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Experimental Investigation of Photovoltaic Panel Surface Temperature at Various Tilt Angles

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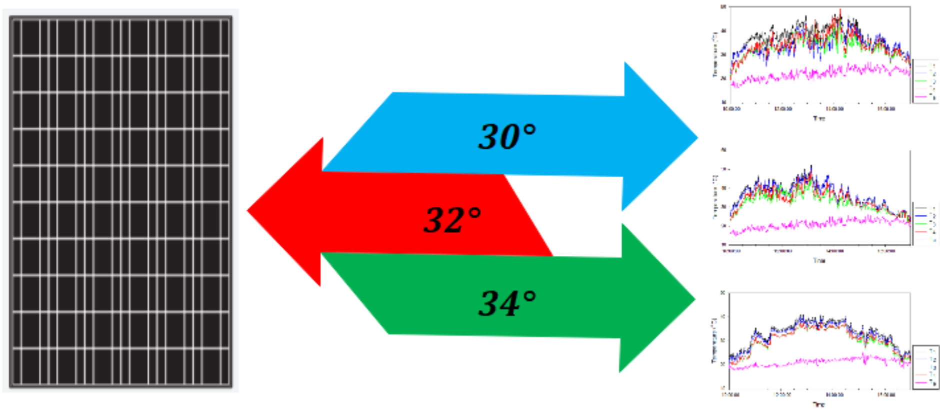
HIGHLIGHTS

- Experiments in three different tilt angles (*30°, 32° and 34°).*
- Comparison of tedlar and PV module temperatures.
- Highest temperature values have been obtained in panel placed in 34° tilt angle.

GRAPHICAL ABSTRACT



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ABSTRACT

By growing the population of the world, the demand for clean and renewable energy resources is increasing, because fossil energy sources available are limited. Solar energy is a sustainable energy source which is widely accessible. Photovoltaic systems are utilized to generate electrical energy from solar radiation. Photovoltaic panel temperature is a major parameter that influence its effectiveness. Decreasing photovoltaic temperature could be rise its performance. In this work, Photovoltaic panel surface temperature has been measured at various tilt angles. This data research consists of time-depending photovoltaic module and tedlar temperature values with climatic characteristics of the test region. In the experimental section, photovoltaic panel were placed at 30°, 32° and 34° tilt angles. Temperature values were obtained from the front glass and tedlar foil. The main goal of this study is investigating the influence of tilt angle on photovoltaic temperature which could be used in numerical works such CFD simulation.

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1. INTRODUCTION

In the last decades clean and renewable energies such as solar energy and wind energy are extensively used in developing countries [1]. Solar energy applications can be divided in two main group including solar thermal and photovoltaic applications [2,3].
Thermal energy production from solar energy is widely used in many regions around the world. Solar heating systems are usually used due to their high effectiveness and their simple applicability. Solar air and water heaters are generally utilized in hot water production, space heating, drying process, greenhouse air conditioning system and etc. [4-8]. The most common application for increasing the performance of solar thermal systems is enhancing heat transfer surface area by using various obstacles such as fins and baffles [9-13].
Photovoltaics are used to generate electricity from solar radiation. There are various researches are available which studied the efficiency of photovoltaics. Photovoltaic panel temperature is a main parameter that affect its efficiency. Reducing photovoltaic temperature can be enhance its efficiency [14]. Various methods can be used to reduce photovoltaic panel temperature [14,15]. In a study, Sellami et al. developed a photovoltaic/thermal system and used air circulation to reduce photovoltaic temperature and also to obtain hot air [16]. In another study, Huo et al. developed a tube plate photovoltaic/thermal system. Their experimental results showed that using this system can decrease photovoltaic temperature in the range of 3.5–6.5 °C [17]. Bambrook and Sproul developed a single-flow and unglazed photovoltaic thermal collector. According to the experimental results, thermal efficiency and electrical efficiency were found in the range of 28- 55% and 10-12%, respectively [18].
In this study, photovoltaic panel surface temperature has been measured at different tilt angles. The main aim of this study is analyzing the effect of tilt angle on photovoltaic temperature which can be utilized in numerical studies like CFD analysis.

