# Investigation of Temperature Effect on Electrical Efficiency for a Photovoltaic - Thermal Hybrid System

**İbrahim BOZ[1], Abdulkadir AYANOĞLU[2], Gizem AYAS[3], Fatih ÜNAL[4]**

**Abstract:** ***In this study, the correlation between electrical efficiency and temperature for a hybrid photovoltaic-thermal (PV/T) system in which double solar panel and thermal collector were found to investigate performance of hybrid-system by independent of the network. One of the panel was cooled by water which pass through the single copper pipe while another one was without any cooling fluid in order to make a comparison between measured results. As a result of measurements, variables were observed at electrical power and its' efficiency which were obtained by cooled panel and other. Additionally, Mardin Meteorology Provincial Directorate data were compared with by measured results of obtained hybrid – system for more accuracy. As a result of cooled panel, an increase of 14.4% was defined at electrical output maximum power point which was calculated for electrical efficiency increased as from 7.5% to 8.6% for each values.***

**Keywords:** Solar system, Solar Radiation, photovoltaic panel, Thermal efficiency

## 1. Introduction

The high cost of photovoltaic panels in terms of production technology has caused to remain as a laboratory study for last decades. High efficiency (10%-20%) of photovoltaic panels costs, whose have decreased thanks to developing production technologies and materials science, showed themselves in the commercial area after 1980 and their usage became widespread [1]. The Europe's first grid-connected PV roof system with kWp power was established [2]. The difficulties in accessing traditional energy sources, the environmental problems and desire of countries to reduce their dependence on foreign energy usage which have played an important role in the increase at renewable energy investments in recent years [3]. With the decrease in photovoltaic panel costs, solar energy has become to the fore among renewable energy sources and the demand is increased day by day.

Photovoltaic panel cells used to generate electrical energy from solar energy perform process by converting photon energy absorbed from the sun. Surfaces formed with semiconductor materials produced are used for this energy conversion [4]. Most of the photon energy used by photovoltaic panel cells cannot be converted into electrical energy and is found in the system as heat energy. This heat energy causes the cells on the photovoltaic panel to heat up and this leads to a decrease in electricity efficiency. Behind the PV surface, the liquid is circulated by natural circulation or forced (pumped), reducing the temperature of the PV cell and making this heat to be emitted to the environment useful and usable [5].

By absorbing this temperature in the cell with the help of a system, the electrical efficiency of the system can be increased to higher levels. And also, literature studies on increasing the efficiency of photovoltaic systems are examined; In order to increase the electrical efficiency of the PV panel, desired to reduce the surface temperature of the PV panel by water. Which was 12% increase in electrical efficiency with a maximum power increase of 12.9W [6] while increase the efficiency to 9% [7].

In experimental study, air and water in the PV/T system to cool the surface of the photovoltaic panel which increased their PV efficiency by 6.5% with air and 7.5% with water [8]. Depending on the temperature increase in PV cells, they recorded a 0.85% efficiency decrease at 1$^{o}$C temperature increase which stated that a low-cost cooling system should be made to minimize this decrease in PV, and the heat removed in the cooling of PVs could be suitable for domestic or industrial uses [9].

In the photovoltaic/thermal (PV/T) system, they observed an electrical efficiency of 13.8% and a thermal efficiency of 54.6% by using water at 800W/m$^2$ radiation level and different flow rates. In the analyzes made at different flow rates, they showed that the flow rate affects the cooling of the panel surface and the thermal energy performance, and they stated that the temperature is significantly affected when the flow rate of the water is reduced from 0.041kg/s to 0.024kg/s [10]. On a day when the temperature was 39.9$^{o}$C, they placed pipes on the back surface of one of the two identical panels (175W) and cooled the panel surface by circulating cold water through it. They observed a power increase of 35% and an efficiency increase of 7% in surface-cooled PV [11].

