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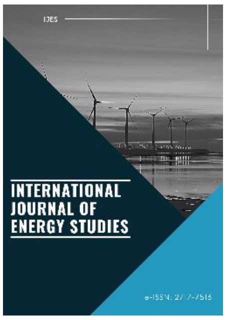

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Investigation of factors affecting photovoltaic thermal system efficiency

Sinan Dölek[a*], Gökhan Arslan[b]

[a]*Mersin University, Mechanical Engineering Department, sinandolekk@gmail.com , Mersin, Turkiye. ORCID: 0000-0001-9992-055X*
[b]*Mersin University, Mechanical Engineering Department, garslan@mersin.edu.tr , Mersin, Turkiye. ORCID: 0000-0002-2611-1740*
*(*Corresponding Author:sinandolekk@gmail.com)*

Highlights

- The PV/T system achieved its highest thermal efficiency (η_{th}) and electrical efficiency (η_{elec}) on January 24, 2023.
- Upon analysis of the experimental results, it was found that the photovoltaic thermal (PV/T) system, designed to reduce the temperature of the photovoltaic panel (PV), effectively utilizes solar energy while also improving the electrical efficiency of the panel.
- The panel electricity generation efficiency increases with the lowering of the cell temperature (T_{cell}) in PV/T panels.

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ABSTRACT

This experimental study investigates the effects of ambient temperature (T_{amb}) and solar irradiance on the efficiency of photovoltaic panels (η_{PV}). Experiments have shown that increasing these parameters, which affect η_{PV}, also raises panel T_{cell}, leading to decreased electrical energy production. A photovoltaic thermal (PV/T) system was created to enhance the η_{PV} by reducing T_{cell}. The excess heat generated in the cells is stored as hot water in this system. In the experiments, water was used as the heat transfer fluid (HTF) to lower the temperature of the PV panel. A closed loop with a 25-liter tank volume circulated the water at a constant mass flow rate of 0.0161 kg/s. The heat transferred from the panel cells to the HTF was accumulated in a 50-liter water tank. The η_{th} of a standard PV panel and a PV/T system, with and without a fan-cooled heat exchanger, was assessed. The results showed that the η_{elec} of the system without a fan-cooled heat exchanger increased by 2%. However, for systems designed for maximum efficiency, the presence of the fan-cooled heat exchanger caused a 13% reduction in η_{th}. Additionally, the temperature of the water in the tank increased by 50%. The efficiency of the designed PV/T system was analyzed without the use of a fan-cooled heat exchanger. The 8-hour average thermal efficiency was calculated to be 66.53%, with an electrical efficiency of 3.42%. The results are presented in graphs for better data visualization.

Keywords: Solar energy, PV/T systems, Energy storage, Heat transfer, Türkiye.

1. INTRODUCTION

High levels of irradiance and ambient temperature (T_{amb}) can cause an increase in the T_{cell} of the PV panels, leading to a decrease in overall efficiency. However, a PV/T system is more effective at mitigating the efficiency drop compared to conventional PV systems as the irradiance intensity and temperature increase. Additionally, this system is designed to enhance the efficiency of traditional PV panels and simplify energy storage enhancements. The study aims to analyze how changes in ambient temperature (T_{amb}) and solar radiation intensity affect the efficiency of a PV/T system.

Throughout history, various techniques and methods have been used to harness the energy of the sun. Initially used as a source of heat and light, the Sun is now utilized as an energy source in numerous fields thanks to technological advancements. As a result, new applications for solar energy are emerging daily. Ongoing research and development are focused on improving the efficiency of these systems, which are then evaluated experimentally [1-6]. Photovoltaic panels are commonly used to generate electricity from solar energy [7-10]. PV panel η_{elec} is affected by various parameters. For instance, an increase in ambient temperature and solar irradiance can cause a decrease in the η_{PV} [11, 12]. PV/T systems are one of the new technologies being developed to reduce PV panel temperature, using different techniques and methods [13, 14]. The research focuses on the analysis of PV/T systems integrating a PV system for electricity generation and a thermal collector system for hot water production. Depending on the technical characteristics of the module, it was observed that the η_{elec} of the PV cells decreased from 10.9% under normal conditions to 7.63% depending on the solar intensity. A 28% increase in the output power of the PV module was obtained. With linear solar intensity, the overall efficiency was reached 46.6% for thermal systems and 53% for PV systems [15]. An innovative PV/T system known as the iron-filled tube-plate (IFTP) system, which efficiently collects solar energy according to a different design, was investigated. The IFTP system uses a tube-plate solar collector to convert solar radiation into both electrical and thermal energy simultaneously. This was intended to increase the heat transfer between the heat sink and the photovoltaic cells. Experimental investigations were carried out at radiation intensity values ranging from 400-800 W/m^2 to improve the conventional structure of the module. The experiments shown that the module experiences a temperature drop of 3.5-6.5 °C, which increases the η_{elec} by 19.8% compared to the other tube-plate system [16]. In an independent investigation, the PV/T hybrid system designed capable of concurrently producing electricity and hot water. This comprehensive system comprised a poly-crystalline module, a storage tank, a controller, a water pump, and an unglazed flat plate. Test results highlighted the system's impressive performance, achieving a η_{th} of 35.33% and a η_{PV} 12.77%. Notably, the water tank's temperature experienced a notable increase from 26.2 °C to 40.02 °C during the testing phase [17]. In a comprehensive examination involving both numerical simulations and practical experimentation of a heat pipe PV/T system, η_{elec} was established at 9.4%, with the ηth concurrently measured at 41.9%. Notably, the numerical findings exhibited a deviation of under 5% from the corresponding experimental data [18]. In an independent research investigation, scholars explored the ηth of a PV/T system by introducing a cooling panel at the rear of the PV panel and integrating a water flow port. This modification led to a notable 9% increase in PV η_{elec}. Moreover, the study revealed that a rise of 1 °C in the panel surface temperature corresponded to an efficiency reduction of approximately 0.5% [19]. Furthermore, a similar investigation concentrated on assessing the η_{elec} and η_{th} of a water-cooled PV/T system employing single cover plates. This configuration led to a 14% reduction in the annual η_{elec} when compared to a single PV system. A comparative analysis of the annual η_{th} between the system and the thermal collector system demonstrated a 19% decline in efficiency. This decrease was linked to the elevated temperature of the circulating fluid [20]. On the contrary, PV/T systems employ air as the cooling medium. To tackle this challenge, a novel air-cooled system was devised, leveraging a natural convection effect. The system featured the installation of a thin metal sheet at the air duct's center, complemented by the addition of fins to enhance heat transfer on the rear wall surface. The research concluded that air-cooled PV/T systems present a cost-effective and efficient solution for fulfilling both electrical and thermal requirements in building applications [21].

