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Photovoltaic Thermal PV/T Solar Panels and Practical Applications

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Abstract

The research and development of renewable energy resources for energy production are of utmost importance due to factors such as the restricted utilization of fossil fuels and the escalating presence of greenhouse gases in the atmosphere resulting from their usage. The conversion of solar energy into electrical energy is made possible through the utilization of photovoltaic (PV) technology. Nevertheless, due to the PV cells' efficiency ranging between 15% and 20%, the excess energy is dissipated into the atmosphere as heat. Photovoltaic thermal (PV/T) systems increase efficiency both by converting solar energy into electrical energy and by converting the generated heat into useful energy. PV/T systems are a technology that increases efficiency by using solar energy to produce both electricity and hot water. PV/T systems have many types and have commercial and domestic applications. PV/T systems harness solar energy to generate electrical energy while simultaneously utilizing the generated heat to produce useful energy. This innovative approach enables the cooling of the PV cell surface, resulting in improved efficiency. Also, thanks to the use of these systems, it is possible to recover the energy lost in conventional photovoltaic systems The primary objective of this study is to provide a comprehensive overview of the progress made in the research and development of PV/T solar collectors, encompassing an in-depth investigation of their various practical applications.

Keywords: Solar panels, PV/T technology, Photovoltaic thermal, Solar cells.

Fotovoltaik Termal PV/T Güneş Panelleri ve Pratik Uygulamaları

Öz

Enerji bugün ülkelerin kalkınmasının ve gelişmişliğinin bir göstergesi durumundadır. Ancak dünyada yaygın olarak kullanılan enerji, üretim ve tüketim yöntemleri yerine yenisi konulamayacak enerji kaynaklarımız tükenmekte bunun sonucunda da tabiat üzerinde geri dönüşü olmayan bir tahribata sebep olunmaktadır. Fosil yakıtların sınırlı olması ve enerji üretimindeki kullanımları nedeniyle atmosferdeki sera gazlarının artması gibi faktörler, enerji üretiminde yenilenebilir kaynaklara yönelik araştırma ve geliştirmeler hayati öneme sahiptir. Güneş enerjisi, yenilenebilir enerji kaynakları arasında en önemli ve hızla büyüyen kaynaklardan biridir. Dünya çapında güneş enerjisinin kullanım oranı, sağladığı avantajlar ve ekonomik getirilerin artmasıyla birlikte artmaktadır.Fotovoltaik (PV) teknolojisi, güneş enerjisini elektrik enerjisine dönüştürebilme imkanı sağlar. Bununla birlikte, PV hücrelerin verimliliği %15-20 aralığında olduğundan, geri kalan enerji ısı olarak atmosfere salınır. PV/T sistemleri, güneş enerjisini hem elektrik enerjisine dönüştürürken hem de oluşan ısıyı faydalı enerjiye dönüştürerek verimliliği arttırmaktadır. PV/T sistemleri, elektrik ve sıcak su üretimi için güneş enerjisini kullanarak verimliliği arttıran bir teknolojidir. PV/T sistemleri, birçok çeşide sahip olup, ticari ve evsel uygulama alanlarına sahiptir. PV/T sistemleri, güneş enerjisi ile elektrik enerjisi üretirken aynı zamanda oluşan ısıyı da kullanarak faydalı enerjiye dönüştürürler. Bu şekilde PV hücrelerin yüzeyi soğutulur ve verimlilik artar. Ayrıca, bu sistemlerin kullanımı sayesinde, geleneksel fotovoltaik sistemlerde kaybedilen enerjiyi geri kazanmak mümkündür. PV/T sistemleri, yenilenebilir enerji kaynakları arasında en verimli olanlardan biri olarak kabul edilir. Bu çalışmada, fotovoltaik termal (PV/T) güneş kollektörlerindeki teknolojik ilerlemenin araştırılmasını ve geliştirilmesini ve bazı faydalı uygulamaları sunmaktadır.

Anahtar Kelimeler: Güneş panelleri, PV/T teknolojisi, Fotovoltaik termal, Güneş hücreleri.

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1. Introduction

As the world's population increases, the need for energy also increases with the increase in population. This energy requirement is mostly met by fossil fuels. The energy obtained from fossil fuels causes climate change and environmental pollution by releasing greenhouse gas emissions into the atmosphere. The combustion process of these fuels leads to the release of carbon dioxide (CO2), methane (CH4), and a variety of other greenhouse gases into the Earth's atmosphere. These greenhouse gases disrupt the natural balance in the atmosphere and lead to an increase in temperature worldwide. The significance of minimizing fossil fuel consumption and transitioning towards renewable energy sources cannot be overstated. This mounting interest in renewable energy sources stems from the finite nature of fossil fuel reserves and the detrimental environmental impacts they entail. In spite of the growing interest in and adoption of renewable energy sources in recent years, the reliance on fossil fuels remains unabated.

