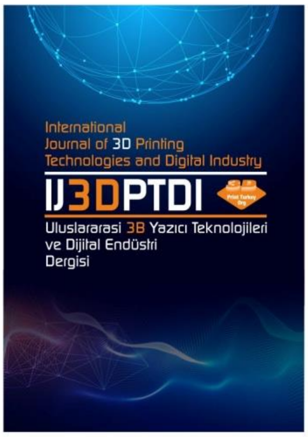

ULUSLARARASI 3B YAZICI TEKNOLOJİLERİ
VE DİJİTAL ENDÜSTRİ DERGİSİ

INTERNATIONAL JOURNAL OF 3D PRINTING TECHNOLOGIES AND DIGITAL INDUSTRY

ISSN:2602-3350 (Online)

URL: https://dergipark.org.tr/ij3dptdi

THE ANALYSIS OF PHOTOVOLTAIC PANEL SYSTEMS

Yazarlar (Authors): Ramazan Burak Domurcuk, Mustafa Asker, Pinar Demircioglu*, Ismail Bogrekci

Bu makaleye şu şekilde atıfta bulunabilirsiniz (To cite to this article): *Domurcuk R.B., Asker M., Demircioglu P., Bogrekci İ.,“ The Analysis of Photovoltaic Panel Systems ” Int. J. of 3D Printing Tech. Dig. Ind., 5(1): 13-22, (2021).*

DOI: 10.46519/ij3dptdi.856185

Araştırma Makale/ Research Article

Erişim Linki: (To link to this article): https://dergipark.org.tr/en/pub/ij3dptdi/archive

THE ANALYSIS OF PHOTOVOLTAIC PANEL SYSTEMS

Ramazan Burak Domurcuk[a], Mustafa Asker[a], Pinar Demircioglu[a]*, Ismail Bogrekci[a]

[a]Aydın Adnan Menderes University, Engineering Faculty, Mechanical Engineering Department, TURKEY

* *Corresponding Author: pinar.demircioglu@adu.edu.tr*

(**Received:** 07.01.2021; **Revised:** 16.02.2021; **Accepted:** 18.02.2021)

ABSTRACT

In this study, two different types of photovoltaic panels such as monocrystalline and polycrystalline solar panels are examined experimentally and the performance of these panels are assessed. The analysis is carried out for the city of Aydın in Turkey. The experimental measurements are achieved under weather conditions of Aydın in the August and September months. Besides, the solar radiation is measured using a pyranometer device. The panel surface temperature is measured using K type thermocouple. This work's primary purpose is to determine the most suitable panel type for the city of Aydın by means of electric power generation and thus to provide scientific data to the investors and companies. The results show that for monocrystalline and polycrystalline solar panels, the maximum power is found to be 49.74 W and 46.13 W, respectively. Also, the maximum efficiency of monocrystalline and polycrystalline solar panels is determined to be 13.94% and 12.13%, respectively.

Keywords: Monocrystalline. Polycrystalline. Photovoltaic. Solar Energy.

1. INTRODUCTION

Rapid population growth and industrialization in developing countries cause energy demand. There is a linear relationship between energy consumption and social development. Both the damages such as environmental pollution and global warming that fossil fuels cause to the environment and the limited resources have led to the search for alternative energy sources. The potential of solar energy to become widespread is higher than other renewable energy sources due to its potential, ease of use, cleanliness, renewability and environmental friendliness.

Most of the energy needed today is obtained from fossil fuels. Both the damages that these fuels cause to the environment and the limited resources have led to the search for alternative energy sources. Turkey has great potential in terms of renewable energy sources. Especially in recent years, our country has made significant advancements in the energy sector and many studies have been carried out to improve the industry. Compared to Europe and other world states, Turkey's annual sunshine duration is relatively high due to its geographical location. Photovoltaic panel systems are one of the substantial renewable energy sources which are rapidly becoming widespread due to its advantage such as converting directly solar energy into electrical energy.