In a study conducted in a temperate climate zone, a monocrystalline cell PV/T system was utilized. The system's surface is covered with photovoltaic cells, which account for 63% of its area. The study found that for hot water demand exceeding 80 kg/m^2 per unit collector surface area, a significant primary energy saving of 65% per day was achieved [22]. A study compared the η_{th} of a conventional solar water heater system with a PV/T system. The findings showed that the system was more efficient [23]. A new water thermosyphon PV/T system was developed, which included heat pipes to reduce temperature differences between the photovoltaic cells and increase the overall conversion efficiency of the system [24]. In addition, one researcher developed a PV/T system for an ice cream factory and analyzed the sensitivity of the system's efficiency and electrical parameters [25]. In addition to investigating a solar thermal energy storage system used for water heating [26].

The experimental study on PV/T systems used tap water as the HTF to cool the PV panel. Additionally, a fan-cooled heat exchanger was added to the system to compare the performance of PV/T systems. The study aimed to investigate the η_{th} and η_{elec} values of both PV panels and PV/T systems under the climatic conditions of Mersin, Turkey. The study analyzes the impact of temperature increase on PV panels, specifically on electrical power loss and storage of waste heat as thermal energy in a water tank for future use. A closed loop system with a 25-liter tank volume and water with a mass flow rate of 0.0161 kg/s as the HTF was used to facilitate fluid circulation. The heat transferred from the panel cells to the water was accumulated in a 50-liter water tank. The analysis assessed the η_{elec} and η_{th} of a standard PV panel and PV/T system, with and without a fan-cooled heat exchanger. The results showed a 2% improvement in the η_{elec} of the system and a corresponding 50% increase in the temperature of the water tank.

2. METHODS AND METHODOLOGY

This study examines the factors that affect the efficiency of PV/T systems. Figure 1 shows the study flowchart.