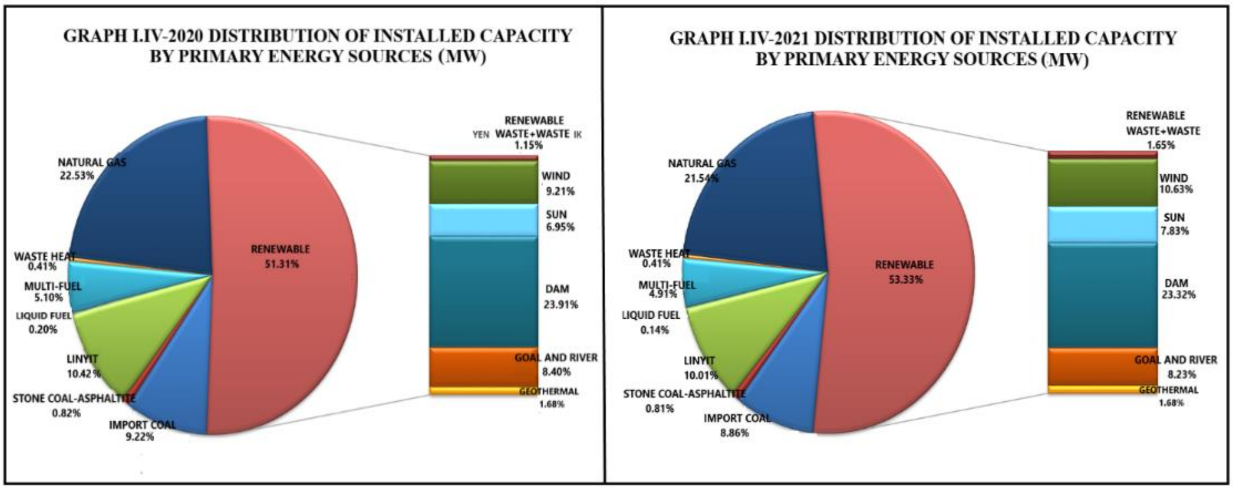

Figure 1. Electricity generation share by energy resources in Turkey in 2020 and 2021 (Türkiye elektrik üretim istatistikleri, 2023).

Figure 1 shows the electricity generation rates in Turkey according to energy sources for the years 2020 and 2021. When we look at the electricity production rates according to energy sources in Turkey, it is seen that fossil fuels (coal, natural gas and oil) still have a large share, but recently there have been changes in these rates with the investments made in renewable energy resources. In particular, electricity generation from renewable sources such as hydraulic, biomass, wind, geothermal solar energy has increased. Based on the 2021 data, renewable energy sources account for approximately 53.33% of Turkey's total electricity production (Türkiye elektrik üretim istatistikleri, 2023).

Solar energy holds significant importance and exhibits substantial potential as a renewable energy source. Solar energy has been widely used in the past and today to obtain hot water with thermal applications. These thermal applications involve systems designed to utilize solar energy for water heating and the production of hot water for various purposes. Turkey is one of the countries that can benefit from solar energy in the best way since it has a geographical location where the sunshine duration is high. Various applications and systems for the production of hot water with solar energy are widely used in Turkey. The adoption of photovoltaic (PV) systems, which enable the direct conversion of solar energy into electrical energy, has not yet attained the desired level in Turkey. The utilization of PV systems for solar energy-based electricity generation in Turkey is still in a developmental phase, indicating that its full potential has yet to be realized. Incentives and investments in renewable energy have increased in Turkey and many parts of the world in recent years. These incentives and investments support the development, establishment and growth of renewable energy projects. However, it is very important that this trend is sustainable and continues.

Thermal solar energy emerges as a highly cost-effective renewable energy technology with immense global market potential. With a global installed solar energy capacity accounting for more than 90%, this system is extensively utilized in various domains such as industrial process heating, solar assisted cooling, space heating, and domestic hot water production. PV technology presently represents a technically and commercially mature solution capable of harnessing solar energy to generate and provide short- and medium-term electricity. In 2021, solar PV production achieved a remarkable growth of 179 TWh (22% increase), surpassing 1,000 TWh. At present, solar PV technology constitutes 3.6% of the global electricity production, solidifying its position as the third largest renewable electricity technology worldwide, trailing behind hydropower and wind (Solar PV,2023).

PV/T systems have been developed as a result of innovative approaches in solar energy systems. PV/T systems are hybrid systems formed by combining photovoltaic (PV) and thermal (T) technologies. In conventional photovoltaic systems, sunlight is directly converted into electrical energy, while in PV/T systems, sunlight is converted into both thermal and electrical energy. This results in higher efficiency in solar power generation and allows more efficient management of energy use.

PV/T technology represents a hybrid approach that integrates photovoltaic and solar thermal elements within a unified module, aiming to enhance the maximum efficiency of the module while optimizing spatial utilization. PV/T module exhibits the capability to generate electricity and heat in parallel, enabling it to harness the advantages offered by both solar thermal and photovoltaic technologies. Leveraging the dual functionality of PV/T allows for a greater conversion of solar energy compared to using PV or solar collectors individually, thereby facilitating the enhanced utilization of solar energy resources.

PV/T systems provide a viable solution for individuals seeking to invest in renewable energy sources while simultaneously contributing to the reduction of fossil fuel usage. Furthermore, the ability to store and utilize thermal energy for extended durations enhances energy efficiency and promotes more effective energy utilization. Consequently, PV/T systems represent a significant technological advancement resulting from innovative approaches in solar energy systems.

