 54.6 percent, and 13.8 percent, respectively.

[55] conducted an experimental and computational analysis to determine the impact on the overall power production of a hybrid PV/T system of using the enclosure-shaped absorber as illustrated in Fig. 3.4. They looked at how the temperature was distributed throughout the system's many layers, and they came to the conclusion that the total efficiency is around 80%. The unique absorber design enhanced the hybrid system's thermal performance in comparison to a conventional hybrid PV/T system with a single absorber layer. The committee did not address the commercial viability of the new design. according to figure 6

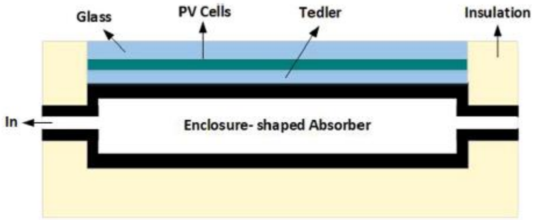


Figure 6. Schematic diagram showing the enclosure-shaped absorber

This paper described a covered photovoltaic/thermal collector, and [56] offered an experimental photovoltaic/thermal collector and a novel dynamic model for modelling flat plate photovoltaic/thermal water collectors. This design made use of roll-bond flat plate absorbers and thin film photovoltaic panels. Additionally, they used a mathematical model to assess its performance. According to this study, PV/T systems were more efficient overall than a single solar module when utilized for primary energy. To ascertain the effect of a-Si regeneration, more study is required on PV/T collector performance under high-temperature summer conditions.An instantaneous thermal efficiency of flat plate collector

$$\eta_{th} = \frac{Q_u}{A_c * I_t} \tag{1}$$

While electrical efficiency

$$\eta_c = \eta_o[1 - 0.0045(T_c - 45)] \tag{2}$$

The solar panel under study has a method for extracting heat. The method we suggest involves superimposing a water layer on the solar panel; the water layer absorbs infrared light while largely preserving visible light. High photovoltaic efficiency and heat generation are made possible by this. Both the electric and thermal components are thoroughly discussed in this particular design, known as Thermal Electric Solar Panel Integration (TESPI). as depicted in figure 7, [57]

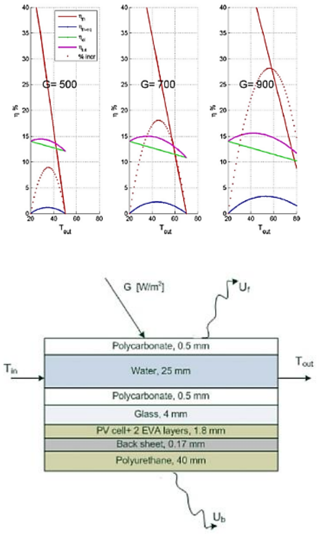


Figure 7. TESPI Efficiency:(electric part (green line), thermal part in red line, total in black. The increase in total efficiency is given in blue.

The photovoltaic conversion of the solar module generates calorific energy, which raises the temperature of the cell and reduces its electrical output. This phenomenon is produced by two factors: first, the partly absorptive solar radiation that heated the cell, and second, the Joule effect induced by the passage of the photo-electrical current created in the external circuit. This heating, which is detrimental to solar cell production, necessitated many research attempts to mitigate its consequences via heat evacuation. Additionally, there was a proposal to leverage this phenomenon by combining a photovoltaic module with a thermal system to create a photovoltaic thermal (PVT) hybrid collector that generates both energy and heat simultaneously. The design of a novel kind of PVT collector is presented in this article, together with its numerical modeling and experimental validation. This innovative collector is a revolutionary technological method for maximizing overall conversion output while maintaining a lower cost than conventional hybrid collectors. [55]

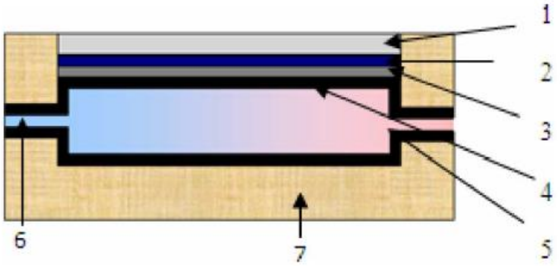


Figure 8: New PVT collector simplified diagram. Tempered glass, solar cells, Tedlar, the absorber, coolant entrance, exit, and entry, and insulation are listed in that order.