Various studies have been carried out in this field. Al-Rousan et al. [1] reviewed the principles and mechanisms of photovoltaic tracking systems to determine the best orientation for installing the photovoltaic panels. The monitoring techniques, efficiency, performance, advantages and disadvantages of simple tracking systems are compared to state-of-the-art systems. Taşçıoğlu et al. [2] measured the power outputs of polycrystalline and monocrystalline panels with two different technologies under the conditions of Bursa province and stated that the power output increases with the increase of the radiation intensity and there is a linear relationship between radiation and power. He obtained that 87.14 W power from monocrystalline solar panel under 1001.13 W/m² total solar irradiance and 80.17 W power from polycrystalline solar panel under 1001.13 W/m² total solar radiation. Zaraket et al. [3] determined the effects of cell temperature on performance, power and efficiency in photovoltaic modules. Researchers stated that cell temperature is the most important factor affecting these three properties. They reported that an inverse relationship between cell temperature and performance. As the cell temperature increases, the efficiency of the photovoltaic panels decreases. Hafez et al. [4] presented an overview of tilt angle and azimuth angles in solar applications containing an overview of design parameter, applications, simulations and mathematical techniques covering different usage applications. Mathematical models allow the calculation of the different parameters of solar radiation, the angle of inclination and the optimum angle of inclination of the collecting surface and the effects affecting the system. Er et al. [5] examined that the impact of temperature and radiation on photovoltaic panel performance; temperature values, voltage and current values were taken for solar panels. Experimental studies show that the conditions in which the efficiency of a photovoltaic panel is affected. Their results show that the high temperatures that occur in the solar panels reduce the open-circuit voltage and cause the current values of the panel to decrease. They observed that the damaged part of the cell cannot generate electricity, therefore the cell has increased its own temperature, and they reported that the performance is reduced. Alaaeddin et al. [6] stated that both the PV cell structure and conversion efficiency may contribute to the progression of the PV system. They used a wide range of advanced materials within the PV cell. The improvement of PV structures and their optical properties result in optimizing solar radiation and reflectance. They reported that modeling and implementing appropriate parameters such as diode, optical, current, voltage, filling factors contributed to the efficiency and performance of the PV system. Senthil Kumar et al. [7] reported that solar energy is an important energy source for the future. They determined that solar PV panel performance changes with temperature increase. They stated that the photovoltaic solar cell's efficiency may be decreased owing to the rise in temperature. They determined that the life of the solar panel will be reduced. Ogbulezie et al. [8] stated that solar cells are sensitive to temperature. They examined the impact of temperature and irradiance source on the efficiency of polycrystalline photovoltaic (PV) solar panels in an environment. Their result showed that there is a decrease in voltage with increasing temperature. Shafique et al. [9] determined that the benefits and challenges related to PV-green roofs. They reported that the PV-green roof is an effective strategy for producing clean energy on the building. They stated that providing the optimum design of PV-green roofs for the climatic region; improving laws and regulations; evaluating life-cycle including social, environmental, and economic benefits; and cooperation tools for the adoption of PV-green roof systems. This work focus on the experimental investigation of the photovoltaic panel.

2. MATERIAL AND METHOD

The experimental study is conducted by using measurement devices such as pyranometer, digital multimeter, K type thermocouple, 80 W monocrystalline and polycrystalline solar panels, a 5-meter-long led light and a system stand with an adjustable inclination in a single axis as test setup. Solar radiation, current, voltage and panel surface temperature values are measured. The effect of some operating condition parameters such as panel surface temperature and solar radiation on the performance of different types of photovoltaic panels will be investigated experimentally. The power values generated by monocrystalline and polycrystalline photovoltaic panels under real atmospheric conditions were measured by the experimental method in Aydın during August and September of month. The optimum inclination angle for both solar panels where they generate the most power was determined at 20°. Monocrystalline photovoltaic solar panel is given in Figure 1, and its technical specifications are listed in Table 1. Polycrystalline photovoltaic solar panel used in this study in Figure 2, and its technical specifications are listed in Table 2.

Figure 1. Monocrystalline photovoltaic solar panel.

