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Experimental İnvestigation of Photovoltaic Panel Surface Temperatures and Electricity Production in Summer

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PV Cooling

Abstract: Due to the efficiency drops in solar panels at temperatures above 25°C, various panel surface temperature reduction studies are ongoing. Phase change materials can cool surfaces without needing an external energy source, but their performance varies depending on seasonal temperatures. Within the scope of this study, instantaneous panel surface temperatures in August were evaluated to present the panel temperature value of the summer months in Bingöl. Along with panel surface temperature values, instantaneous voltage, current, power, and efficiency results were also evaluated. According to the temperature measurement results made with thermocouples, the average and local maximum temperature on the front surface of the panel was 55℃, and 65℃ respectively. On the other hand, according to the thermal camera measurement, it was understood that there was no homogeneous temperature distribution throughout the panel and the temperature value increased to 85℃ in some local areas. It has been understood that this temperature value is far from the panel operating conditions, therefore it is essential to cool the panels with appropriate phase change materials.

Yaz Aylarında Fotovoltaik Panel Yüzey Sıcaklıkları ve Elektrik Üretiminin Deneysel İncelenmesi

Anahtar Kelimeler
Fotovoltaik panel,
Elektrik,
Sıcaklık,
PCM,
TEC,
PV Soğutma

Öz: Güneş panellerinde 25 °C'nin üzerindeki yüzey sıcaklıklarda verim düşüşleri nedeniyle panel yüzey sıcaklığının düşürülmesi üzerine çeşitli çalışmalar devam etmektedir. Faz değiştiren malzemeler harici bir enerji kaynağına ihtiyaç duymadan yüzeyleri soğutabilir, ancak performansları mevsim sıcaklıklarına bağlı olarak değişir. Bu çalışma kapsamında Bingöl ilinde yaz aylarına ait panel sıcaklık değerini ortaya koymak amacıyla Ağustos ayı anlık panel yüzey sıcaklıkları değerlendirilmiştir. Panel yüzey sıcaklık değerlerinin yanı sıra anlık gerilim, akım, güç ve verim sonuçları da değerlendirilmiştir. Termokulplar ile yapılan sıcaklık ölçüm sonuçlarına göre panelin ön yüzeyinde ortalama ve yerel maksimum sıcaklık sırasıyla 55 °C ve 65 °C olarak tespit edilmiştir. Öte yandan termal kamera ölçümüne göre panel genelinde homojen bir sıcaklık dağılımının olmadığı ve bazı yerel bölgelerde sıcaklık değerinin 85 °C'ye kadar çıktığı anlaşılmıştır. Bu sıcaklık değerinin panel standart çalışma şartlarından çok uzak olduğu, dolayısıyla panellerin uygun faz değiştirici malzemelerle soğutulmasının önemli olduğu anlaşılmıştır.

1. INTRODUCTION

Solar energy systems are examined in two parts: collector applications, thermal systems, and photovoltaic panel (PV) applications, which produce electrical energy. Although the efficiency of solar thermal systems is known to be around 60%, the efficiency of PV panels is low, it changes between 12-20% [1,2]. PV efficiency depends on the panel material, panel type, weather conditions, solar incidence angle, panel surface temperature, etc. Due to the heat-absorbing feature of the panel material, most of the radiation also causes the panel to heat up. According to some studies, it is said that approximately 80% of the solar radiation coming to the panel unit surface cannot be converted into electrical energy, and this causes the panel temperature to increase [3]. Also, it has been observed that as solar radiation increases during the day, panel temperature and panel efficiency increase together. However, it is known that increasing panel temperature negatively affects most parameters of the panel and ultimately decreases panel efficiency [4]. So the amount of electricity produced by photovoltaic panels is directly proportional to solar radiation and inversely proportional to the panel surface temperature. It is known that the surface temperature of a panel can rise to 40ºC above the environmental temperature, depending on the solar radiation on the surface [5,6]. Although it depends on the environment where the experiment is performed, the monocrystalline panel surface temperature can increase from 51.8°C to 88.2°C [7]. In another study, it was mentioned that the temperature in the uncooled panel was 95 °C, while the temperature in the cooled panel was 55 °C [8]. According to some studies, if the surface temperature is reduced by 1 °C, PV panel efficiency increases by 0.5% or 0.65% [9]. In a study conducted in an area where solar radiation is 901 W/m^2, it is mentioned that a 7.28% efficiency increase was achieved by reducing the panel surface temperature by 4.7 °C [10]. This means there was a 1.6% increase in panel efficiency with a 1°C temperature drop. In another similar study, a 7.3% efficiency increase was achieved with a 2.4°C temperature drop in the region where solar radiation was 100-1120 W/m^2 [11]. Therefore, a 3% increase in efficiency was achieved with a 1°C temperature drop. According to these results, the increase in panel efficiency at a 1°C temperature drop also depends on solar radiation. In other words, in case of a 1°C temperature drop in regions with higher solar radiation, the increase in panel efficiency will also be higher. Bahaidarah et al., [12] mention that if there is a 20% decrease in panel surface temperature, there will be a 9% increase in electrical efficiency. According to the electrical data graphs in the study by Kane et al., [13], it shows that the change in the panel surface temperature from 25℃ to 75℃ and the change in the environmental temperature from 25℃ to 35℃ will cause a 20%-27% change in the panel electrical efficiency.

The best efficiency in solar panels is achieved when the surface temperature is 25°C at 1000W/m^2 solar radiation, which is the panel's standard operating condition [14]. Today, it is known that even the best panels have a maximum efficiency of 17-18%, whereas monocrystalline panel efficiencies are generally between 12-15% [15]. It is also stated in literature studies that panel efficiency can reach up to 26% depending on the panel material [16]. With the increase in panel temperature, panel open circuit voltage, filling factor, panel output power decrease, and short circuit current increases [16,17]. Although the short circuit current (I_{sc}) increases slightly, the open circuit voltage (V_{oc}) decreases more obviously with the increase in panel temperature [18], so the maximum power and efficiency of the panel decrease significantly [14, 19].