2. Basic Concept of PV/T

Photoelectric conversion stands as one of the most prevalent methodologies employed to harness solar energy. The relatively high cost associated with photovoltaic electricity generation arises primarily from its inherent low efficiency, typically ranging between 10% and 20%. Enhancing the photoelectric conversion efficiency becomes imperative in order to mitigate the expense per unit power generation. Extensive research indicates that the heat load represents one of the factors contributing to the observed low photoelectric conversion efficiency (Huaxu et al., 2020).

In PV solar cells, the semiconductor materials employed must possess a band gap energy within an appropriate range to effectively capture energy from sunlight. The sun's solar spectrum is concentrated in the visible and near infrared regions of the electromagnetic spectrum, with an energy range of 0.5 eV to 3.5 eV. In PV solar cells, photons excite electrons in the band structure of the semiconductor material and create free charges. However, the band gap energy of the semiconductor sets a threshold value at which the photon should have minimum energy. Therefore, photons with band gap energies between 1.25 eV and 1.45 eV are absorbed by the solar cell and converted into electrical energy. Photons with lower energy (0.5 eV-1.25 eV) are not absorbed because they are below the band gap energy and their energy cannot be used. Therefore, these low energy photons cannot be absorbed by the solar cell and solar energy cannot be utilized. Photons with higher energies (greater than 1.45 eV) have more energy than band gap energy and their excess energy is lost by thermalization (heat transfer). This dissipates as thermal energy and becomes unusable by the PV cell. For these reasons, the band gap energy in PV solar cells must be in a suitable range to effectively capture the energy spectrum of sunlight (Schockley & Queisser, 1961).

In 1961, William Shockley and Hans Queisser conducted an important study to determine the factors affecting the energy conversion efficiency. This study has become a fundamental reference for determining the theoretical upper limit of efficiency in solar cells, which is called Shockley-Queisser limit. This shows a fundamental restriction on the maximum efficiency attainable by a solar cell, taking into account various factors such as the semiconductor material's band structure and the spectral distribution of sunlight. Theoretical calculations by Shockley and Queisser determined that an ideal semiconductor solar cell has a maximum theoretical efficiency of around 33% for a bandgap of 1.34 eV. This represents the highest attainable efficiency based on theoretical considerations (Fig. 2.).

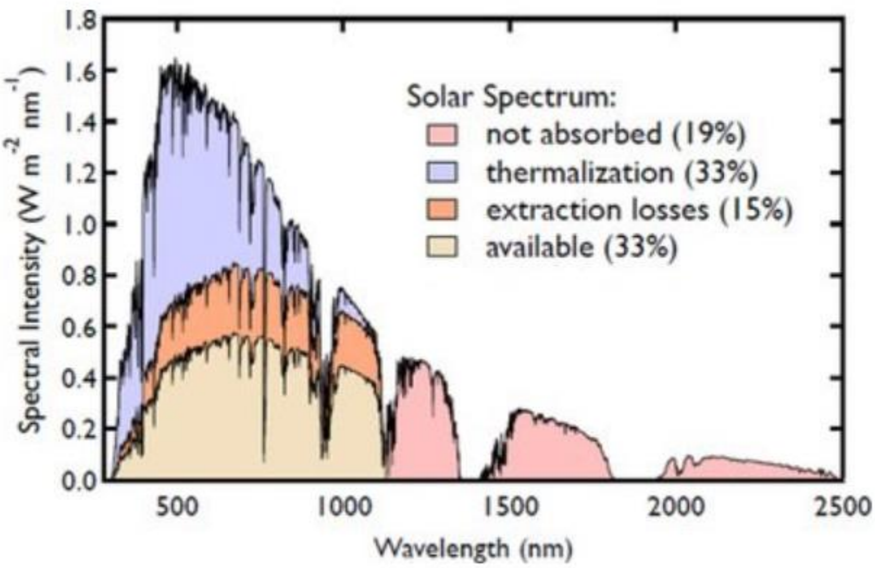

Figure 2. Shockley and Queisser limit (Schockley & Queisser, 1961).

To enhance the electrical efficiency of PV systems and optimize the utilization of incident solar radiation, it is essential to address the dissipation of heat accumulated on the PV surface. The effective management of this heat component is crucial to harness its potential and enhance overall system performance. PV/T, an innovative technology, has been developed to address this requirement by integrating heat extraction components and Photovoltaic cells within a single module. The integration of cooling mechanisms within photovoltaic (PV) cells allows for improved electrical efficiency by effectively managing temperature levels. This integration not only facilitates the cooling of PV cells, but also enables the extraction and utilization of the generated heat for heating purposes. As a result, this approach ensures a dual benefit of enhancing electrical efficiency while making productive use of the extracted heat. By implementing this approach, the PV/T solar collector can achieve greater efficiency from solar energy, thus enabling better utilization of solar energy. Figure 3 represents the network among different technologies for converting solar energy.