Meteorological data obtained by experimental measurements in Mardin province were recorded for a period of one year as of 01.04.2021. Beyond examining the thermal and electrical efficiencies of the installed system, the operating performance for a load profile determined independently of the grid was also evaluated. At this point, this study will provide data as a source for such systems in Mardin province. In this study, an experimental performance evaluation of a PV/T hybrid system, established in Mardin Artuklu University Mardin Vocational School campus, was obtained. For this purpose, physical variables such as inlet-outlet temperatures, air temperature, solar radiation, panel cell temperature in water pipes were measured and recorded. In order to determine the electrical performance of the system, the current and voltage values at the maximum operating point at the electrical output of the system were measured. The current values drawn by these loads and the current values drawn from the PV/T system were recorded instantly and the instantaneous efficiency values of the system were determined. Literature studies are given in Table 1.

**Table 1:** Literature studies study models

| Working models | PV type | increase in efficiency | Reference |
|---|---|---|---|
| PV/T cooling system (water) | monocrystalline | %12 | [6] |
| PV/T hybrid system (water-air) | polycrystalline | %6, 5-7, 5 | [8]. |
| Wind effect on PV surface (air) | --- | %9 | [7]. |
| PV temperature effect | --- | 0, 85 | [9]. |
| PV cooling system (water) | monocrystalline | %7 | [11]. |
| PV cooling system (water) | --- | %13, 8 | [10]. |

## 2. Materials and Methods

### 2.1 The experimental setup

Two PV panels, Copper pipe for water circulation, DC power measuring device, Measurement ohmic resistance, load resistance, Temperature sensor, Pyranometer, Data Logger in the experimental system established in Mardin Artuklu University Mardin Vocational School campus to determine the electrical and thermal properties of the PV/T system. The experimental setup is shown in Figure 2.1.

**Figure 2.1:** PV/T system installed on Mardin Artuklu University Mardin Vocational School campus

In the system, a copper pipe was placed on the underside of one of the two PV panels for water circulation (Figure 2.2), while no changes were made for the cooling process in the other panel. Mains water is connected to the inlet part of the pipe connections made, and water is stored in the pipes with the help of the tap at the outlet part. In Tables 2 and 3, the materials used in the experiment system and their properties are given.

**Figure 2.2:** Placing water pipes at the bottom of the PV panel

**Table 2:** Materials used in the experimental setup

| Product name | Properties | The quantity it measures |
|---|---|---|
| pyranometer | ML-01 | Radiation |
| thermocouple | J Tipi | temperature |
| DC power meter | 4-20 mA | |
| Data Logger | M70R 6 kanallı | recording data |

**Table 3:** PV panel specifications

| Dimensions | 945x675x35 mm |
|---|---|
| Rated Current (A) | 5.56 |
| Short Circuit Current (A) | 6.06 |
| Rated Voltage (V) | 18 |
| Open Circuit Voltage (V) | 22 |

### 2.2 Measuring Setup

In order to examine the operating performance of the system, the basic operating principle diagram of which is given in Figure 2.3, panel temperatures, currents and voltages were measured and the measurements were carried out using the measurement elements given in Table 2. In order to compare the maximum output power of the system with and without cooling, the panel output current-voltages were measured. In addition, necessary meteorological measurements (irradiation amount, wind speed and air temperature) were made and recorded with a datalogger in order to determine the working performances. With the help of PanguAutomationM70R data logger, the data were measured and recorded at intervals of 1, 30 and 60 minutes. By programming the inputs and outputs of the datalogger, a load profile has been obtained and controlled.