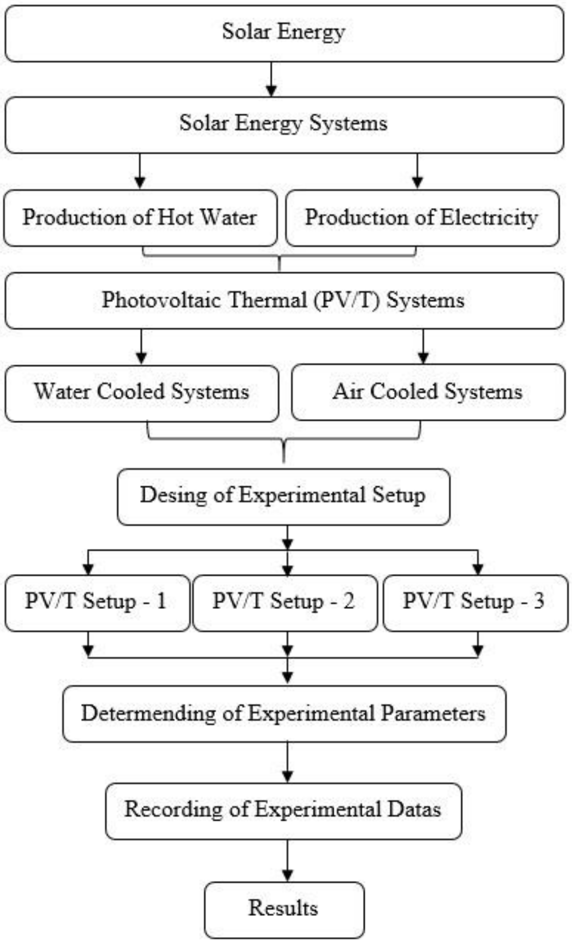

Figure 1. PV/T system schematic view

The experiment took place on the rooftop of the Mersin University's Yenişehir Campus. We developed a PV/T system comprising a panel, a circulation pump, and a storage tank, and carried out the initial set of experiments. To adjust the tilt angle of the solar panel, the experimental set's panel compartment was designed to be movable. The tilt angle of the solar panel was set at 45°. For the subsequent set of experiments, we integrated a heat exchanger into the system to reduce the temperature of the circulating water entering the panel. The experiments took place on January 22^{nd}, 23^{rd}, and 24^{th}, 2023, from 9:00 am to 4:00 pm. Water was used as the HTF in the system. The mass flow rate of the water during the experiment was 0.0161 kg/s. The specific heat value of the water utilized in the experiment was 4.186 kJ/kgºC. Experiments were conducted on January 22^{nd}, 23^{rd}, and 24^{th}, 2023 to investigate the η_{PV} and a designed PV/T system. The experiment lasted for 8 hours, during which measurement data were recorded every 5 minutes using a data logger. The first experiment involved circulating water in the PV/T system only, followed by a second experiment without cooling the PV panel. Finally, the third experiment used a fan-cooled heat exchanger to cool the circulating water and regulate its temperature within a specified range. During the experiments, the dry-bulb temperature ranged from 22 ℃ to 32 ℃, the wind speed varied from 0.1 m/s to 6.5 m/s, and the relative humidity ranged from 50% to 75%.

2.1. Desing of PV/T System with Water-cooled

The purpose of this study is to reduce the power loss caused by the rise in temperature of PV cells and convert this heat into thermal energy. In the experimental setup, the polycrystal photovoltaic panel ORBUS ORB-020P model was utilized to modify the PV/T systems. Technical characteristics for the PV panel are available in Table 1.

Table 1. Technical characteristics of Orbus ORB-020P

Characteristics	PV panel Orbus ORB-020P
Pmax	20 W
Power Tolerance Ratio	-3~+3 %
Impp	1.1 A
Vmpp	18.18 V
Isc	1.2 A
Voc	22.14 V
Temperature Cycle Range	45 ±0.2 %
Max. System Voltage	1000 V_{DC}
Max. System Current	10 A
Number of Cells	36
Weight	1.86 kg
Standard Test Conditions	Am=1.5, E=1000 W/m^2

Initially, an η_{elec} measurement was conducted for a traditional PV panel system. Subsequently, a PV/T system with a water-cooled hot water storage tank (setup-2) was developed. Finally, to investigate how the cooling water temperature impacts the efficiency of the system, a heat exchanger with fan-assisted cooling was incorporated into the system (designated as setup-3).

Figure 2 shows a detailed schematic view of the PV/T system design. The panel of the PV/T system (1) comprises a sheet with copper tubing that permits the circulation of HTF, and a sheet metal cover with a fiberglass coating on the inner surface to prevent heat loss (2). The panel also features a cooling water output port (3), a storage tank input port (4), and a copper coil specifically designed for transferring heat energy to the water in the storage (5). Storage tank output port (6), fan-cooled heat exchanger used for maintaining a constant temperature of the HTF entering the system (7), secondary storage tank directly connected to the pump (8), circulating pump (9), flowmeter (10), panel cooling water input port (11), PV/T system electrical output (12), and computer and data loggers (13) are presented schematically.

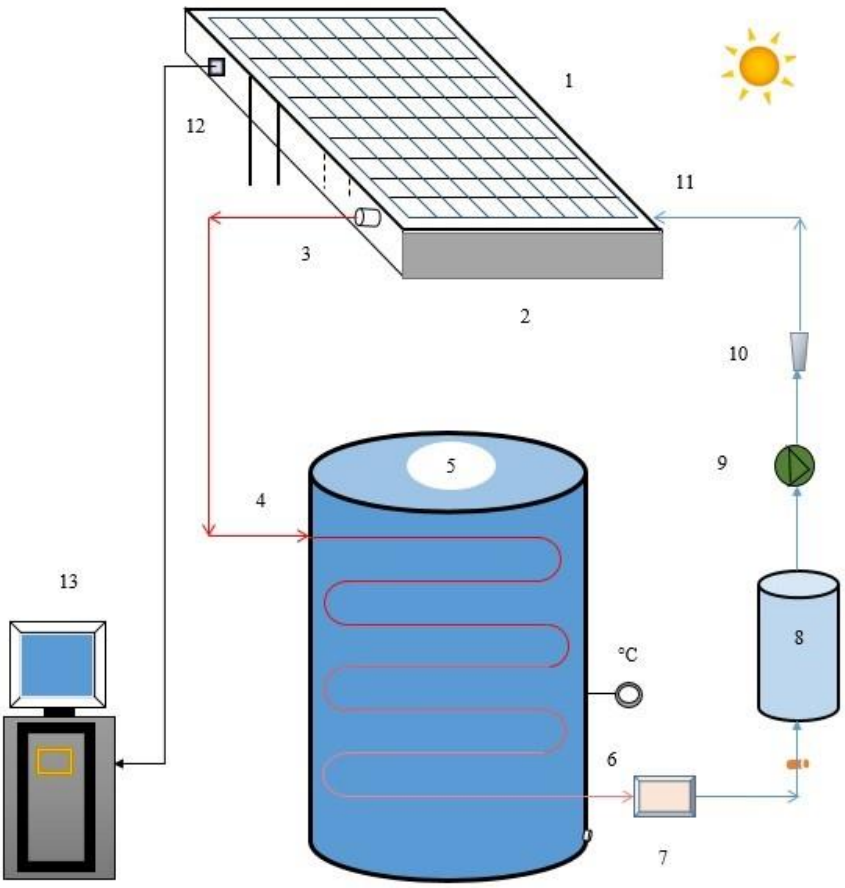

Figure 2. PV/T system schematic view

In this system, the water in the HTF tank is first pumped to the PV/T system. Here, a 3-meter-long copper pipe is attached to the absorber plate by copper welding. After the HTF sent by the pump completes its circulation in the PV/T system, it is transferred to the storage tank containing tap water. There is a 10-meter-long copper pipe in the storage tank. Then, the HTF transfers the heat from the PV panel to the water in the storage tank without contacting the tap water. Thus, the high heat generated in the PV panel is stored as hot water in the storage tank. Finally, the HTF is returned to the storage tank.