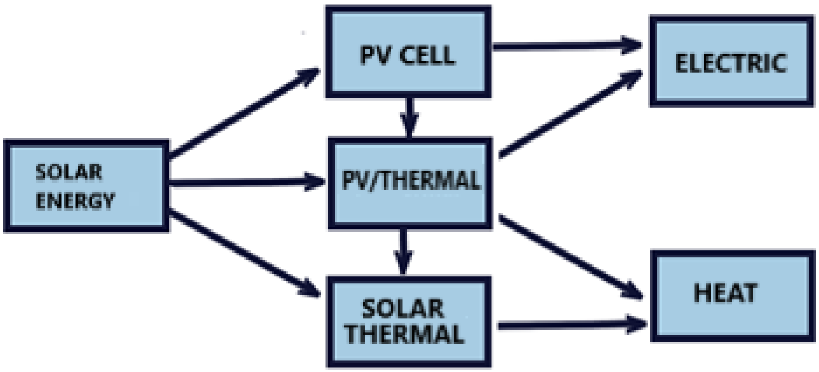

Figure 3. Interrelationship of different solar energy conversion technologies

A standard PV/T module demonstrates a sandwich-like configuration, comprising multiple layers. This structure primarily encompasses a top layer consisting of a top-down, transparent thermal flat coating. Positioned beneath this layer is the photovoltaic cell layer, which can either be placed directly underneath the cover with a small air gap or implemented as a commercial PV lamination. Additionally, tubes or channels are integrated within the absorber, allowing for the flow of fluids, while being securely attached to the PV cell layer. A layer with thermal insulation is positioned just beneath the flow channels. All of these layers are securely attached to a framed module using sufficient clamps and connections. Figure 4 illustrates a schematic diagram of the standard PV/T module structure

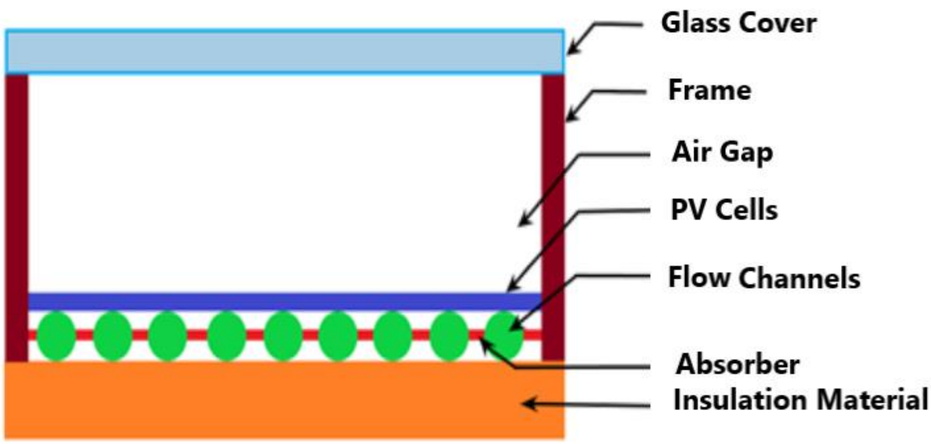

Figure 4. A typical PV/T module cross-section.

The PV/T module can collect different wavelengths of solar energy, resulting in improved energy and exergy efficiency. It has the capability to gather and convert a greater amount of solar energy within a given absorption area compared to individual PV panels or thermal collectors.

Consequently, this technology presents a promising opportunity for cost-effective and efficient power and heat generation (Zhao at al., 2011).A PV/T module represents an integration of a photovoltaic panel and thermal collector , combining their respective functionalities. The total efficiency is obtained by combining of the thermal efficiency (η_{th}) of the collector and the electrical efficiency (η_e) of PVs. Thus, the total efficiency can be given in the Equation (1);

$$\eta_0 = \eta_{th} + \eta_e \tag{1}$$

The enhanced efficiency brings significant advantages in terms of preserving the operational well-being of installed PV panels and diminishing energy expenses. Consequently, these advancements result in increased economic benefits for both investors and consumers. (Tripanagnostopoulos at al., 2005).

2.1 Enhancing the Thermal Efficiency of PV/T Collectors (η_{th})

The thermal efficiency (η_{th}) of a flat plate PV/T collector represents the ratio between the useful thermal energy and the total incident irradiation (I), providing a quantitative measure of the collector's ability to convert solar energy into heat. Mathematically, it can be expressed as follows;

$$\eta_{th} = \frac{\dot{m}C_p(t_{out}-t_i)}{I_s \times A_c} \tag{2}$$

In this equation, (t_i) is the fluid temperature at the collector inlet, (t_o) is the fluid temperature at the outlet. C_p is the specific heat (J/kg K), ($\dot{m}$) is the mass velocity, (I_s) is the solar density and (A_c) is the collector area of the medium

2.2. Enhancing the Electrical Efficiency of Photovoltaic Modules (η_e)

The electrical efficiency (η_e) of a PV module quantifies the relationship between the measured the total incoming solar radiation and output power, representing the module's ability to convert solar energy into electrical power.

$$\eta_e = \frac{I \times V}{I_s \times A_{panel}} \tag{3}$$

Here, A_{panel} is the area of the PV panel, I is the current and V is the voltage.

3. Classifications of PV/T Modules

PV/T modules exhibit significant variations in both structural and functional aspects. These categories of PV/T collectors include air based and water based PV/T configurations.