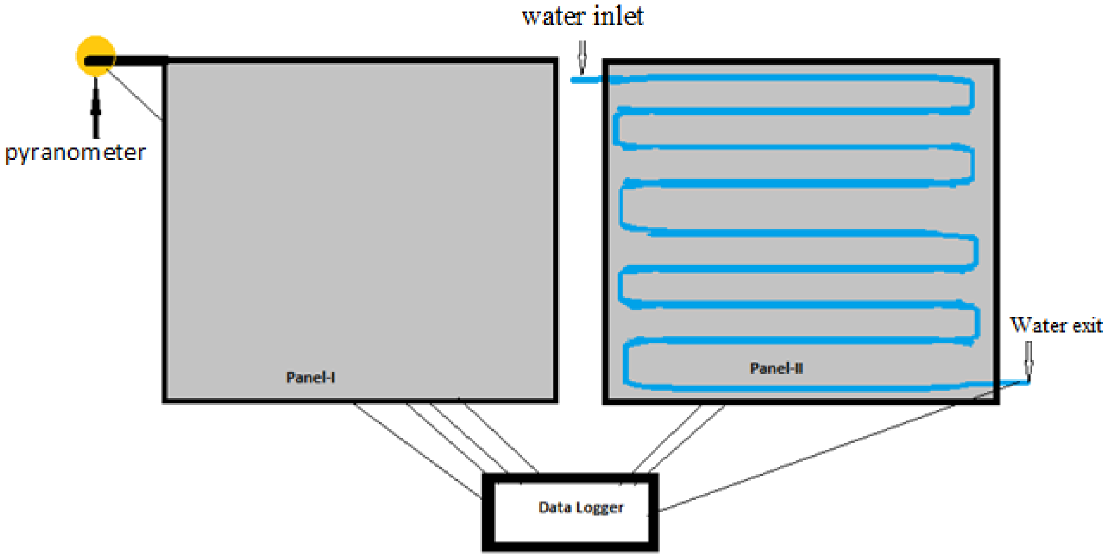


**Figure 2.3:** The schema of the experimental set we prepared

### 2.3 Efficiency and energy calculations of the system

Electrical efficiency calculations of PV panels were calculated using Equation 1 [12]. The output power P of the PV module is calculated using the measured voltage and current values as follows.

$$P=V.I \quad (1)$$

$$\eta e=P / A_m.I(t) \quad (2)$$

Here, ηe is the panel efficiency I (t) unit of the amount of solar radiation per unit area, W/m$^2$ and Am is the panel surface area and its unit is m2. In PV panels, with increasing cell temperature, there is a significant decrease in open circuit voltage and filling factor and a small increase in short circuit current. This results in a decrease in electrical efficiency. According to these effects, the electrical efficiency is rearranged and given in Equation 3.

$$\eta e=\eta_0(1-\beta_0(T_c-25) \quad (3)$$

Here, $\eta_0$ is the electrical efficiency of the PV cell under standard test conditions (25 °C air temperature and 1000 W/m$^2$ radiation) and $\beta_0$ is the electrical efficiency thermal coefficient. $\beta_0$ value depends on the properties of the materials from which the PV panel is produced. Approximately 0.0045/K is taken for crystalline silicon, 0.0035/K for CIS, 0.0025/K for CdTe and 0.002/K for a-Si [13]. The thermal efficiency of the system can be calculated using Equation 3. The mass flow rate of the system, the difference between the inlet and outlet temperatures of the fluid entering the PV/T panel, the efficiency, which changes directly proportional to the specific heat of the fluid, varies inversely with the radiation coming to the total surface [14].

## 3. Results and discussions

In order to examine the effect of operating the PV/T panel with or without cooling with the help of fluid (water) on the operating performance, the current-voltage temperature values and power values at the maximum operating points were measured on 05.05.2021. In the measurements made between 09: 30 and 12: 30 at 1075.4W/m$^2$ radiation value and 22.5°C air temperature, the average output power value of the uncooled panel is 52 W, while the average power output of the cooled panel is 59.5 W. In the case of cooling the panel, a power increase of approximately 14.4% was obtained. In the graph given in Figure 3.1, the temperature values and output power values of the panels with and without cooling for one day are shown.