2. MATERIALS & METHODS

The tests have been done in Burdur Mehmet Akif Ersoy University, Istiklal Campus, Burdur, Turkey (37.69°N, 30.34°E). The temperature of photovoltaic panel has been measured from four different point. Photovoltaic panel dimensions and measurement points on photovoltaic panel are presented in Figure 1. As it can be seen T1 is located on center of the panel and T2 is located on photovoltaic cell. T3 and T4 are located on back side of panel (tedlar) on contrary of T1 and T2, respectively. Also, surrounding air temperature (Ta) has been measured. The data have been measured 1 minute intervals.

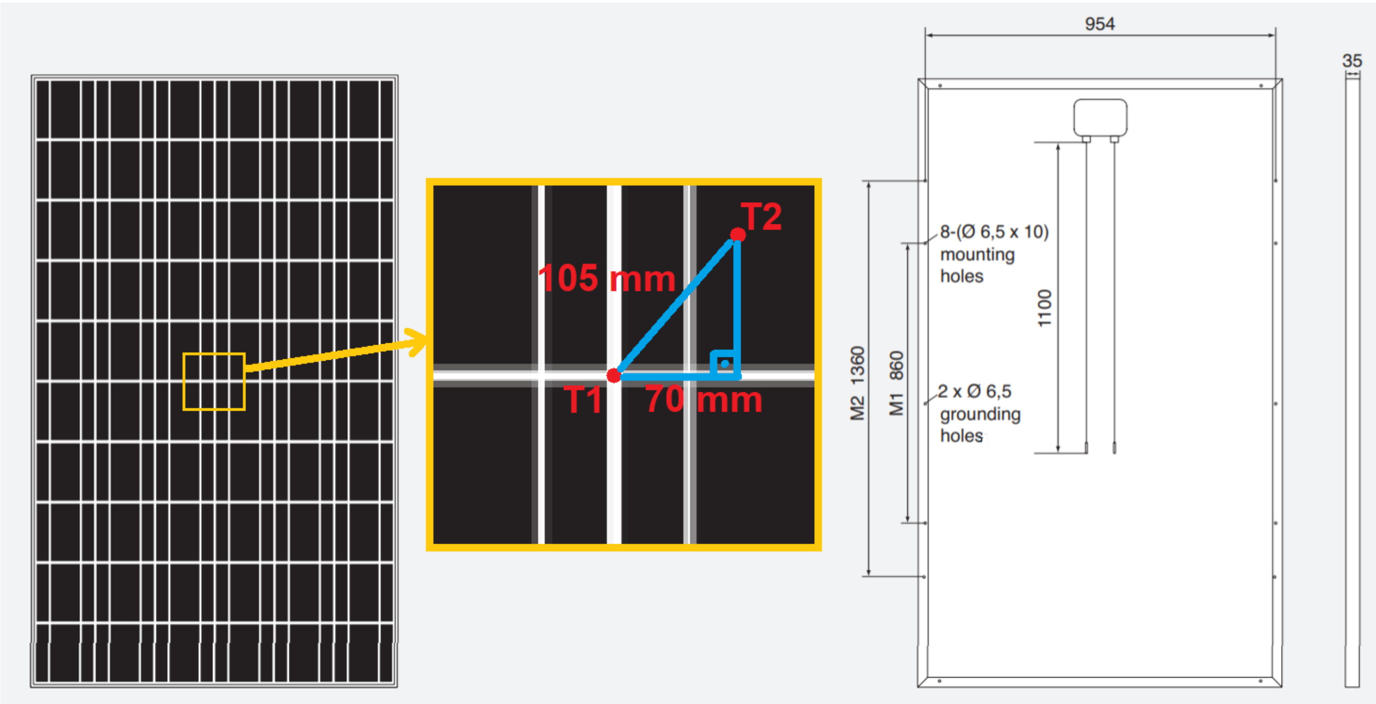

Fig. 1. *Measurement points on photovoltaic panel*

However, wind speed and solar radiation have been measured every 30 second. The experiments have been performed at three various tilt angles including 30°, 32° and 34°. Before starting the experiments, photovoltaic panel has been covered with a cover. photovoltaic panel has been positioned toward the south. The experiments stared at 10:00 and ended at 17:00. Specifications of measurement equipment and photovoltaic panel are given in Table 1 and Table 2, respectively.