3.1. Air based PV/T

Air based PV/T module pertains to a solar heating system that integrates an additional layer of photovoltaic material laminated either above or below mechanically or naturally ventilated air ducts, enhancing the overall functionality of the module. This specific PV/T configuration can be implemented by incorporating an air gap between the rear surface of the PV modules and the building structure, such as the facade or pitched roof. Generally, this type of PV/T module is specifically engineered to cater to end-users who require a range of functionalities, such as hot air supply, space heating, enhanced ventilation, agricultural drying, and generation of electricity. In such modules, air can be delivered to the PV absorber from the top, bottom, or both sides, as illustrated in Figure 5. (Zhanga at al., 2012).

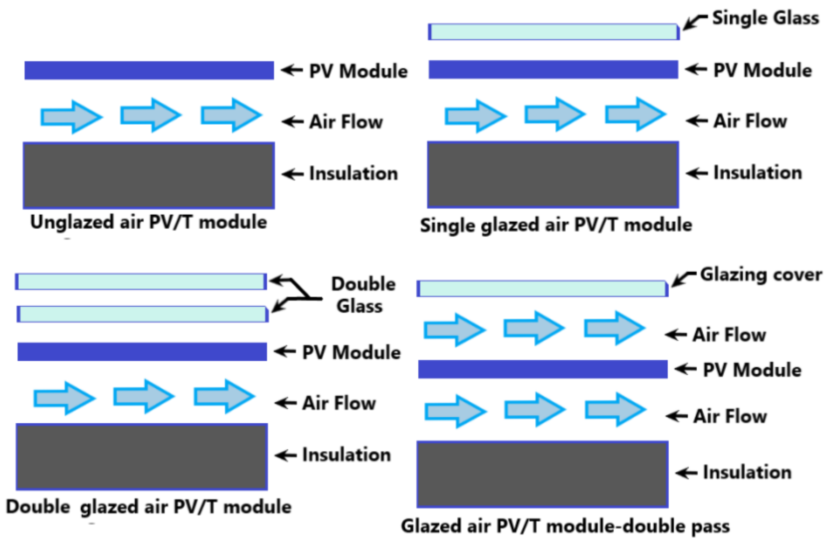

Figure 5. Cross sections of air-based PV/T modules.

3.2. Water based PV/T

In accordance with the illustration presented in Figure 6, a water-based PV/T module exhibits a structure akin to conventional flat plate solar collectors. The absorber within this module comprises a substantial quantity of PV cells interconnected either in series or parallel configuration, which are securely positioned beneath the absorber using either a coil or a series of parallel pipes. Water is compelled to flow through the pipes, and in the event that the water temperature remains relatively low, the PV cells experience cooling effects, thereby resulting in an augmentation of electrical efficiency. Simultaneously, the flowing water absorbs the heat generated by the PV cells, thereby becoming heated itself, and is subsequently directed to specific heat devices for the provision of heating. This portion of water can either be consumed or undergo cooling through heating services before being circulated back into the module to recover heat. In comparison to air-based systems, water-based PV/T systems exhibit superior cooling efficiency due to the higher thermal mass of water, leading to elevated levels of both thermal and electrical efficiencies in these systems. (Zhanga at al., 2012).

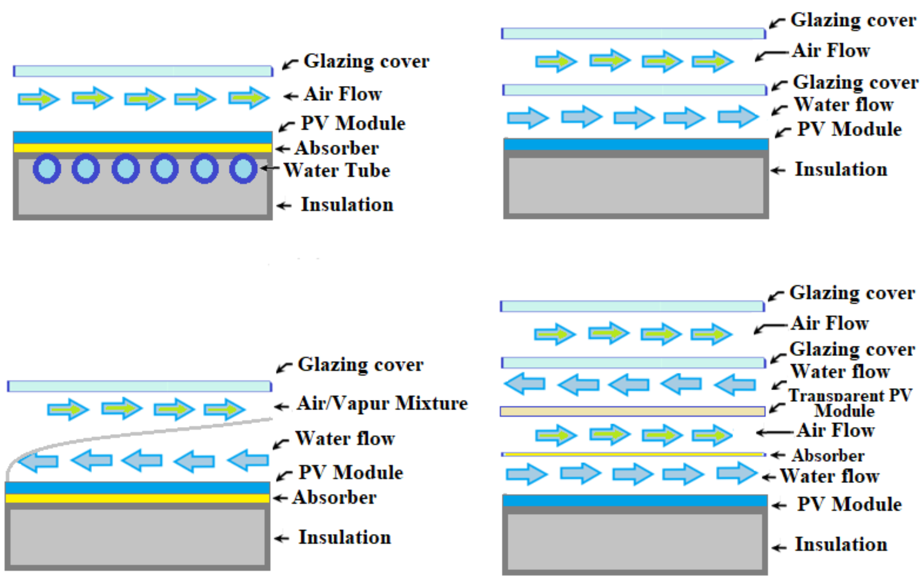

Figure 6. Water PV/T collector types.