To decrease the temperature of the PV cell, a copper plate with a copper coil of 0.5 mm thickness and 6.35 mm outer diameter welded to it was positioned behind the panel as displayed in Figure 3. Additionally, thermal paste with a thermal conductivity coefficient of 1.25 W/mK was applied between the EVA and the copper plate to diminish thermal resistance. Afterward, a sheet metal cover with 4 cm thick glass wool was installed behind the panel to act as a thermal insulation material to prevent heat loss.

Figure 3. Application of copper pipe on a copper plate and PV panel

The PV panels utilized in the experiments consist of successive layers of glass, transparent EVA, solar cells, EVA, and TEDLAR, respectively. Solar irradiance penetrates the panel's surface through the glass and EVA layers before ultimately reaching the solar cells. While a portion of the solar irradiance reflects in the Earth's atmosphere, the remainder is converted into electrical energy through the movement of electrons resulting from diverse chemical reactions. The process of conversion leads to a temperature rise in the cell which deteriorates its efficiency over time. The heat is conducted to other layers and then convected and radiated to the environment.

The PV/T system's thermal energy output is analyzed for a family's typical hot water and electricity consumption. The per capita hot water requirement is 50 liters per day. The household's overall energy consumption serves as the electrical load [21]. To assess η_{PV}, monitor the temperature levels of each layer. Circulation of cooling water between the system and the well-insulated hot water storage tank depicted in Figure 4 with a 50-liter capacity occurs. A 28-mm outer diameter copper coil is present within the storage tank to extract heat from the cooling water.

Figure 4. Hot water storage tank

During the experiment, data loggers recorded temperature measurements at numerous locations on the structural elements of the system. To this end, we employed an Elimko E-680 series universal scanner recorder that enabled us to transfer temperature data to a computer environment and record them hourly.

Furthermore, we added a 24-volt 5-watt load to the system during the experimental setup to measure the current generated by the panel. The voltage and current were measured using two digital multimeters, while temperature values were obtained via a type K thermocouple. The TFA Nexus professional weather station was also utilized to monitor outdoor temperature, humidity, precipitation, wind speed, and direction with wireless sensors. Additionally, wind speed values and atmospheric pressure were measured using the main unit.

2.1.1. Experiment setup

The pyranometer used to measure the solar irradiance data was mounted in the same plane and direction as the panel. By the way, the total solar irradiance intensity on the panel of the PV/T system was measured. The system and pyranometer are positioned in the south direction and at an angle of 45°. The flow meter and the fan-cooled heat exchanger, which allows this flow fluid to enter the system approximately within a certain temperature range are shown in Figure 5.

Figure 5. A fan-cooled heat exchanger with PV/T system

Figure 6 demonstrates the multimeters utilized to measure the panel's current and voltage data. Type K thermocouples were employed to measure the temperatures of the experimental setups. Four thermocouples were affixed to the top and bottom of the test setups, while two thermocouples were mounted on the copper plate at corresponding points for measuring layer temperatures. Thermocouples were also attached to the inner and outer of the panel to measure cooling water temperatures. Additionally, we monitored the temperature changes of the water held in the tank using a thermocouple placed within it. We recorded temperature values at 9 different points to ensure greater accuracy in our analysis.

Figure 6. Control panel in experimental setups

2.2. Uncertainty analysis

A method known as uncertainty analysis is utilized to examine errors associated with experimental data. Eq. 1 was formulated by Kline and McClintock to measure the quantity in the R system, where the value is impacted by n independent variables, x_1, x_2, x_3,...,x_n.

The equation shows that R is a function of x_1, x_2, x_3,...,x_n. Error rates for these variables are represented as w_1, w_2, w_3,...,w_n, while the error rate for the size of R is defined as W_R [22]. Error rates for these variables are represented as w_1, w_2, w_3,...,w_n, while the error rate for the size of R is defined as W_R [23].

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \left(\frac{\partial R}{\partial x_3} w_3\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{0.5} \tag{1}$$

2.3. Efficiency of PV panel and PV/T systems

This study calculates the η_{elec} and η_{th} of PV/T systems. It compares the conventional PV panels with a water-cooled PV/T system designed to reduce the PV panel temperature. The study also evaluates the η_{th} of the system after a fan-cooled heat exchanger is added.