In his study, Yılancı [14] mentions an approximately 20% increase in panel efficiency with appropriate thermoelectric cooling. Considering these situations, it is understood that an efficiency increase of approximately 20-30% will be achieved by reducing the panel temperature from 50 °C to 40 °C in the summer months when solar radiation is at its highest. Therefore, it is predicted that panel efficiency will increase by up to 50% with good cooling. There are studies stating that PV/T systems will always produce more electricity, the payback period will be shorter, and their lifespan will be longer than the PV system [20]. It is also possible to store energy as electricity or heat in PV/T systems. Kabul and Duran [8] achieved a 7% increase in efficiency and a 31% increase in power by reducing the panel surface temperature by using cold water in the PV/T study. It has been determined that if nanofluid water is used instead of pure water in PV/T systems, much better cooling will be achieved on the panel surface, hot water can be obtained and the electrical output power will be 51% higher [21]. Gürbüz et al. [22] by using commercial-type phase change material (RT55) for cooling purposes, a maximum power of 31.5W was achieved in a 40W power PV/T panel with 424 × 674 × 25 dimensions and 36° angle. The necessity of cooling PV and PV/T modules due to high summer temperatures is established in much literature [23]. Kerem et al. [17] stated in their study at Osmaniye Korkut Ata University that the panel efficiency increased by 14% as a result of cooling the panel surface with cold water. It is understood that effective surface cooling of PV panels is very important in terms of efficiency.

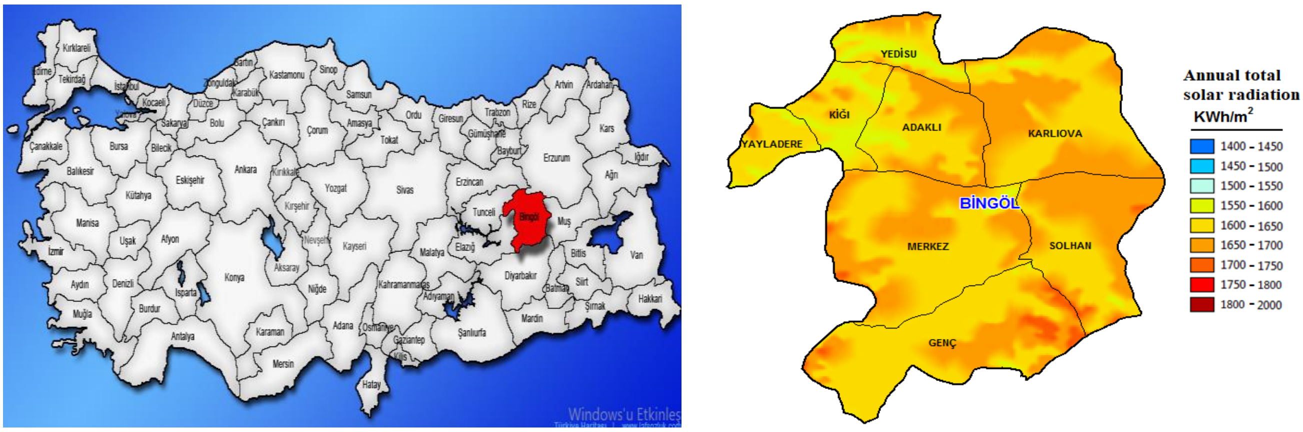
Panel active cooling systems require pumps, compressors, etc. Since they use energy-consuming devices, they reduce the efficiency of the entire system. Passive cooling systems developed as an alternative to these can provide a lower cost of energy produced in the long run, as there are no energy-consuming devices. Passive cooling systems, which are more economical and state-of-the-art, are under development. Phase change materials are being tested within the scope of passive cooling systems. However, since phase change materials(PCM) have different melting/freezing temperatures and the daily/annual operating conditions of solar panels constantly change, PCMs to be used in passive cooling systems must be carefully selected. It will not be possible to use the system actively in the long term with a randomly selected phase change material. To select appropriate phase change materials, it is necessary to know the long-term operating conditions of PV panels in different regions. Particularly local solar radiation and panel temperature data will be of great importance in the studies to be carried out. With the use of relevant comprehensive data, more appropriate PCM selection and passive cooling system designs will be useful for a longer period. In this sense, instantaneous and average experimental/numerical data are to be obtained for each region to be used for proper PCM selections.

It is also possible to passively cool PV panels by using a thermoelectric generator. There are studies in this field using thermoelectric coolers (TEC), which have the same operating principle as thermoelectric generators [24, 25]. However, if a thermoelectric cooler is used in panel cooling, electricity will be consumed, but if a thermoelectric generator(TEG) is used instead, no additional electrical energy will be used, and additional electrical energy will be produced from the heat of the hot panel. This will increase the total efficiency of the PV/TEG system. So is of great importance to determine the surface temperatures of panels in different regions and different climatic conditions to design good systems, whether it is a PV/PCM or PV/TEG system, which can be called panel passive cooling systems.

In this study, panel surface temperatures, panel power, and efficiency were investigated in the high-temperature month of August in Bingöl province, to serve as a reference for future studies on panel cooling. For this purpose, data obtained from the panel's front and back surfaces were evaluated. The panel temperatures to be obtained for Bingöl province within the scope of our study will be of great importance for suitable designs in suitable PV/TEG or PV/PCM passive cooling systems.

2. MATERIAL AND METHOD

Bingöl province, located in the northern hemisphere of the world, is surrounded by Muş in the east, Erzurum and Erzincan in the north, Tunceli and Elazığ in the west, and Diyarbakır in the south(Figure 1a). Bingöl borders are between 41 - 20 and 39 - 56 eastern longitudes and 39 - 31 and 36 - 28 northern latitudes. High temperatures in Bingöl start in mid-June and last until mid-September. The average daily high temperature on these dates is above 28°C. The hottest months in the Bingöl region are July and August. In these months, the average high temperature is 33°C, the low temperature is 19°C, and maximum temperatures can reach 40°C [26]. Bingöl's annual sunshine duration is 2719 hours, and as seen from Bingöl's solar map (Figure 1b) annual average solar radiation is around 1650 kWh/m^2.



a) b)

Figure 1. a)The location of Bingöl on the map of Turkey b)Solar radiation map of Bingöl (GEPA)[27]

Turkey Solar Energy Atlas [27] data were taken as the basis for solar radiation values. Accordingly, Figure 2a shows the amounts of solar radiation in Bingöl province by month, and Figure 2b shows the daily sunshine distribution for months. Here, the daily average amount of solar radiation is 5.81kWh/m^2-day, and the average daily sunshine duration is 10.7 hours for August. In the light of these data, the total solar radiation (E) incident on the panel surface is equal to the product of the solar radiation falling on the panel unit area (I) and the panel effective surface area (A_p) and can be calculated with equation number 1 [16, 28]. The electrical efficiency (η) of a panel shows the ratio of the maximum electrical energy (P_{max}) obtained from the panel to the total solar radiation (E) incident on the panel surface [16, 28]. Panel efficiency can be calculated with Equation 2. In Equation 2 and Equation 3 I_{max}, V_{max}, I_{sc}, V_{oc}, and FF indicate the maximum current, maximum voltage, short circuit current, open circuit voltage, and fill factor, respectively. In the study, instantaneous electricity and temperature data were taken throughout the day in August, one of the hottest months of the year. According to meteorological data, on the relevant date (26 August - 3 September 2023), the related Bingöl outdoor temperature is between 30-31°C and the average wind speed is 7m/s.