3.3. General comparison of PV/T types and specifications

Table 3.1 presents a comprehensive comparison of the specifications among the four presently accessible PV/T types. (Quan at al., 2010; Solanki at al., 2009)

Air- and water-based PV/Ts appear to be risk-free and low-cost, and therefore can be considered as more practical systems for application. Air based PV/T has average efficiency %24-47 and water based has average efficiency %33-59, respectively. However, these two systems also have disadvantages, which are discussed in Table 1. In summary, the air-based PV/T type demonstrates suboptimal heat removal performance attributed to its limited thermal mass and less consistent air flow. The type of water, due to the change of water temperature during the working period, the increase in water temperature and the decrease in solar energy efficiency continue to increase, and during high temperature operation, the efficiency of heat removal significantly deteriorates.

Table 1. Comparison of the properties of different heat extraction methods.

PV/T type	Advantages	Disadvantages
Air Based	Simple Structure Low cost	Low thermal mass Large air volume High heat loss Poor thermal removal effectiveness
Water Based	Low cost Direct contribution High thermal mass Low flow volume	High PV temperature Complex structure Risk of leakage Possible piping freezing

4. Utilization of PV/T Technologies In Practical Applications

Although PV/T technology is in its infancy, the demand for PVT collectors has grown rapidly over the past two years. The following section presents a discussion on various commercial products and engineering projects associated with the application of PV/T technology.

Grammer Solar, a German company, has successfully developed an air-based PV/T solar collector known as 'TWINSOLAR.' This collector is specifically designed to preheat ventilation air in buildings, and it features an absorber area ranging from 1.3 to 12.5 m^2 (see Figure 7). The modules can be installed in either vertical or horizontal orientations on rooftops or on facades facing south, southeast, or southwest. Up to 125 m^3 of fresh hot air per hour is supplied to the room by the TWINSOLAR compact 2.0 and the system works reliably not only on sunny days but even when it is cloudy (Twinsolar, 2023)

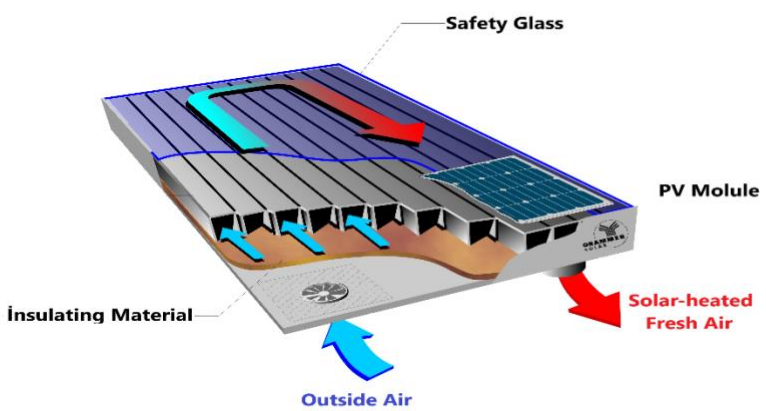

Figure 7. 'TWINSOLAR' PV/T product (Twin solar, 2023).

Within Denmark, SolarVenti units serve as primarily utilized solutions for providing ventilation, supplemental heating, and air dehumidification. Notably, larger capacity SolarVenti models demonstrate substantial thermal energy outputs and facilitate significant air circulation driven by buoyancy effects. These systems harness thermal energy from direct solar radiation across the entire spectrum, supplementing the space heating systems within residential or commercial buildings. Table 2 outlines the energy outputs associated with various SolarVenti models. (Solar Air Colectors, 2023).

Table 2. Energy output of different Solarventi models (Solar Air Colectors, 2023).

Model	Air volume (m^3/h)	Temperature increase (◦C)	Efficiency (%)	Annual Estimated Energy (kWh)
SV14	110	~30	66	660
SV20	140	~30	67	1340
SV30	200	~40	70	2100

Conserval Engineering, a Canadian company, offers SolarWall and rooftop SolarDuct products. SolarWall, an exclusive solar air heating system, effectively utilizes ventilation air for building heating and can be installed on walls or roofs to serve various purposes, such as building heating and facilitating agricultural and manufacturing drying operations. SolarWall represents a PV/T integrated system that boasts a considerably shorter payback period compared to standalone PV systems. In 2014, the SolarWall system was recognized by the American Society of Mechanical Engineers (ASME) as one of the nine most remarkable energy innovations of the past two centuries, alongside groundbreaking advancements such as the jet engine, electric generator, and light bulb.

Similar to the original SolarWall technology, SolarDuct systems harness solar energy to heat the ventilation air in buildings, leading to reductions in energy consumption, heating expenses, and greenhouse gas emissions. The implementation of rooftop solar heating plays a pivotal role in attaining Zero Carbon or Net Zero Energy Building objectives. These systems feature modular SolarDuct units that are installed and positioned in a manner akin to conventional PV solar panels, allowing the resulting SolarDuct arrays to seamlessly integrate with pre-existing rooftop mechanical equipment. (Solarwall, 2023). Figure 8 shows the product lines available in this company.