Eq. 2 calculates the electrical power P_{PV} generated by both conventional PV panels and designed PV/T systems, using the current I_{PV} and voltage V_{PV} of the PV panel. [24].

$$P_{PV} = I_{PV} V_{PV} \tag{2}$$

The PV panel's incident solar irradiance I_{rad} and surface area A_{PV} are the determining factors. The η_{elec} of the system is calculated by using Eq. 3 [25].

$$\eta_{elec} = \frac{P_{PV}}{I_{rad}A_{PV}} \quad (3)$$

Thus, specific heat C_p, mass flow rate $\dot{m}$, the inner temperature of the HTF to the system T_{in}, and the outer temperature of the fluid from the system are shown by T_{out}. To determine the η_{th} of the system, the useful energy Q_f in Eq. 4 is calculated at [26].

$$Q_f = \dot{m}C_p(T_{out} - T_{in}) \quad (4)$$

The thermal efficiency of the system (η_{th}) is calculated by using Eq. 5 [27].

$$\eta_{th} = \frac{Q_f}{I_{rad}A_{PV}} \quad (5)$$

The total efficiency η_{total} of the system is calculated by using Eq. 6 [28].

$$\eta_{total} = \frac{Q_f + P_{PV}}{I_{rad}A_{PV}} \quad (6)$$

3. RESULTS

The experiments were conducted from 9:00 a.m. to 4:00 p.m. to maximize the benefit of solar irradiance. The experimental data were obtained using three setups: setup-1 (uncooled PV panel) on January 23, 2023, setup-2 (PV/T system) with only HTF on January 24, 2023, and setup-3 (PV/T system with fan-cooled heat exchanger) on January 22, 2023.

The irradiance data recorded during the experiment under clear sky conditions, as shown in Figure 7, are very similar. The solar irradiance intensity on the panel surface varied between 560 and 590 W/m^2 at 9:00 in the morning, between 950 and 980 W/m^2 from noon to 13:00, and decreased to between 530 and 550 W/m^2 at 16:00.

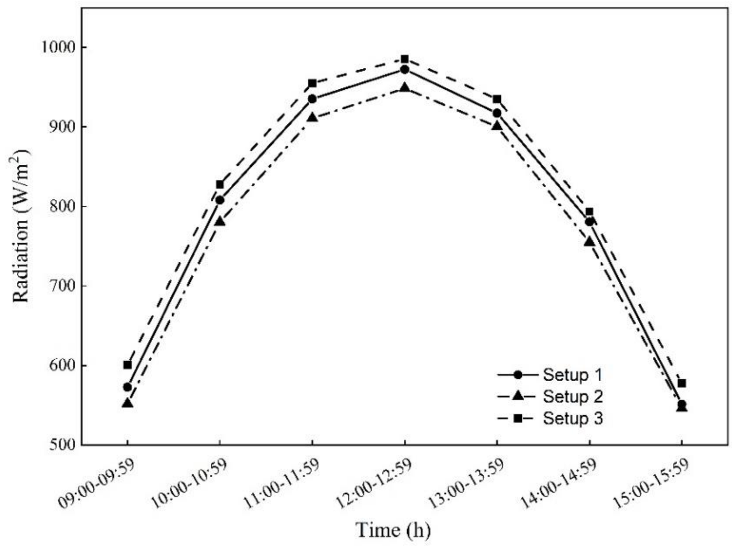

Figure 7. Hourly irradiance variations on experimental days

The thermal and electric efficiencies of PV/T systems are affected by various parameters, with meteorological conditions being the most significant. It is important to note that panel cell efficiency is dependent on both ambient temperature and solar irradiance intensity.

Hourly monitoring of ambient temperature was conducted during the experiments. The data in Figure 8 shows that the hourly temperature changes were consistent despite variations in ambient temperature during the experiments.

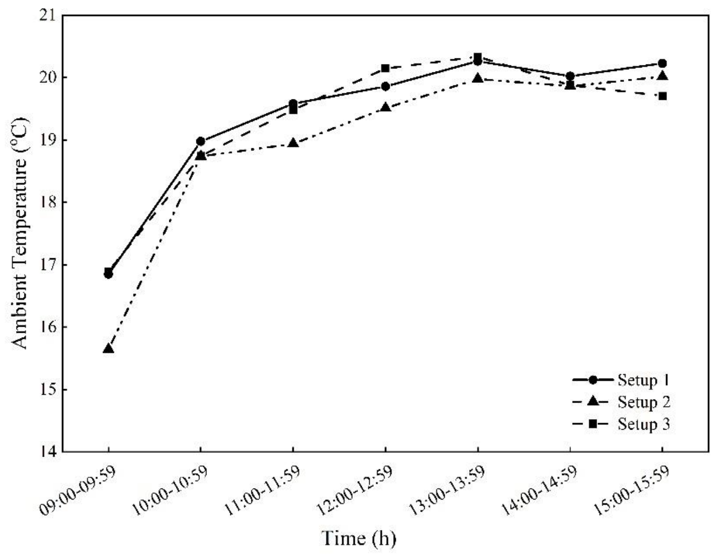

Figure 8. Hourly ambient temperature changes on experimental days

In setup-1, the PV panel surface temperature and T_{cell} increased from 36 °C in the morning to 53 °C in the afternoon. However, in setup 2, the panel surface and T_{cell} rose from 25.5 °C to a maximum of 37 °C. Figures 9 and 10 show the surface temperatures of the panels. The panel surface and T_{cell} were reduced by approximately 35% in setup 2. The surface temperature of setup 2 rose to 35.6 °C and the T_{cell} to 36.8 °C. With the inclusion of a fan-cooled heat exchanger in the system, the temperatures have decreased by an average of 4%.