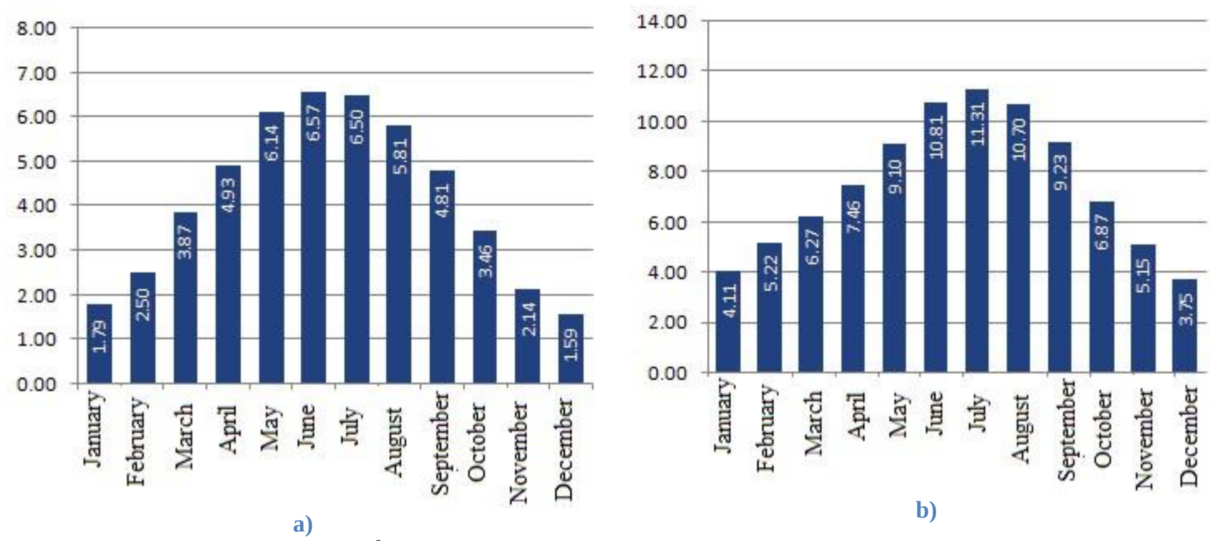


Figure 2. a) Global radiation values (kWh/m^2-day) of Bingöl, b)The daily sunshine duration of Bingöl(hour)(GEPA)[27]

$$E = IxA_p \quad (1)$$

$$\eta = \frac{P_{max}}{E} = \frac{I_{max}V_{max}}{IxA_p} = \frac{I_{sc}xV_{oc}xFF}{IxA_p} \quad (2)$$

$$FF = \frac{I_{max}V_{max}}{I_{sc}xV_{oc}} \quad (3)$$

Two identical panels with 25W power were used to investigate panel production power, efficiency, and panel surface temperatures. The monocrystalline panel, whose properties are given in Table 1, was preferred because it is the most preferred in Turkey and has higher efficiency than polycrystalline [29].

Table 1. Panel label data

Rated Power (Pm)	25W
Type	Monocrystal
Total Number of Cells (Ns)	36
Open Circuit Voltage (V_{oc})	24.84V
Max. Voltage (V_{mp})	20.70V
Short Circuit Current (A_{sc})	1.27A
Max. Current (A_{mp})	1.21A
Max. System Voltage (V)	1000V
Module Dimensions (mm) **Panel efektif alanı(A_p)**	362*433*20 0.157m^2
Weight (kg)	1.68

Instantaneous voltage and current values were noted with a digital voltmeter/ampermeter. 10 LED lamps with a power of 1.5W and 1 single lamp with a power of 10W were used to create resistance to read the current and voltage values through the system (Figure 3, Table 2). As seen in Figure 3, temperature data were taken with digital thermometers at a total of 6 points on both panels, 4 points on the front surface of the panel (T_1, T_2, T_3, T_4), 2 points on the back surface of the panel (T_5, T_6). Ambient temperature (To) was also measured for accurate evaluation of panel surface temperatures. Surface temperatures were measured with the help of k-type thermocouples in the 2-channel CEM DT 612 model thermometer and the 4-channel CEM DT 3891G model digital thermometer (Table 2). Temperature data were taken with the thermal camera also to see local temperature changes.

Table 2. Information of devices used

Instrument name	Measurement range	working environment conditions	Error rate
Digital manual-type thermometer With 2 two input signals	-50°C ÷1300°C	0°C ÷50°C	±2.2°C or ±0.75%
Digital manual type thermometer with 4 input signals	-50 ÷ 1370°C	0°C ÷75°C	± 0,15 % K type ± 2 % Infrared
Voltmeter /amper meter	Dc 4.5-100V Dc 0.00-10.00A	-10°C ÷65°C	± 1%
Thermal Camera	-30÷ 750℃	-15÷ 50°C	
Resistance	10 of 1.5W led lamps +10W single lamp		

A thermal camera, whose detailed specifications are given in Table 2, was used to see local temperature fluctuations on the surface. The data were taken at 15-minute intervals during the daytime between 10:30 and 16:30 when solar radiation is at its highest.

A 45° tilt angle was used in this study as the best data was obtained at the related angle according to our previous study[29]. It is known that the highest efficiency is achieved in regions located in the northern hemisphere if the solar panels are directed toward the south. In this regard, the panels are oriented towards the south(Figure 4). The experimental setup was installed in an environment where there was no shadow factor between the specified measurement times.