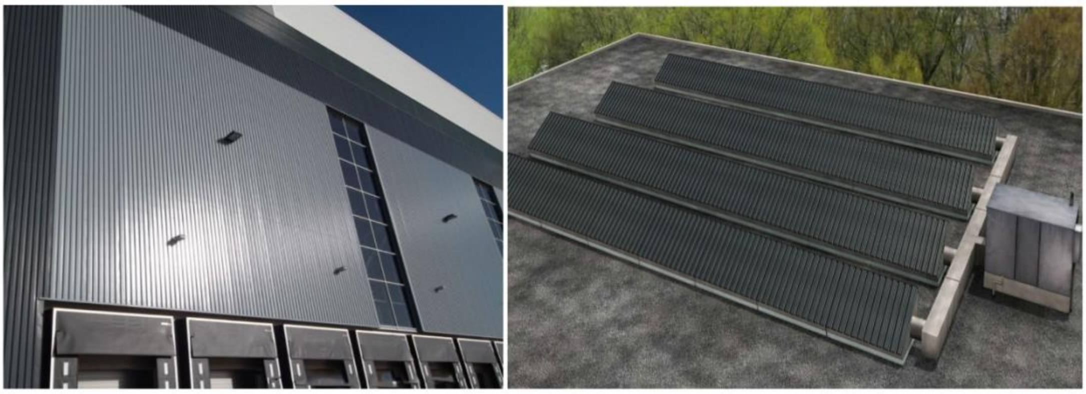

Figure 8. Solar air PV/T products from 'Conserval Engineering' (Solarwall, 2023).

Millennium Electric Ltd', an innovative company based in Israel, has introduced a groundbreaking PV/T System that revolutionizes solar energy utilization. This pioneering system enables the simultaneous conversion of solar energy into both thermal and electrical forms through a single hybrid configuration, visually represented in Figure 9 (Milenyum Solar, 2023). The Multi Solar System comprises panels resembling facade and roof tiles, designed to act as an active shell enveloping buildings. This inventive approach not only generates electricity but also actively regulates temperature within the living spaces. Achieved by facilitating the flow of water to cool the PV cells, the system efficiently captures and stores heat in a well-insulated tank. The integrated design showcases the company's commitment to sustainable energy solutions and marks a significant stride in advancing solar technology.

Figure 9. 'Millennium Electric PV/T System (Milenyum Solar, 2023).

Absolicon is a Swedish-based company and its focus is the development and production of concentrated solar collectors. These collectors are used to harness solar energy for a variety of applications such as heating, cooling and electricity generation. Absolicon's technology works by focusing the sun's rays onto a receiver tube using mirrors. The receiver tube contains a heat transfer fluid heated by concentrated solar energy. This heated liquid can be used for different purposes such as heating water or generating steam for power generation.

The T160 Solar Collector, one of the products of Absolicon company shown in Figure 10, is designed for applications used on an industrial scale. This collector uses mirrors to collect solar energy in a highly efficient manner and can track the sun's movement This collector includes a tracking system that tracks the sun's path throughout the day, maximizing the capture of solar energy. The T160 collector can be integrated into different systems such as heating networks, industrial processes and solar power plants (Absolicon, 2023).

Figure 10. 'T160' PV/T system from 'Absolicon' (Absolicon, 2023).

DualSun is a French company that produces dual-function solar panels. The company integrates solar panels into both photovoltaic (PV) systems for electricity generation and thermal (solar thermal) systems for hot water production. DualSun solar panels, shown in Figure 11, are capable of using solar energy for both electricity and hot water production at the same time. While these panels can generate electricity from sunlight via photovoltaic cells, they can also heat water via thermal pipes on the back of the panel. Thus, it is possible to obtain both electrical energy and hot water from a single panel. DualSun solar panels can be used in a variety of applications. For example, they can be used to meet electricity and hot water needs in residential, commercial and industrial facilities (Dualsun, 2023).

Figure 11. DualSun solar panels (Dualsun, 2023).

In Figure 12, Türkiye-based Solimpeks company produced Excel PV-T Hybrid panels. Excel PV-T hybrid panels both use sunlight to generate electricity from photovoltaic (PV) panels and collect solar energy via thermal collectors to heat water or use in heating systems. These panels combine two different technologies to use solar energy more efficiently. Excel PV-T hybrid panels can be used in various applications. They can be used in homes, businesses, industrial facilities and agricultural applications to increase energy efficiency (Solimpeks, 2023).

Figure 12. Excel PV-T Hybrid solar panels (Solimpeks, 2023).

5. Conclusion and Recommendations

Hybrid photovoltaic thermal systems are composed of integrated PV modules and heat evacuation units that are combined during installation. These systems possess the unique capability of generating both thermal and electrical energy simultaneously, resulting in a notably increased conversion efficiency of absorbed solar radiation compared to standalone photovoltaic systems. The demand for concurrent heat and electricity is prevalent across various sectors, including industries engaged in processes such as solar cooling, water desalination, solar greenhouse utilization, solar still operation, and solar heat pump functionalities. Given that industries exhibit substantial energy requirements for both heat and electricity, hybrid PV/T systems emerge as a compelling and practical solution to address the ever-growing energy needs associated with these diverse applications.

In regions with warm climates, photovoltaic systems often experience reduced efficiency due to the absence of sufficiently low ambient temperatures to cool the PV cells. The integration of a PV/T system offers a strategic solution by positioning a solar collector behind a solar photovoltaic (PV) array, providing selective cooling for the PV cells. This innovative approach not only enhances the overall efficiency of the system but also captures and repurposes a significant portion of the otherwise wasted energy, redirecting it for practical and effective applications. By utilizing water or air as cooling mediums within the solar collector, PV cells can be efficiently cooled, offering precise control over the circulation liquid's flow rate to maintain an optimal operating temperature range. This integrated approach to cooling and energy capture represents a promising advancement in photovoltaic technology, especially in regions with high solar exposure and elevated temperatures.