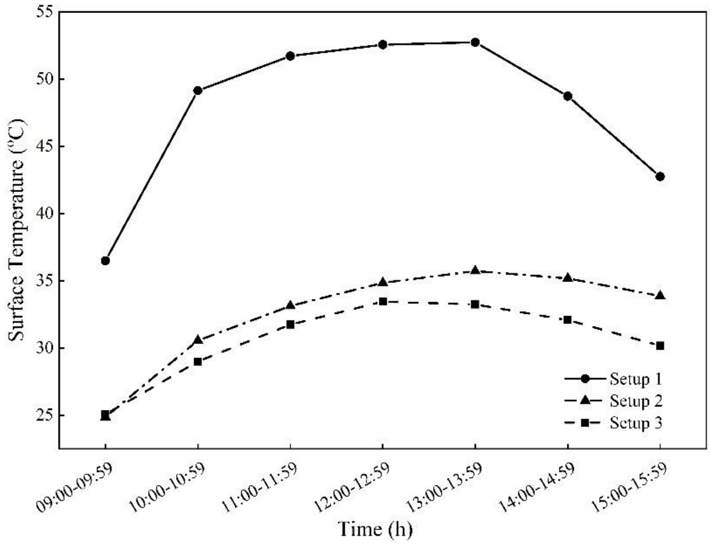

Figure 9. Hourly measurements of PV panel surface temperatures in experimental setups

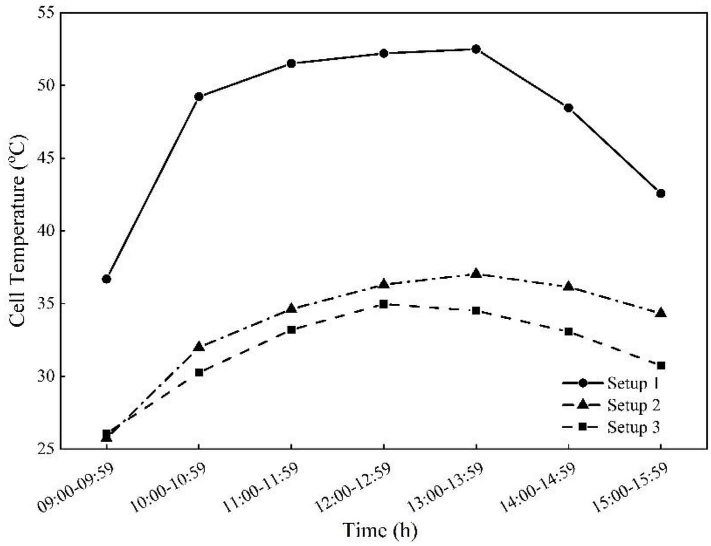

Figure 10. Hourly measurements of PV panel T_{cell} in experimental setups

Figure 11 shows the temperature variations of the setup's two layers. The T_{cell} increased to 37 °C, while the cooling water temperature at the inlet was a maximum of 30 °C and 32.2 °C at the outlet.

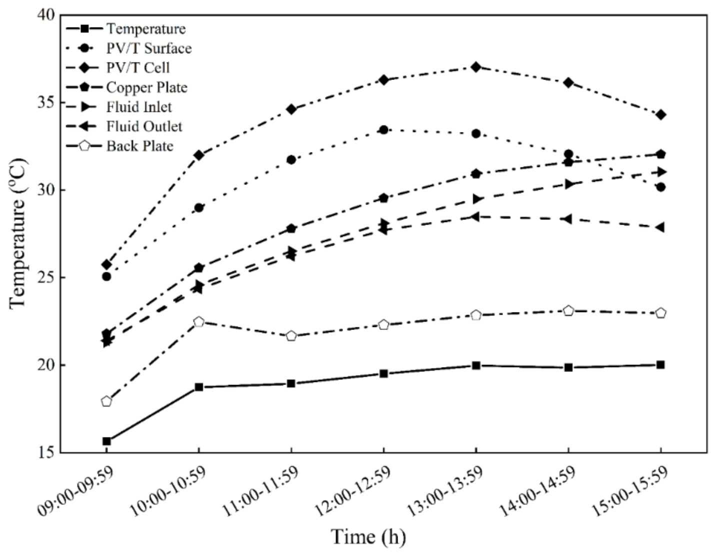

Figure 11. Hourly variation of layer temperatures of setup-2 (PV/T system)

However, Figure 12 shows that the cooling water inlet temperature is 27 °C and the cooling water outlet temperature is 28 °C. It can be observed that these temperatures change by an average of 1% when a fan-cooled heat exchanger is added to the PV/T system. The cooling water used in the system had a lower temperature difference during the experiment.