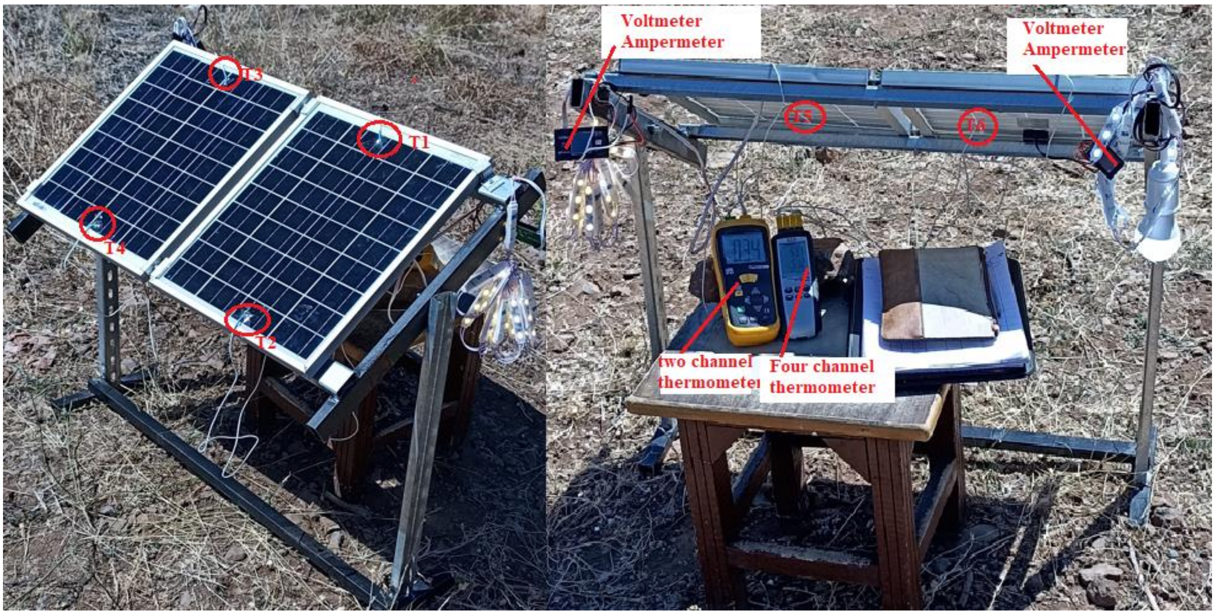


Figure 3. Experimental setup

3. RESULTS

The changes in panel surface instantaneous temperature (T_{ps}) data taken in different weeks in August according to time (h) are presented in Figure 5. As seen in the figure, digital temperature measurements were taken from two points on the back surface of the panel and four points on the front surface of the panel, measured with an interval of 15 minutes. According to the results, the front surface temperatures of the panel (T_1, T_2, T_3, and T_4) were generally higher than back surface temperatures (T_5, and T_6) with a difference of 10°C. It has been understood that a temperature difference of 10°C between the front and back surfaces of the panel is compatible with the literature [28]. According to the temperature measurement results made with thermocouples, the average temperature on the front surface of the panel was 55°C, local maximum temperature also reached 65°C. From the relevant graph, it can be read that all panel front temperatures are above 45°C. The average temperature value of the back surface was calculated as 45°C. It is also possible to read similar results from the instantaneous temperature graph (Figure 5). According to Figure 5, it is seen that the panel front surface temperature data is much higher than the environmental temperature (> T_o = 35°C) throughout the day, and the panel back temperatures T_5 and T_6 are close to the environmental temperature.

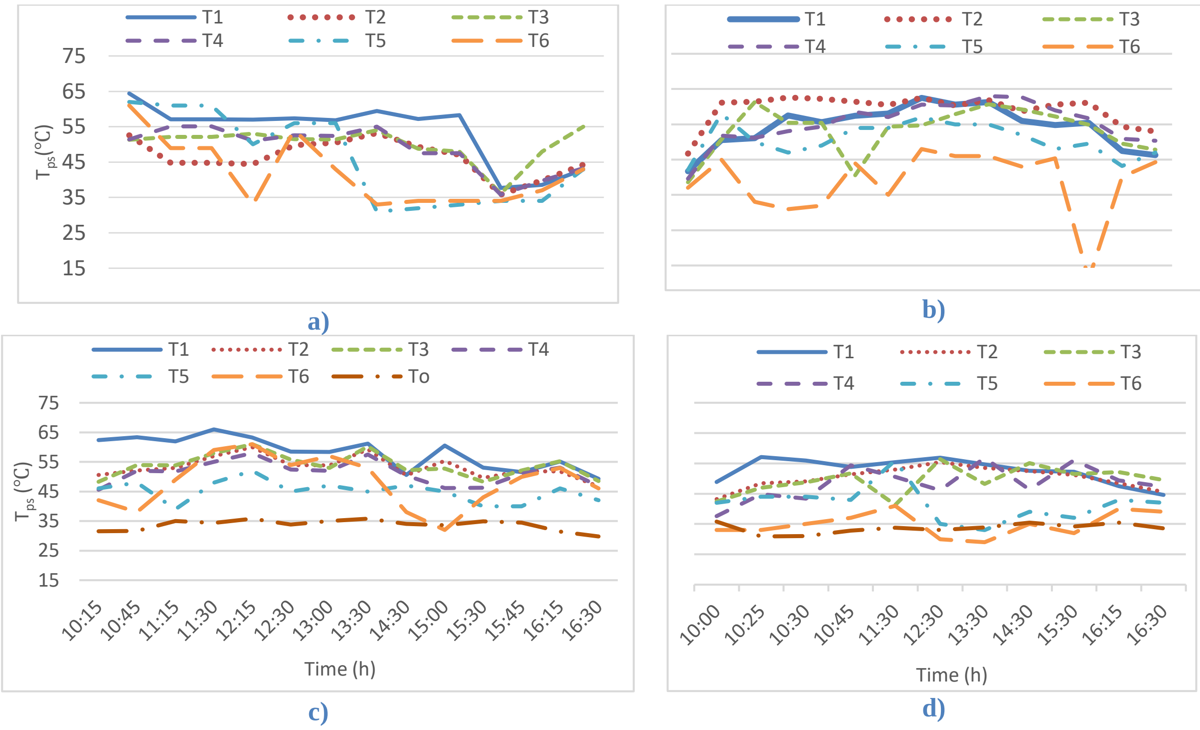


Figure 5. Instant temperature graphs, a) First day, b)Second day, c)Third day, d) Fourth-day data

According to the data taken from another day, it is seen that the panel minimum surface temperature is around 30℃ throughout the day, the average temperature is around 40-45℃, and the maximum surface temperature rises to 80℃ at 12:30 (Figure 7b). Therefore, due to their ability to absorb and retain heat, panel temperatures can reach up to 80-85℃ (Figure 6c and Figure 7b). However, according to both meteorological data and also according to Figure 5b, and Figure 5c, the average temperature value of the surrounding environment (T_o) on the relevant date is 30-36℃.

Thermal camera images were taken from the panel's front surface every two hours. Thermal images of the panel pair, whose real images are shown in Figure 3 and Figure 4, and corresponding clocks, are presented in Figure 6 and Figure 7. The images more clearly reveal a non-uniform temperature distribution on the panel surfaces. Although the panels are identical in Figure 6, at different times (11:30, 12:30, 13:30, 14:30), a higher temperature region was detected in the second panel. It is thought that the relevant temperature difference is due to the insufficient orientation of the panel towards the south. It can be said that this situation is related to the Azimuth angle not being adjusted properly. As it is known, while the panels are oriented exactly to the south, they can lean a little east or a little west. This can be possible by adjusting the Azimuth angle professionally. According to the images, higher temperature regions were seen in the upper region of both panels. During the day, the minimum temperature value is approximately 40℃ (Figure 6c, Figure 6d), the minimum average temperature is approximately 45℃, and the maximum temperature is up to 85℃ (Figure 6c). In similar literature studies, it was understood that the average solar radiation value was 1100W/m^2 between 11:00 and 13:00 hours, and the panel temperature was around 110℃ [30].