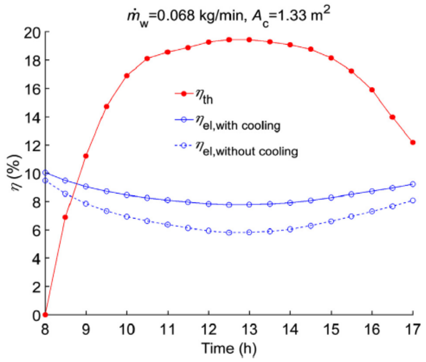
The researcher show that the ongoing growth of solar system installations (thermal and electric) may deplete the available surfaces for collector exposure, especially in urban and suburban regions. As show in figure 10 A viable option is to utilize hybrid photovoltaic-thermal systems, in which the panels generate both heat and electricity. The experimental findings for two photovoltaic strings based on the proprietary technology were reported in this research. respectively, the average electrical efficiencies of the system are 13.19 percent. This equates to a 34% decrease in efficiency.[58]

Figure 9. A part of the apparatus

A photovoltaic/thermal collector with a mass flow rate of 0.012 kg/s to 0.0255 kg/s was used for the experiment. The PV/T collector increases convectional heat transfer with help from the water flow and stainless steel absorber.The power output increases as the amount of radiation increases. The effectiveness of PVT changes with the intensity of the radiation, which was 750 W/m2 and 900 W/m2 in this experiment. The energy and exergy analyses are carried out, and the findings indicate that the energy output of a water-based photovoltaic/thermal collector is 346 W for solar radiation 700 W/m2 and 457 W for solar radiation 900 W/m2. Meanwhile, the total exergy production was raised by 22.48 percent for 700 W/m2 and by 20.87 percent for 900 W/m2. 5.786 W and 46.534 W, respectively, are the thermal and electrical exergy for 700 W/m2 radiation. Thermal and electrical outputs for 900 W/m2 radiation are 8.858W and 58.828W, respectively, as indicated in Table 4. The PVT exergy is 52.32 W for 700 W/m2 and 67.68 W for 900 W/m2.

Numerical and experimental analysis of the performance of a solar still linked to a photovoltaic thermal water collector was performed in this research. A transient thermal model was developed by examining the energy balance of the various components of a solar still system (i.e. PVT water collector & saline water, glass cover and absorber plate). Additionally, an equation for the energy efficiency of the system was derived. A laboratory setup was developed and constructed. Experimental data were used to verify the simulation findings. The impact of various design and operational factors on freshwater productivity, energy efficiency, and output electrical power was then examined using parametric analysis. In order to maximize energy efficiency, it was demonstrated that there is a suitable value for the area of the PVT water collector and the mass flow rate of saline water. The needed mass flow rate for the PVT water collection was 0.068 kg/min, and the required area was 1.33m2. Along with increasing energy efficiency and freshwater production, the PVT water collection's connection to stepped solar panels also provided excess electrical power for other uses. [59]

A



B

Figure 10. Stepped solar still attached to PVT collector in experimental configuration (A). (B) Stepped solar still thermal efficiency and PV/T collector electrical efficiency for cooling and non-cooling modes with time.

the three-day electrical performance of the system is the main subject of this paper, which also draws conclusions regarding how ambient conditions and solar radiation affect conventional photovoltaic panels and photovoltaic/thermal collectors. The suggested PV/T displays higher electrical performance over the course of the test period, consistently outperforming typical PV in terms of electrical efficiency. Peak electrical output and voltage for the system are roughly 67 Wp and 18.9V, respectively. Figure 11 illustrates that the average power output of the PV/T panel is 6% greater than the average power output of a normal photovoltaic panel [60].