Figure 2. and Figure 3 present five years average ambient temperature and wind speed values for the test region, respectively. As it can be seen, ambient temperature and wind speed values have similar trend.

Table 1. *The content of anions impurities in some popular electrolytes*

Equipment	Quantity	Range	Accuracy
Solarimeter	1	0-1999 W/m²	±10 W/m²
Anemometer	1	0.4-30 m/s	3%
Thermocouples	5	-200+1200 °C	±0.5 °C
Datalogger	2	-195+1200 °C	±0.3 °C

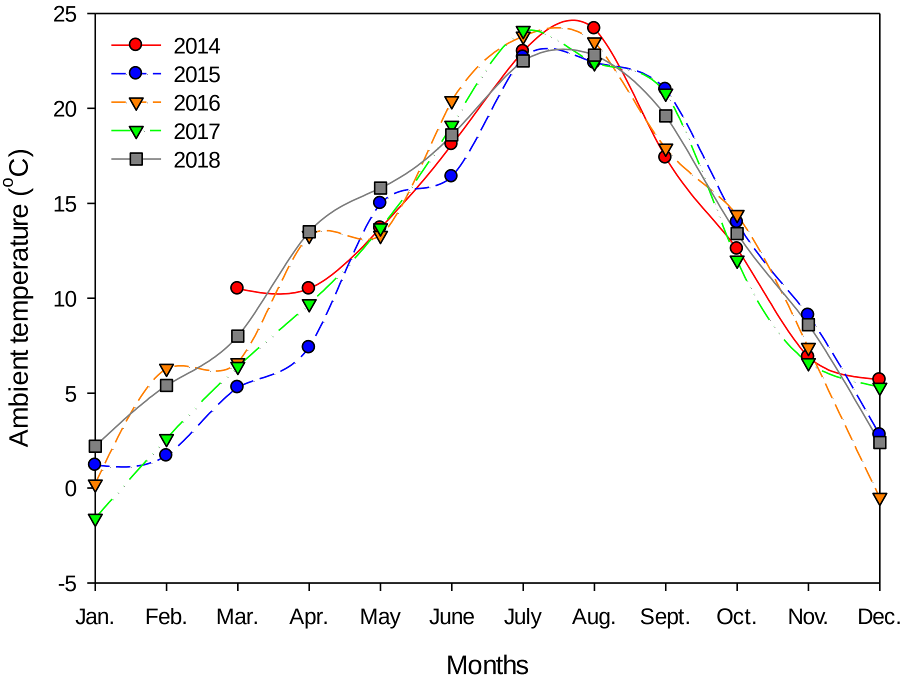

Fig. 2. *Five years average ambient temperature values for the test region*

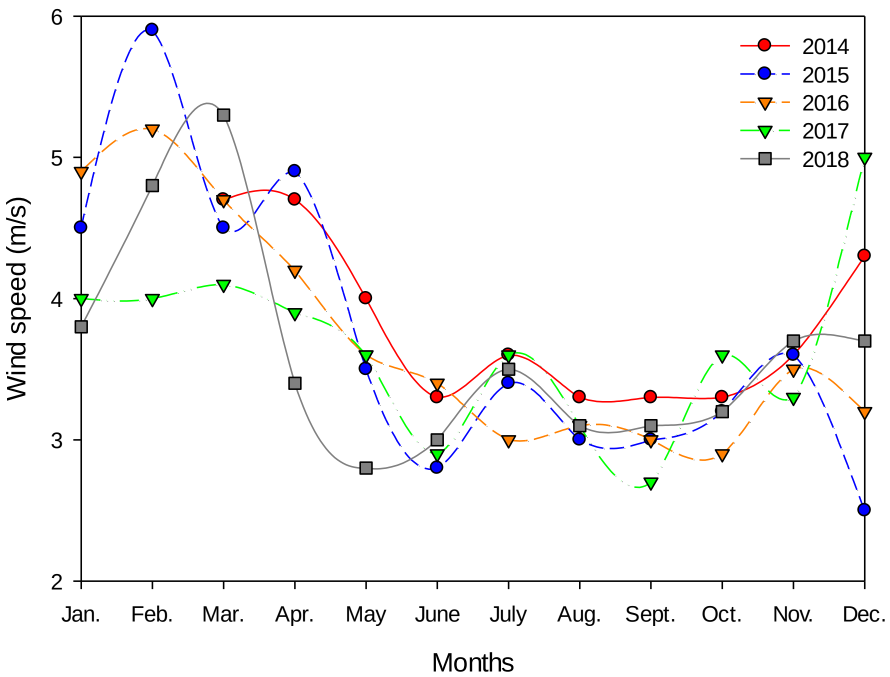

Fig. 3. *Five years average wind speed values for the test region*

Table 2. *Specifications of the photovoltaic panel*

Item	Specification
Brand name	AXITEC
Model	AC-260P/156-60S
Materials	Polycrystalline silicon
Dimensions of the panel	1640 x 992 x 35 mm
Dimensions of a cell	156 mm x 156 mm
Maximum power (P_{max})	260 W
Short circuit current (I_{sc})	9.01 A
Open circuit voltage (V_{oc})	38.00 V
Current at P_{max}. (I_{mpp})	8.43 A
Voltage at P_{max}. (V_{mpp})	30.92 V
STC	Irradiance level 1000 W/m^2, Cell Temperature 25 °C, Spectrum AM 1.5

3. THEORY OF THE PHOTOVOLTAIC PERFORMANCE

Ambient and module temperature values have significant effect on photovoltaic efficiency. This is because photovoltaic module current and voltage parameters depend on temperature. Maximum power of photovoltaic module can be found by using Eq. 1 [19].

$$P_{mp} = I_{mp} \times V_{mp} = I_{sc} \times V_{oc} \times FF \quad (1)$$

Here, P_{mp} is maximum power of photovoltaic module, I_{mp} is maximum current, V_{mp} is maximum voltage, I_{sc} is short circuit current, V_{oc} is open circuit voltage and FF is fill factor. Photovoltaic cell efficiency can be calculated as follows:

$$\eta = E_{out}/E_{in} \quad (2)$$