After conducting an extensive review of the existing literature, it becomes apparent that PV/T collectors possess significant potential as devices. However, there exists a clear need for concerted endeavors aimed at cost reduction and improved competitiveness. Focusing on elevating the efficiency and concurrently decreasing the expenses associated with PV/T collectors stands as pivotal measures to bolster the competitive edge of this technology. By addressing these key factors, the pathway towards establishing PV/T collectors as a formidable contender in the renewable energy landscape becomes more viable. Future work may focus on the following areas:

1. Increasing Efficiency: Studies should be carried out to increase the photovoltaic and thermal efficiency of PV/T collectors. Studies can be made on improved photovoltaic cells, thermal collection efficiency increasing design optimization and more efficient heat transfer techniques.

2. Integration and Design Improvement: The integration and design of PV/T collectors can be improved in terms of energy efficiency and thermal management. Focus can be placed on an efficient temperature control system, optimized PV/T configurations, and more efficient cooling methods.

3. Material and Production Costs: In order to reduce the costs of PV/T collectors, studies should be done on material selection, production processes and economies of scale. Steps such as the use of cheaper and more efficient materials, automation and the development of mass production techniques can reduce costs.

4. Marketing and Promotion Policies: Marketing strategies and incentive policies should be developed to encourage more widespread use of PV/T collectors. Measures such as government incentives, tax cuts and energy policies can encourage the adoption of PV/T technology.

Such studies will be important steps to increase the efficiency of PV/T collectors, reduce their costs and make them more competitive. In this way, more effective and sustainable energy systems that can use solar energy as both electricity and heat can be provided.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

References

Absolicon, (2024). Retrieved, from https://www.absolicon.com/solar-technology/ (Date Accessed: January 18, 2024)

Dualsun, (2024). Retrieved from https://dualsun.com/en/solutions/solar-electricity/ (Date Accessed: January 05, 2024)

Huaxu, L., Fuqiang, W., Dong, Z., Ziming, C., Chuanxin, Z., (2020). "Experimental İnvestigation Of Cost-Effective Zno Nanofluid Based Spectral Splitting Cpv/T System" Energy, Issn: 0360-5442, Vol: 194, pp. 116913. doi: 10.1016/j.energy.2020.116913

Millenyum Solar, (2023). Retrieved, from http://www.amitecmillenniumsolar.com/Products.html (Date Accessed: October 25, 2023)

Schockley, W., Queisser, H.J.J., (1961). "Detailed balance limit of efficiency of p-njunction solar cells", J Appl. Phys., vol. 32, pp. 510-519 doi:10.1063/1.1736034

Solanki, S.C., Dubey, S., Tiwari, A., (2009) "Indoor simulation and testing of photovoltaic thermal (PV/T) air collectors," Applied Energy, Elsevier, vol. 86(11), pp 2421-2428

Solar Air Collector, (2023). In Solarventi, Retrieved from https://www.solarventi.com/product-category/solar-air- colectors (Date Accessed: May 25, 2023)

Solar PV, (2023). In İEA. Retrieved, from https://www.iea.org/reports/solar-pv (Date Accessed: December 12, 2023)

Solimpeks, (2023). Retrieved from https://www.solimpeks.com.tr/hibrit-pv-t-panel/ (Date Accessed: December 09, 2023)

Solarwall, (2024). Retrieved from https://www.solarwall.com/technology. (Date Accessed: January 15, 2024)

Technologies", Renewable and Sustainable Energy Reviews, Elsevier. Vol 16 pp. 599-617 doi:10.1016/j.rser.2011.08.026

Türkiye elektrik üretim istatistikleri. (2023). Retrieved from https://www.teias.gov.tr/tr-TR/turkiye-elektrik-uretim-iletim-istatistikleri (Date Accessed: November 22, 2023)

Twinsolar, (2023).In Grammer Solar, Retrieved from https://grammer-solar.com/de/solarluft/solarluft-kollektoren/twinsolar.html (Date Accessed: November 22, 2023)

Tripanagnostopoulos, Y., Souliotis, M., Battisti, R., Corrado, A., (2005) "Energy cost and LCA results of PV and hybrid PV/T solar systems",Prog. Photovoltaics Res. Appl. Vol. 13 (3) pp.235-250 doi:10.1002/pip.590

Quan, Z., Li, N., Zhao, Y., Tang, X., (2010) "The experiment research for solar PV/T system based on flat-plate heat pipes" In: Proceeding the 17th Chinese national HVAC&R academic conference. doi:10.1109/APPEEC.2011.5749155

Zhao, X., Zhang X., Riffat S.B., Su X., (2011). "Theoretical investigation of a novel PV/e roof module for heat pump operation", Energy Convers Manage, vol. 52 pp. 603–614 doi:10.1016/j.enconman.2010.07.036

Zhanga, X., Zhaoa, X., Smitha, S., Xub, J., Yuc, X., (2012) "Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T)