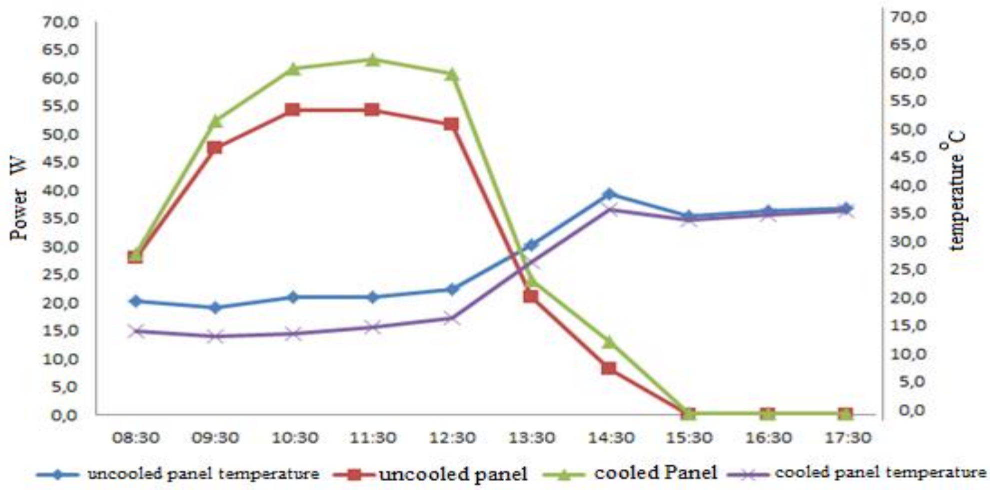


**Figure 3.1:** The daily average power values of the cooled and uncooled panels, depending on the temperature

In the radiation measurements made to determine the grid-independent electrical performance of the PV/T system, the lowest day of radiation between 1-7 May 2021 was 274 W/m2/day on August 5, while the highest day was 323 W/m2/day on 5 May.

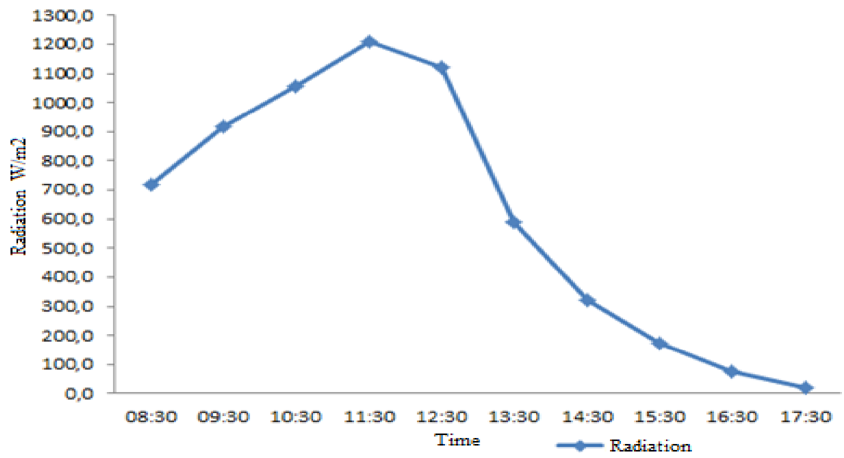


**Figure 3.2:** Solar radiation values for May 5

The data received from Mardin Meteorology Provincial Directorate between 1-7 May 2021 are shown in the chart below.