It is also stated in the literature that the monocrystalline panel surface temperature can increase from 51.8°C to 88.2°C, depending on the environment temperature in which the experiment is performed [7]. In the study conducted for Isparta province, it was mentioned that the temperature in the uncooled panel was 95 °C, while the average temperature in the cooled panel was 55 °C [8]. If the panel surface temperature value of Bingöl is high like this, located in the northern hemisphere of Turkey, it is clear that these temperatures will be even higher in the southern provinces such as Antalya, Şanlı Urfa etc. So it is essential to cool the solar power systems to be installed in the relevant regions with appropriate cooling methods, both to increase their electrical efficiency and make the panels last longer. Since the high temperatures the panels are exposed to will deteriorate the structure of the panels, the panels will have a shorter lifespan and produce less electricity than expected.

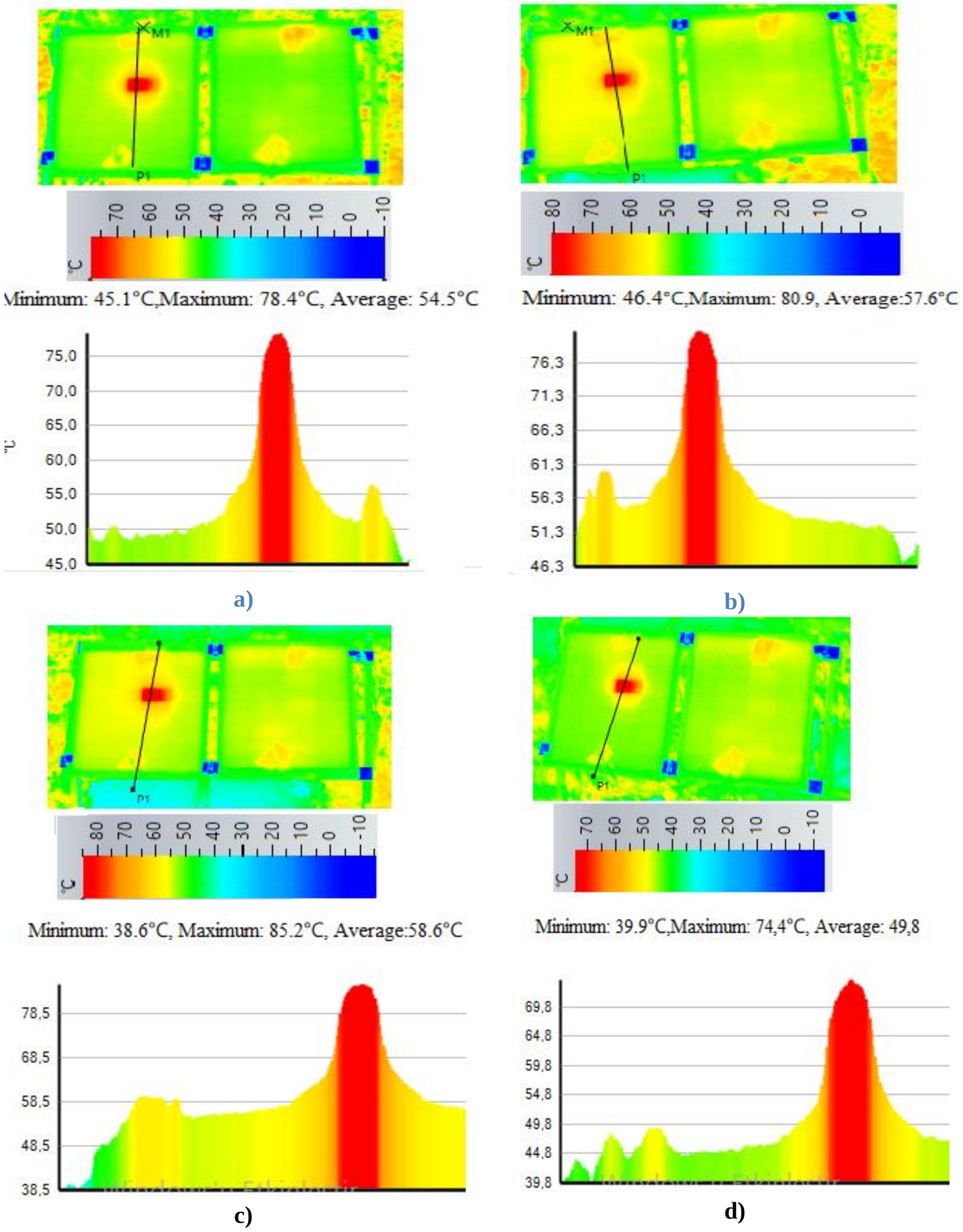


Figure 6. Thermal images of PV panel, a) at 11:30, b) at 12:30, c) at 13:30, d) at 14:30

Since high temperatures are a result of high solar radiation, high solar radiation increases both the panel surface temperature and electrical data. For example, according to the temperature data on the first day (Figure 5a), since the panel temperatures were not stable throughout the day, the electricity efficiency curve peaked in a narrower range (between 12.00 and 15.30) (Figure 8a). In Figure 5b, temperatures throughout the day (especially the panel front surface temperatures T_1, T_2, T_3, and T_4 values) are more uniform and higher, and in parallel, the related electrical data is also higher (Figure 8b).