Table 1. Monocrystalline photovoltaic solar panel technical specifications

Technical Specifications	Values
Maximum Power (P_{max})	80 W
Maximum Power Voltage (V_{mp})	17.20 V
Maximum Power Current (I_{mp})	4.66 A
Open Circuit Voltage (V_{oc})	22.10 V
Short Circuit Current (I_{SC})	5.30 A
Maximum System Voltage	700 V DC
Number of Cells	36
Dimension	1190mm × 550mm × 30 mm

Figure 2. Polycrystalline photovoltaic solar panel.

Table 2. Polycrystalline photovoltaic solar panel technical specifications

Technical Specifications	Values
Maximum Power (P_{max})	80 W
Maximum Power Voltage (V_{mp})	17.7 V
Maximum Power Current (I_{mp})	4.51 A
Open Circuit Voltage (V_{oc})	21.5 V
Short Circuit Current (I_{SC})	5.05 A
Maximum System Voltage	1000 V DC
Power Tolerance	± 3%
Dimension	810mm × 670mm × 30 mm
Weight	8 kg

The Apogee MP-200 pyranometer solar radiation measurement device is used to measure solar radiation values as displayed in Figure 3. The Apogee MP-200 pyranometer solar radiation measurement device technical specifications are reported in Table 3. The TT-TECHNIC Class MY-62 digital multimeter measurement device was used to measure values of the current, voltage and panel surface temperature with K type thermocouple. The K type thermocouple for photovoltaic solar panel surface temperature measurement was used to measure values of panel surface temperature by using a digital multimeter. The SMD led light flexible strips were used to measure current and voltage values by generating charge on a photovoltaic system. The current and voltage values are measured by digital multimeters and recorded hourly. At the same time, the solar radiation value and the panel surface temperature are determined and the measured parameters are recorded.

Figure 3. Pyranometer solar radiation measurement device.

Table 3. Apogee MP-200 pyranometer solar radiation measurement device technical specifications

Technical Specifications	Values
Calibration Uncertainty	± 5 %
Measurement Repeatability	< 1 %
Non-stability (Long-term Drift)	< 2 % per year
Non-linearity	< 1 % (up to 1750 W/m2)
Response Time	< 1 ms
Field of View	180°
Spectral Range	360 to 1120 nm
Directional (Cosine) Response	± 5 % at 75° zenith angle
Temperature Response	0.04 ± 0.04 % per C
Operating Environment	0 to 50 C
Meter Dimensions	12.6 cm length, 7.0 cm width, 2.4 cm height
Sensor Dimensions	2.4 cm diameter and 2.8 cm height
Mass	180 g

The test setup is established in Aydın Adnan Menderes University, Faculty of Engineering, Department of Mechanical Engineering in Aydın province, measurements are conducted in August and September period. The relationship between the instantaneous power produced hourly and the solar radiation value and the panel surface temperature was determined. Monocrystalline and polycrystalline photovoltaic solar panels are given in Figure 4.

Figure 4. Monocrystalline and polycrystalline photovoltaic solar panels.

There are factors such as efficiency and filling factors affecting the performance of photovoltaic panels. The photovoltaic panel efficiency effect is the relationship between the power obtained from the solar cell and the energy recieved from the sun rays. The efficiency parameter of the solar cell is the ratio of the output power obtained from the solar cell to the P_{max} input power (P_{in}). The input power is obtained by dividing the solar intensity (W/m^2) on the cell by the cell area. The photovoltaic panel efficiency is given in Equation 1 [10,11];

$$\eta = \frac{P_{max}}{P_{in}} = \frac{(V_{max}\ I_{max})}{G \times A} = \frac{(FF\ V_{oc}\ I_{sc})}{G \times A} \tag{1}$$

where;