Also, photovoltaic module efficiency can be written as follows:

$$\eta = P_{mp}/E \times A_{PV} \quad (3)$$

Here, E is solar radiation at standard test conditions and A is module surface area. Temperature dependent photovoltaic efficiency can be written as [20]:

$$\eta_{PV} = \eta_{RT} \times [1 - \beta(T_{PV} - T_{RT})] \quad (4)$$

Here, η_{PV} is photovoltaic cell efficiency, η_{RT} is photovoltaic module efficiency at the reference temperature (can be taken as 25 °C) [20], T_{PV} is photovoltaic module cell temperature, β temperature coefficient of power and T_{RT} is photovoltaic module reference temperature. The temperature effect of a photovoltaic cell could be found utilizing the expression for photovoltaic array power output:

$$P_{PV} = Y_{PV} \times f_{PV} \times \left(G_T/G_{T,stc}\right) \times \left[1 + \alpha_P \times \left(T_C - T_{C,stc}\right)\right] \quad (5)$$

In Eq. 5, Y_{PV} is rated capacity of the photovoltaic array, G_T is the incident solar radiation on the photovoltaic array, $G_{T,stc}$ is the incident radiation at standard test conditions, f_{PV} is the photovoltaic derating factor, α_P is the temperature coefficient of power (%/°C), T_C is the photovoltaic cell temperature and $T_{C,stc}$ is the phovoltaic cell temperature at standard test conditions.

4. RESULTS

In this work, the tests have been performed in three days. The findings of three tilt angle experiments have been presented and concluded in this section. Temperature values for 32° tilt angle experiment is presented in Figure 4(a). Average ambient temperature in 34° tilt angle test is 21.58°C. Average temperature values at T1, T2, T3 and T4 points are 37.21 °C, 33.88 °C, 32.78 °C and 34.43 °C, respectively. However, maximum instantaneous temperature was obtained as 49.20 °C at T4 point in 14:15. Also, average wind speed was measured as 2.06 m/s.