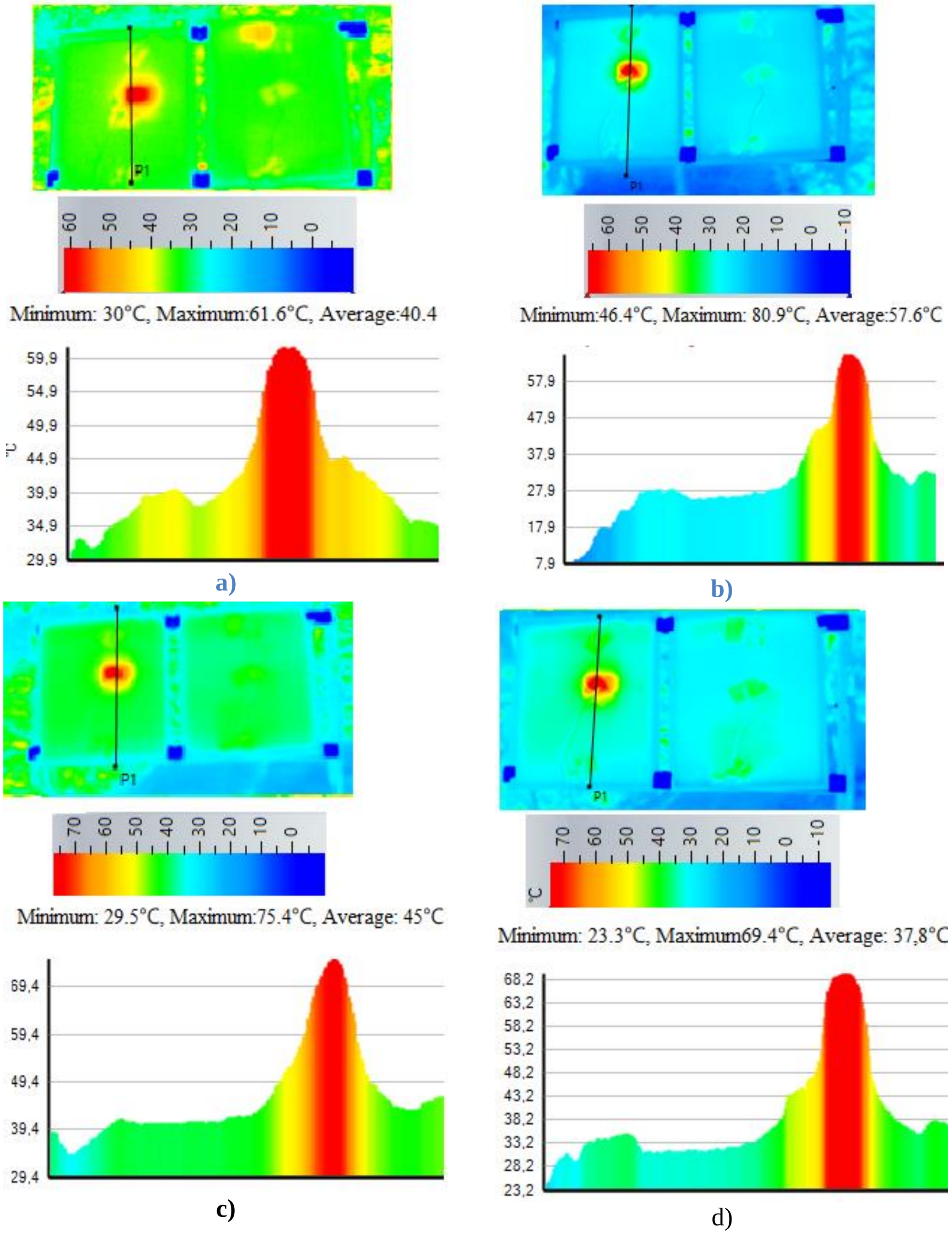
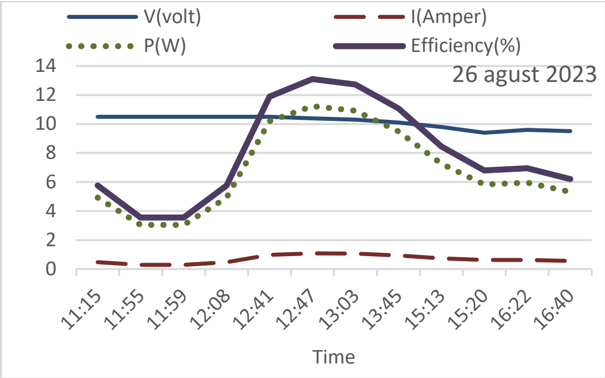
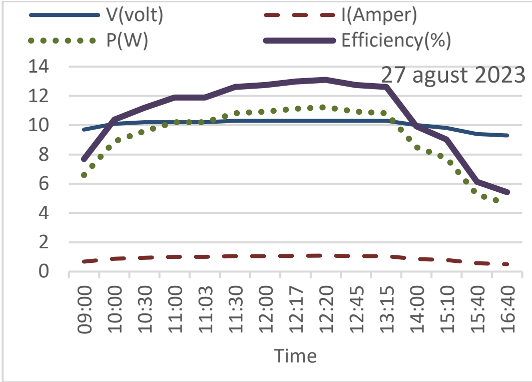


Figure 7. Thermal images of PV, a) at 10:30, b)at 12:30, c) at 14:30, d) at 15:30

The ideal panel temperature value should be 25℃ according to literature research. According to the IEC 60904-3 [31] panel standard, it is stated that at 1000 W/m^2 radiation, which is the standard test conditions, the air mass flow rate is 1.5 and the relevant panel ideal temperature value is 25℃. Under the same radiation intensity, panel surface temperatures closest to 25℃ will be the most efficient. In this regard, the high surface temperature of panels should be reduced with appropriate cooling methods. Therefore, if the surface temperature had been reduced with proper cooling on the second day, the efficiency would have been higher (Figure 5b and Figure 8b). Various literature has stated that by reducing panel temperatures by applying appropriate cooling under the same radiation conditions, significant efficiency increases will be achieved and panel life will increase, as thermal stresses that will occur in the material will be prevented [15, 32, 33]. Figure 8 shows that panel power and efficiency values are at their highest during the 12:00-15:00 hours when the solar radiation value is highest. Parallel to this, panel front surface temperatures increase proportionally during the same hours. Therefore, in passive cooling designs can be developed especially for these noon hours.



a)



b)

Figure 8. Instant electrical data, a) First day, b)Second day

Gürbüz et al. [22] by using commercial-type PCM (RT55) for cooling purposes in a 40W PV/T panel, a maximum power of 31.5W was achieved. Considering that the maximum electricity obtained without cooling in the 25W panel used in this study is around 11-12W (Figure 8a, Figure 8b), Gürbüz et al., [22] reported significant efficiency gains with panel cooling (FDM cooling) in the PV/T study. While an average of 20W electricity was expected to be obtained without cooling from a 40W panel, approximately 1.5 times higher electricity (31.5W) was obtained with the hot water obtained. If we make an evaluation from here, there is actually an increase in efficiency of at least 30% thanks to PCM. For example, in another study conducted for Pakistani climate conditions, it was mentioned that the breading yield was increased by 29% with the organic PCM used [34]. Based on all these results, it is of great importance for the country's economies to carefully observe the increasing panel temperatures, especially in the summer months, and to carry out appropriate cooling processes. For panel passive cooling systems, especially those developed using PCM, to have relatively longer and wider usage areas, data on the outdoor temperatures where the panel is operated and the panel surface temperature will be needed. In this regard, the operating conditions of panels and relevant panel surface temperature data should be established throughout the country, especially in the summer months.