η = Photovoltaic Panel Efficiency

P_{max} = Maximum Power

P_{in} = Input Power

A = Cell Area

V_{oc} = Open Circuit Voltage

V_{max} = Maximum Voltage

I_{max} = Maximum Current

G = Solar Radiation

FF = Filling Factor

I_{sc} = Short Circuit Current

3. RESULTS AND DISCUSSION

In this study, two different types of photovoltaic panels such as monocrystalline and polycrystalline solar panels are examined experimentally and the performance of these panels is assessed. The analysis is carried out for the city of Aydın in Turkey. The experimental measurements are achieved under weather conditions of Aydın in the August and September months. The results obtained from the experimental work are analyzed. The influence of environmental parameters such as solar radiation intensity and temperature on the performance of monocrystalline and polycrystalline solar panels in Aydın province are presented. The measurement of the current, voltage and power values produced by photovoltaic cells under different radiation intensities and operating conditions is fundamental to assess the system performance, since the current, voltage and power output of photovoltaic devices depend on the radiation intensity, panel surface temperature and other climatic parameters.

Increasing the intensity of solar radiation increases the current and power value; it will increase the possibility of breaking more electrons than the n-type semiconductor material on the photovoltaic cell. As temperature effects solar radiation falling on the photovoltaic cells significantly, the temperature of the photovoltaic cell changes. This difference also causes the efficiency values to be changed by affecting the structure of the semiconductors in the cell.

It is possible to examine and interpret the efficiency of two types of solar panels, 80 W monocrystalline and polycrystalline. In the framework of efficiency and cost analysis, optimum performance panel type has been determined as monocrystalline photovoltaic for Aydın province and Aegean Region.

The performances are compared in terms of the current, voltage, panel surface temperature, and the maximum power parameters produced by the panel and concluded. The instantaneous power values produced by 80 W monocrystalline and polycrystalline solar panels in August and September are discussed. In the time interval between 10:00 and 16:00 hours, in the monocrystalline solar panel, the highest power value was observed at 13:00 and measured as 49.74 W. In the polycrystalline solar panel, the highest power value was also observed at 13:00 and measured as 44.47 W.

The maximum current, voltage and power output values of the monocrystalline solar panel are 2.66 A, 18.80 V, 49.74 W as shown in Table 4. Solar radiation value of monocrystalline solar panel increased towards noon with respect to time. The maximum solar radiation value of it is 1050 W/m^2 at the hour of 13:00. The maximum efficiency value is 13.94% at the hour of 10:00. At time 13:00 The maximum filling factor and performance rate are 0.42, 62.18%, respectively.

The maximum current, voltage and power output values of the polycrystalline solar panel are 2.43 A, 18.30 V, 44.47 W as shown in Table 5 belong to August. Solar radiation value of polycrystalline solar panel increased towards noon with respect to time. The maximum solar radiation value is 1050 W/m^2 at time 13:00. The maximum efficiency value is 12.13% at 10:00. The maximum filling factor and performance rate of it are 0.41, 55.59% at hour of 13:00.

The maximum current, voltage and power output values of the monocrystalline solar panel are 2.59 A, 19.10 V, 49.47 W as shown in Table 6 belongs to September. The solar radiation value of the monocrystalline solar panel increased towards noon with respect to time. The maximum solar radiation value of it is 1095 W/m^2 at the hour of 14:00. The maximum efficiency value of it is 11.51% at the hour of 10:00. The maximum filling factor and performance rate of it are 0.42, 61.84% at the hour of 12:00.

The maximum current, voltage and power output values of polycrystalline solar panels are 2.48 A, 18.60 V, 46.13 W as shown in Table 7 belong to September. The solar radiation value of polycrystalline solar panels increased towards noon with respect to time. The maximum solar radiation value of it is 1095 W/m^2 at hour of 14:00. The maximum efficiency value of it is 10.97% at hour of 10:00. The maximum filling factor and performance rate of it are 0.42, 57.66% at hour of 12:00.

Table 4. Measurement values for a monocrystalline photovoltaic solar panel on the date of 10.08.2020.