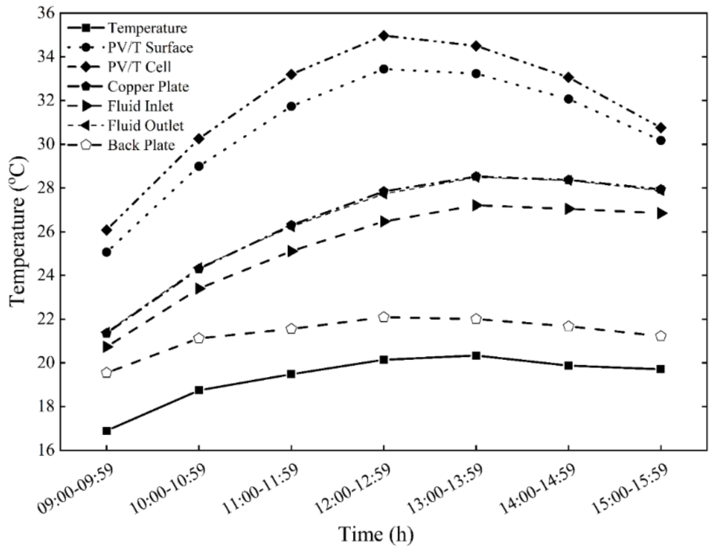

Figure 12. Hourly variation of layer temperatures of setup-3 (Heat exchanger with PV/T system)

In the designed setup-2, the heat energy extracted from the PV panel can typically be stored in water tanks of specific volumes. To ensure the most effective use of these systems, certain parameters must be considered to indicate their operating capacity and efficiency. Figures 13 and

14 monitor the electrical and thermal efficiencies of setup-1, setup-2, and setup-3 on an hourly basis. It is important to note that this evaluation is objective and based solely on the data presented. On average, the η_{elec} of setup-2 was 2% higher.

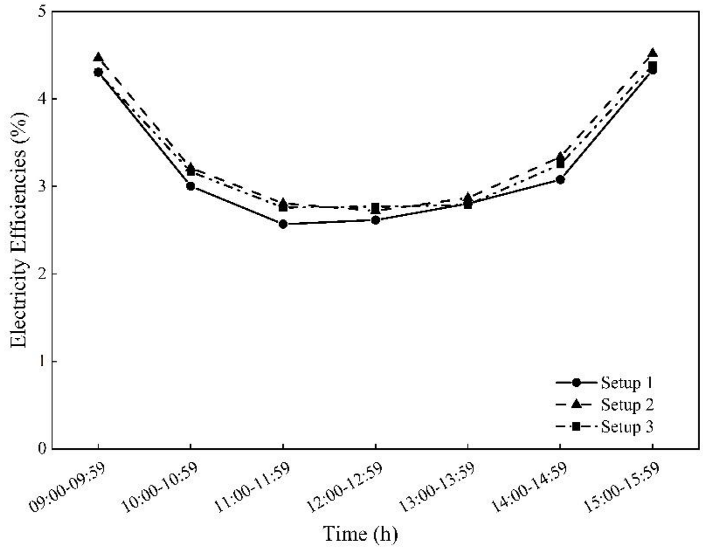

Figure 13. Hourly variation and comparison of electricity efficiencies in experimental setups

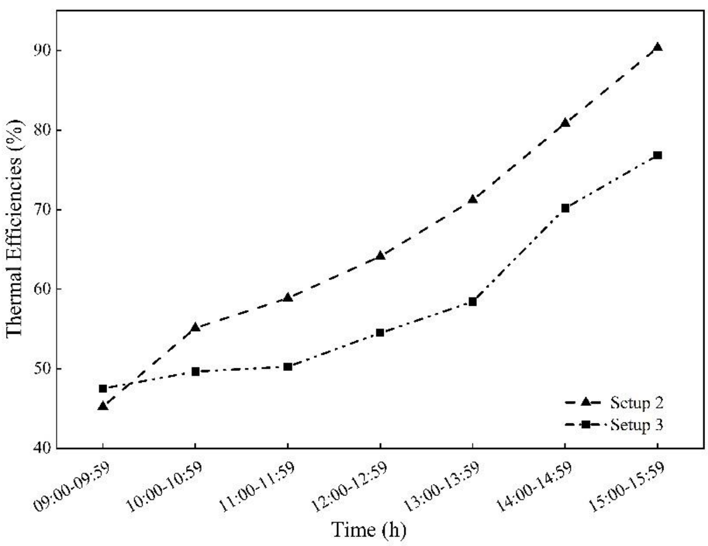

Figure 14. Hourly variation and comparison of thermal efficiencies in experimental setups

Figure 15 shows the η_{th} of setup-2 and setup-3 in the experiments. The results indicate a 13% difference in η_{th} between the two systems. The lower η_{th} of setup-3 can be attributed to the use of a fan-cooled heat exchanger and the limited temperature range of the HTF. The thermal efficiency difference between the two systems was 13%. The η_{th} of setup-3 was lower due to the HTF flowing within a specific temperature range and the fan cooling of the heat exchanger.