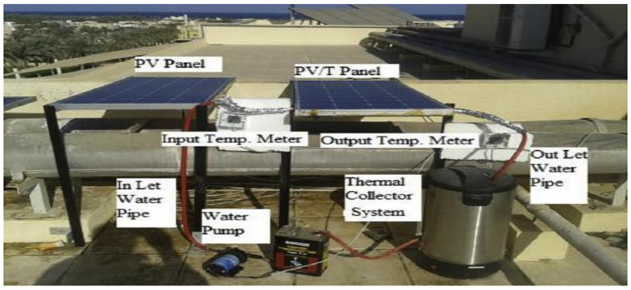
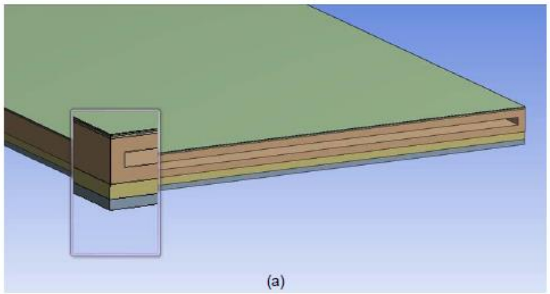


Figure 11. PV and PV/T systems

[61] is concerned with the three-dimensional theoretical and numerical study as in figure 13 of the electrical performance of a photovoltaic (PV) system with active fluid cooling (PVFC) in order to improve its efficiency at converting solar energy to electricity. The photovoltaic system consists of twenty modules that are cooled by a circulating fluid on the bottom, a piping network, and a circulating pump. Comparisons of the one- and three-dimensional models' outputs and experimental results demonstrate the one-dimensional model's effectiveness and limitations, as well as the advantages of using the three-dimensional model to investigate the effect of the spatial cell temperature distribution in a photovoltaic module on thermal mismatch effects.



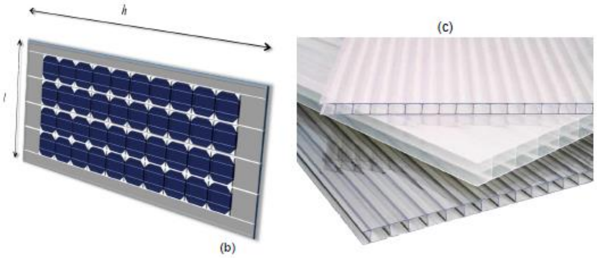


Figure 12. (a) Schematic of the PVFC module (height of the module h = L4 = 1.42 m, corresponding to the length of the water; width of the water duct l = 0.6 m; module height s = 0.0363 m). (b) Anti-reflective layer comprising 40 series- connected m-Si solar cells. PV cells are spread over four columns and ten rows, resulting in a total height of 1.22 m. (c) Specific alveolar polycarbonate ducts, each measuring L4 = 1.42 m in length

5. Conclusions

The flat-box solar PV/T collector has a number of benefits over traditional solar PV/T collectors. Metallic sheet-and-tube collectors, as well as flat / box plastic / rubber collectors, such as the enormous contact collectors, feature a region optimized for heat transfer between the absorber plate and the fluid, uniform temperature dispersion transversely across the collector's breadth, and a metallic surface that acts as a superior lamination between the photovoltaic cells and absorber plate. Although it is more difficult to manufacture owing to the direct contact and the need to develop a way to avoid water leakage, it has a better thermal efficiency than sheet and tube and also works well to cool the solar panel.

The method used to integrate thermal absorbers and PV modules is important because the thermal resistance between the PV modules and the thermal absorber has a direct impact on the thermal efficiency of the PV/T module. In contrast to more established methods such as direct contact, thermal adhesive, and mechanical fixing, recent research indicates that the direct contact approach offers a lot of advantages. In any case, more research and results are expected in this field of photovoltaic/thermal collector development.

Conflict of interest

The authors declare that the publication of this article cause no conflict of interest.

Abbreviations

η_{th}	Thermal efficiency
η_c	electrical efficiency
Q_u	Useful energy
A_c	Cross sectional area
T_c	cell temperature

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