Hour	I (A)	V (V)	P (W)	G (W/m^2)	Panel Surface Temperature (°C)	Panel Efficiency (%)	Filling Factor (FF)	Performance Rate (%)
10:00	2.12	18.50	39.22	430	30	13.94	0.33	49.03
11:00	2.46	18.60	45.76	640	31	10.92	0.39	57.20
12:00	2.56	18.40	47.10	730	40	9.86	0.40	58.88
13:00	2.66	18.70	49.74	860	36	8.84	0.42	62.18
14:00	2.62	18.50	48.47	920	42	8.05	0.41	60.59
15:00	2.60	18.40	47.84	950	43	7.69	0.41	59.80
16:00	2.54	18.10	45.97	836	39	8.40	0.39	57.46
Average	**2.51**	**18.46**	**46.3**	**766.57**	**37.29**	**9.67**	**0.40**	**57.88**

Table 5. Measurement values for polycrystalline photovoltaic solar panel on the date of 10.08.2020.

Hour	I (A)	V (V)	P (W)	G (W/m^2)	Panel Surface Temperature (°C)	Panel Efficiency (%)	Filling Factor (FF)	Performance Rate (%)
10:00	1.59	17.80	28.30	430	32	12.13	0.26	35.38
11:00	1.98	17.90	35.44	640	33	10.20	0.33	44.30
12:00	2.31	18.00	41.58	730	42	10.50	0.38	51.98
13:00	2.43	18.30	44.47	860	38	9.53	0.41	55.59
14:00	2.38	18.10	43.09	920	45	8.63	0.40	53.86
15:00	2.36	18.00	42.48	950	44	8.24	0.39	53.10
16:00	2.26	17.60	39.78	836	40	8.77	0.37	49.73
Average	**2.19**	**17.96**	**39.31**	**766.57**	**39.14**	**9.71**	**0.36**	**49.13**

Table 6. Measurement values for a monocrystalline photovoltaic solar panel on the date of 11.09.2020.

Hour	I (A)	V (V)	P (W)	G (W/m^2)	Panel Surface Temperature (°C)	Panel Efficiency (%)	Filling Factor (FF)	Performance Rate (%)
10:00	2.44	18.4	44.90	596	30	11.51	0.38	56.12
11:00	2.55	18.8	47.94	840	35	8.72	0.41	59.93
12:00	2.59	19.1	49.47	972	33	7.78	0.42	61.84
13:00	2.54	19	48.26	1090	36	6.76	0.41	60.33
14:00	2.51	18.7	46.94	1095	38	6.55	0.40	58.67
15:00	2.36	18.1	42.72	1000	39	6.53	0.36	53.40
16:00	2.43	18.4	44.71	860	34	7.94	0.38	55.89
Average	**2.49**	**18.64**	**46.42**	**921.86**	**35.00**	**7.97**	**0.40**	**58.02**

Table 7. Measurement values for a polycrystalline photovoltaic solar panel on the date of 11.09.2020.

Hour	I (A)	V (V)	P (W)	G (W/m^2)	Panel Surface Temperature (°C)	Panel Efficiency (%)	Filling Factor (FF)	Performance Rate (%)
10:00	2.1	16.9	35.49	596	29	10.97	0.33	44.36
11:00	2.4	18.3	43.92	840	33	9.63	0.40	54.90
12:00	2.48	18.6	46.13	972	31	8.74	0.42	57.66
13:00	2.4	18.1	43.44	1090	34	7.34	0.40	54.30
14:00	2.47	18.5	45.70	1095	36	7.69	0.42	57.12
15:00	2.26	17.6	39.78	1000	37	7.33	0.37	49.72
16:00	2.29	17.8	40.76	860	36	8.73	0.38	50.95
Average	**2.34**	**17.97**	**42.17**	**921.86**	**33.71**	**8.64**	**0.39**	**52.72**

The power output and solar radiation values of monocrystalline photovoltaic are compared as depicted in in Figure 5. In this figure, it can be seen that there is a linear relationship between power output and solar radiation of monocrystalline photovoltaic with respect to time. As the solar radiation of monocrystalline photovoltaic increases, the power output increases.