4. DISCUSSION AND CONCLUSION

Passive cooling systems that are more effective and more economical should be developed. So there is a need to select the appropriate phase change materials with suitable melting/freezing temperatures and to have specific passive cooling systems for certain climatic conditions and certain regions. To select appropriate phase change materials, it is necessary to know the long-term operating conditions of PV panels in different regions. Particularly local solar radiation and panel temperature data will be of great importance in the studies to be carried out. With the use of relevant comprehensive data, more appropriate phase change material selection and passive cooling system designs that will be useful for a longer period will be possible. In this sense, the instantaneous and average experimental and numerical data obtained for each region to be used in panel cooling studies are important in selecting the appropriate PCM.

According to the results of the 25W monocrystalline panel used in our study, panel efficiency values were found to be as low as 3% to 13%. Due to their heat-absorbing properties, solar panels absorb most of the solar energy as heat, approximately 80% or 60% [3, 16]. This causes the panel surface temperatures to warm up well above the ambient temperature. According to our study, data taken in August, one of the hottest months in Bingöl, the temperature value of the panel front surface was on average 10°C higher than the rear surface. On the other hands front surface temperature values can rise to a maximum of 85°C, especially during the noon hours (12:00-15:00), when solar radiation values are most intense, in parallel with the radiation intensity. In this regard, PCM material selection and system design accordingly can provide better performance, especially in passive cooling designs. For example, according to the thermal camera temperature results, the maximum temperature was 85°C on one day and 80°C on the other day. In this case, if higher efficiency will be obtained from the panel, especially at noon hours, PCM material with an average melting temperature of 50-65C can be used. Or, if it is desired to increase efficiency throughout the day, the PCM melting temperature can be selected lower a. Ccordint to average temperature of panel surface. For example, if the average temperature of the panel throughout the day is around 55-60C, it would be more appropriate to choose a PCM melting point of 40-45°C. Of course, these scenarios need to be tested in the field and more data must be obtained for different regions and different seasons. Different material performances can be tried in this range. Thus, material melting temperature selections can be made more accurately thanks to extensive panel surface temperature data.

Panel efficiency will be further increased if the panel temperature is reduced from 85°C to at least the environment temperature (40°C) with appropriate cooling methods within the relevant period. The panel temperature values obtained as a result of our study are of great importance for the selection of appropriate PCMs, especially in passive cooling, which is likely to be used in the future. In this regard, if the panel surface temperature has reached a maximum of 85°C in Bingöl province, these temperatures will be much higher in the southern provinces of Turkey. So cooling operations will be more meaningful as they will provide a higher efficiency increase in southern regions. In northern regions where radiation is low, the application of passive cooling systems is more suitable in terms of system total cost and total efficiency. As can be seen, the widespread use of cooling PV panels, both passively and actively, will increase panel efficiency. In this respect, any progress in both active and passive cooling methods will be important. In active cooling/heating systems such as vapor compression cooling systems or heat pumps, additional electricity is consumed in the system because a pump or fan systems are used to circulate the intermediate fluid[35]. However, since there is no pump or fan in passive systems, there is no additional energy cost. In southern regions where radiation is higher, active or passive cooling systems may be preferred, but it would be more appropriate to choose passive systems as they are more economical in the long term [36]. In addition, studies on increasing the conductivity coefficient of PCM material continue in these studies. For example, there are studies using nanomaterials to increase the transmission coefficient of the PCM material in order to achieve higher efficiency in this field [37]. In addition, since PV panel cooling is costly, increasing panel applications that do not require cooling will be an important development. For example, it is possible to use PV panels more efficiently in moving vehicles. Since the PV cells to be used on the top, front, and sides of the vehicle will be exposed to airflow while in motion, they will be protected from overheating that will cause efficiency drops and there will be no need for panel cooling. In this regard, studies on the use of PV panels in moving objects such as vehicles should be accelerated. It would be beneficial for future panel cooling studies to be carried out in this direction. In addition, another way to reduce panel cooling system costs will of course be PV/T systems. The widespread use of PV/T panels on roofs is extremely important in terms of meeting building electricity and hot water needs more efficiently. As a matter of fact, in PV/T systems, the complete system will be much more efficient as the PV panel will be actively cooled thanks to the domestic water circulated behind the PV panel. As we mentioned in our previous study [37], under normal conditions, if the payback period of PV systems installed on the roof of a house is 6 years on average, if this system is designed as PV/T, this payback period will be approximately halved. It is clear that the dissemination of PV/T systems, especially in industry, will make a significant contribution to the economy. Because in the industrial area, there is a need for hot water, hot air, heat pump etc. It will be possible to meet the electricity needs with the electricity produced at high efficiency by using it for the needs and by actively cooling the PV system. In solar energy systems, PV/T systems should be considered first, depending on the facilities located in the installation area. It would be more logical to choose a PV/T system instead of classical PV in all regions that require hot water or hot air (such as a heat pump).

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REFERENCES

[1] Tyagi VV, Rahim NA, Rahim NA, Jeyraj A, Selvaraj L. Progress in solar PV technology: Research and achievement. *Renewable and sustainable energy reviews*, 2013; *20*: 443-461.

[2] Sharma S, Jain KK, Sharma A. Solar cells: in research and applications a review. Materials Sciences and Applications, 2015; 6(12):1145.

[3] Sun X, Dubey R, Chattopadhyay S, Khan MR, Chavali RV, Silverman, TJ, et al. A novel approach to thermal design of solar modules: Selective-spectral and radiative cooling. In *2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC), 2016;* 3584-3586). IEEE.

[4] Sudhakar P, Kumaresan G, Velraj R. Experimental analysis of solar photovoltaic unit integrated with free cool thermal energy storage system. *Solar Energy*, 2017; *158*: 837-844.

[5] Makki A, Omer S, Sabir H. Advancements in hybrid photovoltaic systems for enhanced solar cell performance. *Renewable and sustainable energy reviews*, 2015; *41*: 658-684.

[6] Sheik MA, Aravindan MK, Cuce E, Dasore A, Rajak U, Shaik S, et al. A comprehensive review on recent advancements in cooling of solar photovoltaic systems using phase change materials. *International Journal of Low-Carbon Technologies*, 2022; *17*: 768-783.

[7] Khanna S, Sundaram S, Reddy KS, Mallick TK. Performance analysis of perovskite and dye-sensitized solar cells under varying operating conditions and comparison with monocrystalline silicon cell. Applied Thermal Engineering, 2017; 127: 559-565.