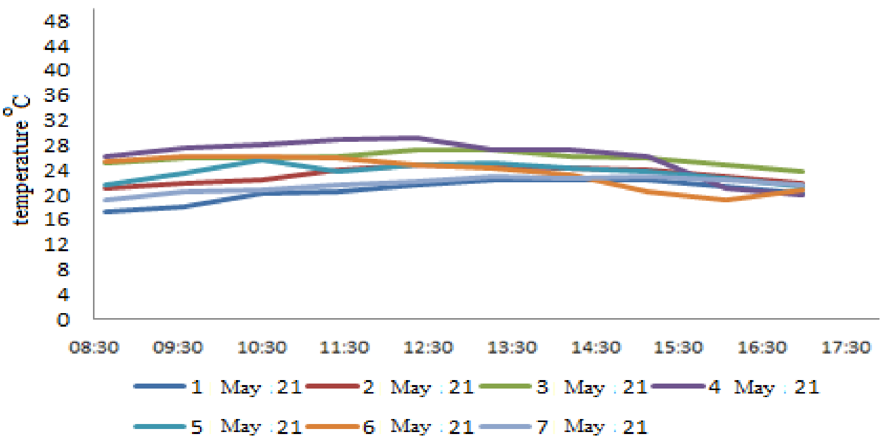


**Figure 3.3:** Air temperature data for 1-7 May from Mardin Meteorology Provincial Directorate

Between 1-7 May 2021, the lowest day of the radiation is May 5 with 274 W/m$^2$/day, while the highest day is May 5 with 394 W/m$^2$/day.

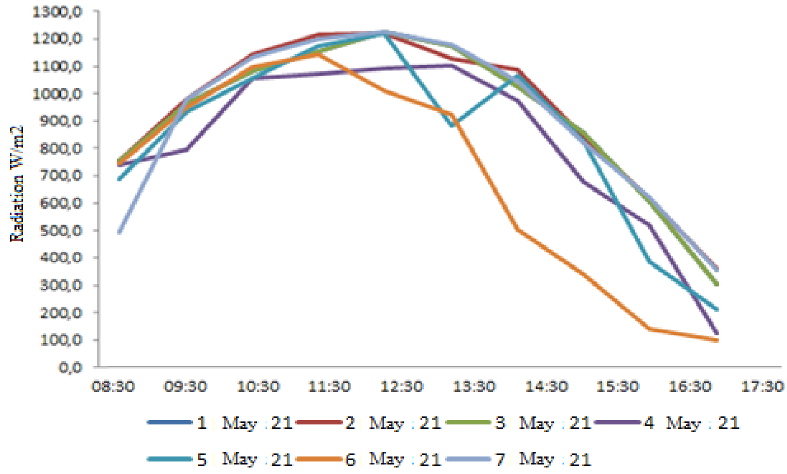


**Figure 3.4:** Hourly solar radiation data for 1-7 May from Mardin Meteorology Provincial Directorate

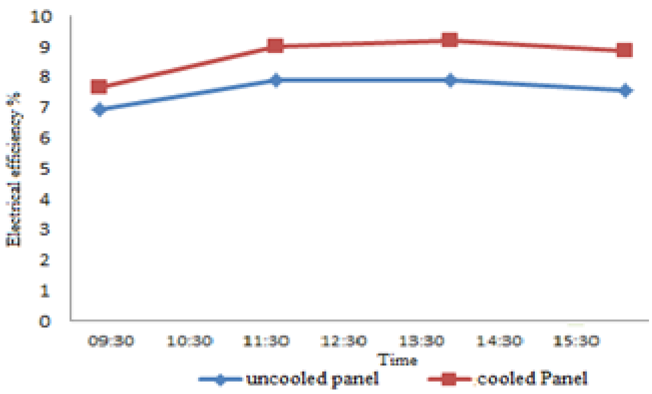


**Figure 3.5:** Electrical efficiency changes of cooled and uncooled panels over time

## 4. Conclusion

In this study, the relationship between electrical efficiency and temperature in a hybrid PV/T system in which solar panel and thermal collector are used together in the experimental set up in the territory of Mardin Artuklu University, Mardin Vocational School was investigated. As result of experiments and calculations were declared by the following matter.

The electrical efficiency values of the panels with and without cooling means calculated by Equation 1 are given in Figure 5. As a result, it was observed that the electrical efficiency obtained by using the cooling system panel increased from approximately 7.5% to 8.6%.

As the radiation on the panel increases, the panel temperature also increases. Increasing panel temperature reduces the power produced. This is clearly seen in equation 3. Passing mains water through the pipes placed behind the panel allowed the panel to cool. As a result, power has increased. The graphic showing the relationship between power and temperature is given in Fig.