Temperature values for 32° tilt angle experiment is presented in Figure 4(b). Average ambient temperature in 32° tilt angle test was measured as 21.24 °C. Average temperature values at T1, T2, T3 and T4 points are 34.02 °C, 33.74 °C, 29.34 °C and 31.06 °C, respectively. Maximum instantaneous temperature was obtained as 50.10 °C at T1 point. Also, average wind speed was measured as 2.06 m/s. Also, average wind speed was measured as 3.13 m/s.

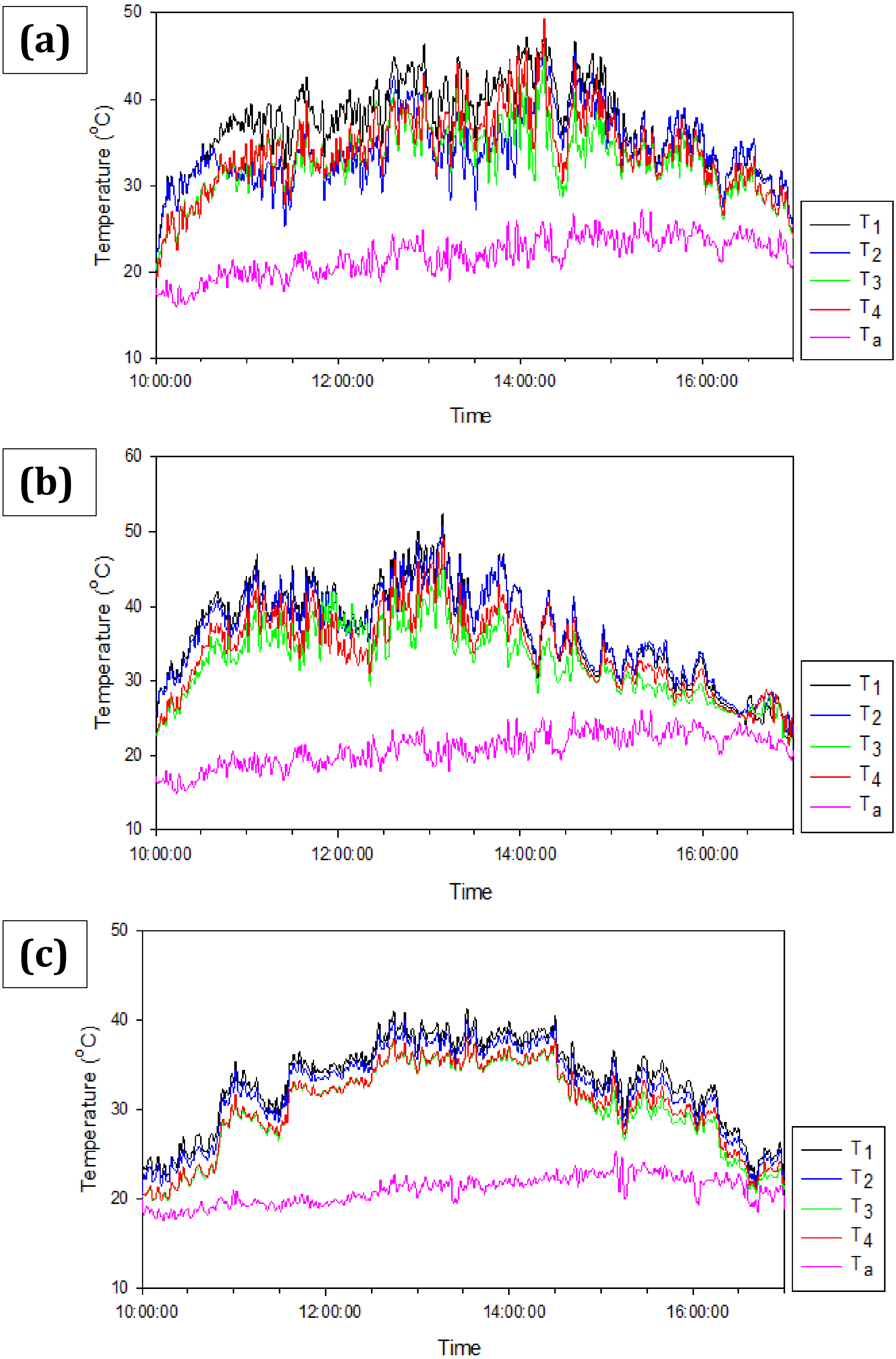

Fig. 4. *Time dependent variation of temperature values: (a) 34° tilt angle, (b) 32° tilt angle, (c) 30° tilt angle*