[8] Kabul A, Duran F. Isparta ilinde fotovoltaik/termal (PV/T) hibrit sistemin performansı. Tr. Doğa ve Fen Derg., 2014; 12 (2):68 -75.

[9] Klugmann-Radziemska E, Wcisło-Kucharek P. Photovoltaic module temperature stabilization with the use of phase change materials. Solar Energy, 2017; 150: 538-545.

[10] Luo Z, Huang Z, Xie, N, Gao X, Xu, T, Fang Y. Numerical and experimental study on temperature control of solar panels with form-stable paraffin/expanded graphite composite PCM. Energy Convers. Manage., 2017; 149: 416–423.

[11] Indartono YS, Suwono A, Pratama FY. Improving photovoltaic performance by using yellow petroleum jelly as phase change material. Int. J. Low-Carbon Technol., 2016; 11 (3): 333–337.

[12] Bahaidarah H, Subhan A, Gandhidasan P, Rehman S. Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions. *Energy*, 2013; *59*: 445-453.

[13] Kane A, Verma V, Singh B. Optimization of thermoelectric cooling technology for an active cooling of photovoltaic panel. *Renewable and Sustainable Energy Reviews*, 2017; *75*: 1295-1305.

[14] Shastry DM, Arunachala UC. Thermal management of photovoltaic module with metal matrix embedded PCM. Journal of Energy Storage, 2020; 28: 101312.
[15] Yılancı A. Performance analysis of a photovoltaic panel cooled by thermoelectric effect. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 2020; *35*(2), 619-634.
[16] Pathak SK, Sharma PO, Goel V, Bhattacharyya S, Aybar HŞ, Meyer JP. A detailed review on the performance of photovoltaic/thermal system using various cooling methods. *Sustainable Energy Technologies and Assessments*, 2022; *51*: 101844.
[17] Kerem A, Atik M, Bayram A. Fotovoltaik (PV) panel sisteminde yüzey soğutma işleminin elektrik üretimine etkisinin deneysel incelenmesi. International Journal of Engineering Research and Development, 2020; 12(2), 565 -578.
[18] Rezvanpour M, Borooghani D, Torabi F, Pazoki M. Using CaCl2· 6H2O as a phase change material for thermo-regulation and enhancing photovoltaic panels' conversion efficiency: Experimental study and TR-NSYS validation. Renewable Energy, 2020; 146: 1907-1921.
[19] Dwivedi P, Sudhakar K, Soni A, Solomin E, Kirpichnikova I. Advanced cooling techniques of PV modules: A state of art. Case studies in thermal engineering, 2020; 21: 100674.
[20] Sohani A, Cornaro C, Shahverdian MH, Pierro M, Moser D, Nižetić S & Doranehgard M H. Building integrated photovoltaic/thermal technologies in Middle Eastern and North African countries: Current trends and future perspectives. *Renewable and Sustainable Energy Reviews*, 2023; *182*, 113370.
[21] Ahmadlou LA, Najafi G, Loni R, Kasaeian A, Mamat R, Ghazali MF, et al. Experimental investigation of PV/T and thermoelectric systems using CNT/water nanofluids. *Applied Thermal Engineering*, 2023; *227*: 120350.
[22] Gürbüz H, Demirtürk S, Akçay H, Topalcı Ü. Experimental investigation on electrical power and thermal energy storage performance of a solar hybrid PV/T-PCM energy conversion system. *Journal of Building Engineering*, 2023;*69*:106271.
[23] Su Y, Zhang Y, Shu L. Experimental study of using phase change material cooling in a solar tracking concentrated photovoltaic-thermal system. *Solar Energy*, 2018; *159*: 777-785.
[24] Gillott M, Jiang L, Riffat S. An investigation of thermoelectric cooling devices for small-scale space conditioning applications in buildings. International Journal of Energy Research, 2010; 34(9): 776-786.
[25] Kandry H, Ennawaoui C, El Ballouti A, Malki Z, El Jouad M, Balhamri A, et al. Optimized photovoltaic panels power using cooling system based thermoelectric materials. Materials Today: Proceedings, 2022; 66: 479-483.
[26] Çulun P, Varolgüneş FK, Gonca Ö, Kılınç C. Thermal Comfort Comparison of Different Dwelling Typologies. *İDEALKENT*, 2022;*13*(38): 2677-2701.
[27] GEPA [Internet] [cited 2023 March 3] Available from: https://gepa.enerji.gov.tr/MyCalculator/pages/12.aspx
[28] Yıldırım E, Aktacir MA. Investigation of azimuth and tilt angle effects on building integrated photovoltaic systems. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 2019;*34*(2): 609-619.
[29] Işık SK, Çulun P. Experimental Investigation Of Photovoltaic Panel Performance In Bingol Province For Different Parameters. *Türk Doğa ve Fen Dergisi*, 2023; *12*(2): 68-75.
[30] Soliman AM. A numerical investigation of PVT system performance with various cooling configurations. *Energies*, 2023;*16*(7): 3052.
[31] Standard IEC 60904-3, International Electrotechnical Commission, "Standard IEC 60904-3: photovoltaic devices," Part 3: measurement principal for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data, 1987.
[32] Looser R, Vivar M, Everett V. Spectral characterisation and long-term performance analysis of various commercial Heat Transfer Fluids (HTF) as Direct-Absorption Filters for CPV-T beam-splitting applications. *Applied energy*, 2014; *113*: 1496-1511.
[33] Hamada AT, Sharaf OZ, Orhan MF A novel photovoltaic/thermal (PV/T) solar collector based on a multi-functional nano-encapsulated phase-change material (nano-ePCM) dispersion. *Energy Conversion and Management*, 2023; *280*:116797.
[34] Durez, A., Sohail, M. U., Ali, M., & Khan, U. A. (2024). Thermal analysis and efficiency enhancement of solar modified PV panels through organic PCM under climate conditions of Pakistan. Mehran University Research Journal of Engineering and Technology, 43(1), 97-110.
[35] Der, O., Alqahtani, A. A., Marengo, M., & Bertola, V. (2021). Characterization of polypropylene pulsating heat stripes: Effects of orientation, heat transfer fluid, and loop geometry. Applied Thermal Engineering, 184, 116304.
[36] Kameswara Rao, D., Sudhakar Reddy, K., & Subba Rao, V. V. (2024). Influence on solar PV performance integrated with heat sinks and nano-enhanced phase change material. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 09544089241253149.
[37] Çulun P, Kılıçkap IS, Recent Developments in Coolıng of Photovoltaıc Solar Panels, Gece Akademi, Çankaya/ANKARA, 2023; 113-136