In this experimental study using water, the electrical power value produced by reducing the panel surface temperature from approximately 20.8 $^{o}$C to 15.3 $^{o}$C, increased from 52W to 59.5W on average at the end of 7 days, resulting in a 14.4% power increase. has been done. This value is in agreement with the studies seen in the literature.

In this study, the solar panel in the experimental setup set up in the garden of Mardin Artuklu University Mardin Vocational School. In order to increase the efficiency with more radiation, the experimental setup can be installed on the solar tracking system and analyzed again. The use of the mains water used in the system and whose temperature increases due to the panel in the houses will ensure the recovery of the idle energy.

## Acknowledgment

The authors would like to thank Mardin Artuklu University Project Support Unit (BAP) with the project No.: MAÜ.BAP.20.MYO.015

## References

[1] Fahrenbruch, A.L. ve Bube, R.T., (1983), “Fundamentals of Solar Cells”, Academic Press
[2] Erge, T & Hoffmann, V.U & Kiefer, Klaus. (2001). The German experience with grid-connected PV-systems. Solar Energy. 70. 479-487
[3] Girgin, M. H., Bir fotovoltaik güneş enerjisi santralinin fizibilitesi, karaman bölgesinde 5 mw’ lık güneş enerjisi santrali için enerji üretim değerlendirmesi ve ekonomik analizi, Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, Enerji Enstitüsü, (2011)
[4] Markvart, T. and Castaner. L., **Solar Cells: Materials, Manufacture and Operation**, Elsevier Ltd., (2005).
[5] Engin D. (2008). Yarı-Saydam Güneş Pili / Termal Toplayıcı PV/T) HibritSistemin İzmir Koşullarında Analizi, CBÜ Soma Meslek Yüksekokulu Teknik Bilimler Dergisi, 10 (2)
[6] Gül M., & Akyüz E. (2019). Fotovoltaik-termal (PV/T) bir sistemin deneysel performansının incelenmesi. BAUN Fen Bil. Enst. Dergisi, 21(1): 444-458
[7] Du C. J., Fell B., Duck D., Chen K., Liffman Y., Zhang M., Gu Y. Zhu (2016). Evaluation of photovoltaic panel temperature in realistic scenarios, Energy Conversion and Management 108: 60–67
[8] Rawat P, & Dhiran T. S. (2017). Comparative Analysis

of Solar Photovoltaic Thermal (PVT) Water and Solar Photovoltaic Thermal (PVT) Air Systems, International Journal of Civil, Mechanical and Energy Science (IJCMES), 3 (1)

[9] Sahay A., Sethi V. K., Tiwari A. C., Pandey, M. (2015). A review of solar photovoltaic panel cooling systems with special reference to Ground coupled central panel cooling system (GC-CPCS). Renewable and Sustainable Energy Reviews, 42: 306-312

[10] Fudholi A., Sopian K., Yazdı M., Ruslan., Kazem, H. (2014). Performance analysis of photovoltaic thermal (PVT) water collectors, Energy Conversion and Management, 78: 641-651

[11] Kabul A., & Duran, F. (2014). Isparta İlinde Fotovoltaik / Termal (PV/T) Hibrit Sistemin Performans Analizi. Uluslararası Teknolojik Bilimler Dergisi, 6 (1): 31-43

[12] Engin, D., Yapı ile bütünleştirilebilir güneş pili/termal toplayıcı (pv/t) hibrid sistemin performans analizi ve optimizasyonu, Doktora Tezi, Ege Üniversitesi, Fen Bilimleri Enstitüsü, İzmir, (2006)

[13] Ceylan, İ., Gürel, A. İ., Demircan, H., Aksu, B., Cooling of a photovoltaic module with temperature controlled solar collector, **Energyand Buildings**, 72, 96-101, (2014).

[14] Engin D., Çolak M., Yarı-saydamgüneşpili / termaltoplayıcı (pv/t) hibridsistemin İzmir koşullarındaanalizi, **Celal Bayar Üniversitesi Soma Meslek Yüksekokulu Teknik Bilimler Dergisi**, 2 (10), (2008).