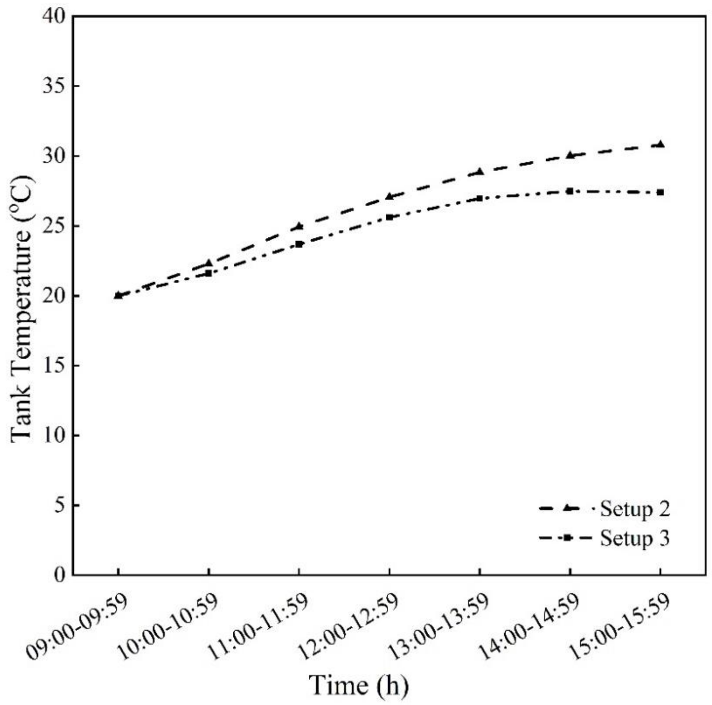

Figure 15. Variation and comparison of hourly tank temperatures for setup-2 and setup-3

Experimental data showed that the addition of a fan-cooled heat exchanger to the system reduced T_{cell} by 10%. Furthermore, it was found to improve η_{elec} by 2%. However, the η_{th} decreased by 13% when the HTF was cooled in the heat exchanger before entering the panel.

Experimental data were obtained using measuring instruments that comply with international standards. In general, when conducting studies using measuring devices produced according to international standards, it is important to consider potential errors that may occur in the measured data. Calculations made using the uncertainty analysis method, taking into account the factors arising from the devices and equipment used in these experimental studies, are shown in Table 2.

Table 2. Uncertainty of the measured and calculated quantities

Sources of uncertainty	Total uncertainty (%)
$W_{mass\ flowrate}$	3.39
$W_{Q\text{-}PV/T}$	2.06
$W_{thermal\ efficiency}$	2.13
$W_{electrical\ efficiency}$	3.91
$W_{pyranometer}$	14
$W_{data\ logger}$	0.5
$W_{multimeter}$	1.5
$W_{weather\ station}$	7.14

Apart from meteorological factors, the efficiency of setup-2 is also affected by design and material properties. It is crucial to consider these factors for optimal efficiency. Parameters such as the thermal conductivity of the HTF in the absorbent plate, technical characteristics of the layers, diameter of the pipes behind the absorbent plate, mass flow rate, and system size and design are important. In experimental studies, it is crucial to track the effects of parameters using appropriate technical infrastructure. Uncertainty analyses of the measuring instruments used to track data in experimental studies should always be conducted.

4. CONCLUSIONS

As the world's population grows, so do the demands for energy to meet the needs of people. However, the technologies used to meet these demands require energy themselves. Fossil fuels, which are being depleted at an increasing rate, are commonly used to produce energy. Wastes consisting of gaseous, liquid, or solid particles, such as aerosols, are known to contribute to global climate change due to the damage they cause to the environment. It is important to consider the negative ecological impact of energy production technologies, even those that are considered clean, as they may still cause permanent pollution. Technical terminology should be explained when first used.

On January 22, 2023, the first experiment involved adding an air-cooled heat exchanger to the designed PV/T system (setup-1). The system's efficiency was analyzed, and the 8-hour average thermal efficiency was calculated to be 58%, with an electrical efficiency of 3.34%. On January 23, 2023, the electrical efficiency of the PV panel (setup-2) was calculated as 3.25%, without the use of any HTF. In the final experiment on January 24, 2023, water was utilized as the HTF in the PV/T system (setup-3). The system's efficiency was analyzed, and the 8-hour average thermal efficiency was calculated to be 66.53%, with an electrical efficiency of 3.42%. Notably, the system did not employ a heat exchanger.

The PV/T system achieved its highest thermal and electrical efficiency on January 24, 2023. The absence of a heat exchanger in the system resulted in a higher calculated thermal efficiency. A heat exchanger typically regulates the temperature of the HTF as it enters the system. Consequently, the temperature of the water in the hot water tank increases at a slower rate. Upon analysis of the experimental results, it was found that the system, designed to reduce the temperature of the PV panel, effectively utilizes solar energy while also improving the electrical efficiency of the panel. The panel electricity generation efficiency increases with the lowering of the T_{cell} in PV panels. It has been seen that these systems can be developed with different technologies and designs to improve their electrical and thermal efficiency and to be used more effectively by adding an energy storage system.

NOMENCLATURE

P	modular power of PV, (W)
I	solar irradiance, (W/m^2)
A	the surface area of PV, (m^2)
I	current, (A)
V	voltage, (V)
η	efficiency, (%)
T	temperature, (℃)
Q	transfer of heat energy, (W)
ṁ	mass flowrate, (kg/s)
Cp	specific heat, (J/kg.℃)
Subscripts	
amb	ambient
cell	cell of PV panel
elec	electrical efficiency
th	thermal efficiency
PV	photovoltaic panel
PV/T	photovoltaic thermal system
rad	irradiance
in	inlet of HTF
out	outlet of HTF
f	useful

Abbreviations

EVA	ethylene vinyl acetate
HTF	heat transfer fluid

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DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Sinan Dölek: The PV/T system's experimental set used in this study was prepared by the author, who also conducted the analyses and wrote the manuscript. The main simulation scheme was designed, and the necessary experimental data were obtained through the author's designed experimental sets.

Gökhan Arslan: The author was the thesis supervisor of the first author.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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