Table 3. *Solar radiation and wind speed values during experiments*

	34°		32°		30°	
	I (W/m²)	V_w (m/s)	I (W/m²)	V_w (m/s)	I (W/m²)	V_w (m/s)
10:00	751	2.52	778	2.21	702	3.58
10:30	815	1.28	849	2.12	786	4.56
11:00	927	1.35	927	2.05	804	2.45
11:30	997	1.82	1008	3.16	713	4.16
12:00	1044	1.63	1095	4.58	853	3.84
12:30	1082	2.21	1148	4.36	940	4.15
13:00	1168	1.69	1214	3.28	1068	4.84
13:30	1112	2.76	1148	3.47	1024	3.16
14:00	1101	1.51	1099	4.53	920	4.74
14:30	1083	1.79	645	3.74	845	4.15
15:00	1091	2.37	614	3.46	796	4.78
15:30	934	2.55	848	2.24	667	4.56
16:00	884	2.79	752	3.26	604	3.78
16:30	773	2.52	583	2.48	332	4.54
17:00	551	2.21	624	2.15	484	4.11

Temperature values for 30° tilt angle experiment is shown in Figure 4(c). Average ambient temperature in 30° tilt angle test was measured as 21.01°C. Average temperature values at T1, T2, T3 and T4 points are 30.02 °C, 28.97 °C, 28.42 °C and 27.86 °C, respectively. Maximum instantaneous temperature was obtained as 40.49 °C at T1 point. Also, average wind speed was measured as 4.09 m/s. Also, average wind speed was measured as 3.13 m/s. Additionally, solar radiation and wind speed values during experiments are given in Table 3. The effects of environmental conditions like cloudy conditions can be understood from table. At the same time, increasing wind speed led to decrease in photovoltaic panel temperature.

5. CONCLUSION

Big portion of electrical energy generated from non-renewable resources. Fossil resources are limited and have negative effects on environment. Therefore, renewable and clean energy sources should be used to generate energy which have less negative influence on environment. Photovoltaic are used to generate electricity from solar radiation. photovoltaic panel temperature is a main parameter that affect its efficiency. Reducing photovoltaic temperature can be enhance its efficiency. In this study, photovoltaic panel surface temperature has been measured at different tilt angles. In the experimental part, photovoltaic panel were placed at 30°, 32° and 34° tilt angles. Temperature values were measured from the front glass and tedlar foil. The main aim of this study is analyzing the effect of tilt angle on photovoltaic temperature which can be utilized in numerical studies like CFD analysis.

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REFERENCES

[1]. Işık, A.H., Düden Örgen, F.K., Şirin, C., Tuncer, A.D., & Güngör, A., (2019). Prediction of wind blowing durations of Eastern Turkey with machine learning for integration of renewable energy and organic farming-stock raising. *Tecnho-Science,* 2, 47-53.

[2]. Panayiotou, G., Kalogirou, S., & Tassou, S., (2012). Design and simulation of a PV and a PV-Wind standalone energy system to power a household application, *Renewable Energy,* 37,355-363.

[3]. Khanlari, A., Sözen, A., Afshari, F., Şirin, C., Tuncer, A.D., & Gungor, A., (2020). Drying municipal sewage sludge with v-groove triple-pass and quadruple-pass solar air heaters along with testing of a solar absorber drying chamber, *Science of The Total Environment*, 709, 136198.

[4]. Khanlari, A., Sözen, A., Şirin, C., Tuncer, A.D., & Gungor, A., (2020). Performance enhancement of a greenhouse dryer: Analysis of a cost-effective alternative solar air heater, *Journal of Cleaner Production*, 251, 119672.

[5]. Azaizia, Z., Kooli, S., Elkhadraoui, A., & Hamdi, A.A., (2017). Guizani, Investigation of a new solar greenhouse drying system for peppers, *International Journal of Hydrogen Energy*, 42, 8818-8826.

[6]. Güler, H.Ö., Sözen, A., Tuncer, A.D., Afshari, F., Khanlari, A., Şirin, C., & Gungor, A., (2020). Experimental and CFD survey of indirect solar dryer modified with low-cost iron mesh, *Solar Energy*, 197, 371-384.

[7]. Koçer A., Şevik S., & Güngör A., (2016). Determination of Solar Collector Optimum Tilt Angle for Ankara and Districts, *Uludağ University Journal of The Faculty of Engineering*, 21, 63-78.

[8]. Kaya, M., Gürel, A.E., Ağbulut, Ü., Ceylan, I., Çelik, S., Ergün, A., & Acar, B., (2019). Performance analysis of using CuO-Methanol nanofluid in a hybrid system with concentrated air collector and vacuum tube heat pipe. *Energy Conversion and Management*, 199, 111936.
[9]. Fudholi, A., Sopian, K., Ruslan, M.H., & Othman, M.Y. (2013). Performance and cost benefits analysis of double-pass solar collector with and without fins. *Energy conversion and management*, 76, 8-19.
[10]. Afshari, F., Khanlari, A., Sözen, A., Şirin, C., Tuncer, A.D., & Güngör, A., (2019). CFD analysis on fin and baffle configurations in solar air collector. *Energy And Environmental Studies For The Near Future*, 79-87, Akademisyen Publishing, Ankara, Turkey.
[11]. Hu, J., Liu, K., Ma, L., & Sun, X., (2018). Parameter optimization of solar air collectors with holes on baffle and analysis of flow and heat transfer characteristics. *Solar Energy*, 174, 878-887.
[12]. Khanlari, A., Güler, H.Ö., Tuncer, A.D., Şirin, C., Bilge, Y.C., Yılmaz, Y., & Güngör, A., (2020). Experimental and numerical study of the effect of integrating plus-shaped perforated baffles to solar air collector in drying application. *Renewable Energy*, 145, 1677-1692.
[13]. Ghiami, A., & Ghiami, S. (2018). Comparative study based on energy and exergy analyses of a baffled solar air heater with latent storage collector. *Applied Thermal Engineering*, 133, 797-808.
[14]. Elminshawy, N.A.S., Ghandour, M.E.I., Gad, H.M. El-Damhogi, D.G., El-Nahhas K., & Addas, M.F., (2019). The performance of a buried heat exchanger system for PV panel cooling under elevated air temperatures, *Geothermics*, 82, 7-15.
[15]. Dhoke, A., Sharma, R., & Saha, T.K., (2019). An approach for fault detection and location in solar PV systems, *Solar Energy*, 194, 197-208.
[16]. Sellami, R., Amirat, M., Mahrane, A., El-Amine Slimani, M., Arbane, A., & Chekrouni, R., (2019). Experimental and numerical study of a PV/Thermal collector equipped with a PV-assisted air circulation system: Configuration suitable for building integration, *Energy and Buildings*, 190, 216-234.
[17]. Huo, Y., Lv, J., Li, X., Fang, L., Ma, X., & Shi, Q., (2019). Experimental study on the tube plate PV/T system with iron filings filled, *Solar Energy*, 185,189-198.
[18]. Bambrok, S.M., & Sproul, A.B. (2012). Maximising the energy output of a PVT air system. *Solar Energy*, 86, 1857-1871.
[19]. Sethi, V.P., Sumathy, K., Yuvarajan, S., & Pal, D.S., (2012). Mathematical model for computing maximum power output of a PV solar module and experimental validation. *Ashdin Publ. J. Fundam. Renew. Energy Appl.* 2(5), 1–5.
[20]. Kaldellis, J.K., Kapsali, M., & Kavadias, K., (2014). Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece. *Renewable Energy*, 66, 612–624.

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