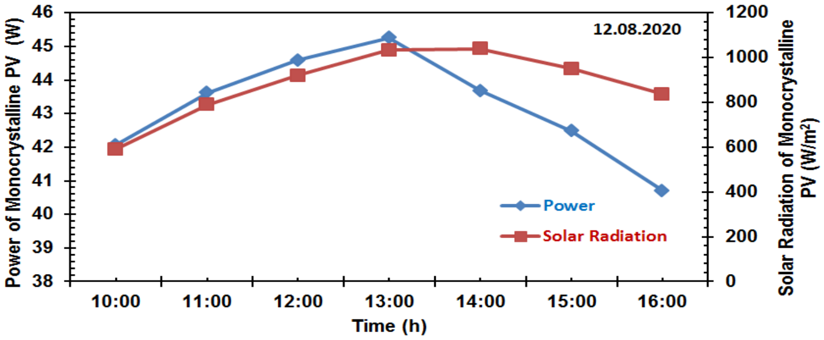

Figure 5. Variation of the power and solar radiation for monocrystalline solar panel with respect to time.

In monocrystalline photovoltaic, there is an inverse relationship between efficiency and surface temperature of monocrystalline photovoltaic with respect to time as shown in Figure 6. When the surface temperature of monocrystalline photovoltaic increases, the efficiency of monocrystalline photovoltaic decreases.

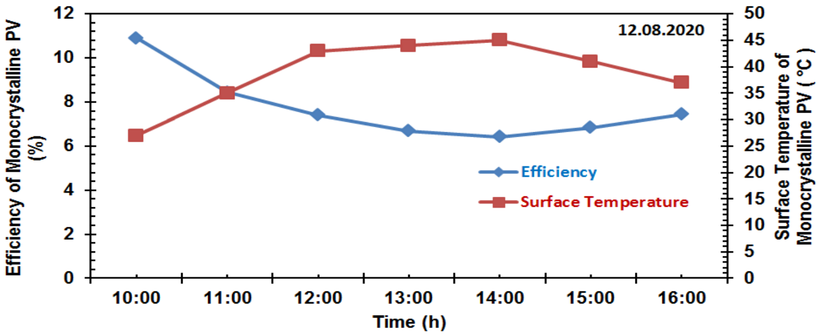

Figure 6. The relation between the efficiency and surface temperature values for monocrystalline solar panel with respect to time.

When measured power output and solar radiation values of polycrystalline photovoltaic are compared, there is a linear relationship between power output and solar radiation of polycrystalline photovoltaic with respect to time as shown in Figure 7. When the solar radiation of polycrystalline photovoltaic increases, the power output of polycrystalline photovoltaic increases.

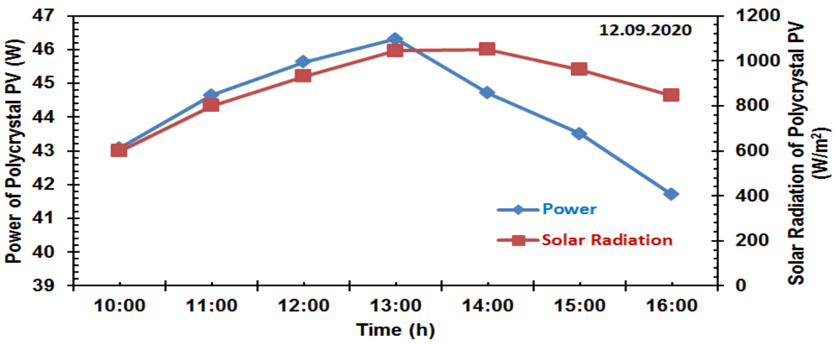

Figure 7. The relation between the power and solar radiation values for polycrystalline solar panel with respect to time.

When measured efficiency and surface temperature values of polycrystalline photovoltaic are compared, there is an inverse relationship between efficiency and surface temperature of polycrystalline photovoltaic with respect to time, as shown in Figure 8. When the surface temperature of polycrystalline photovoltaic increases, the efficiency of polycrystalline photovoltaic decreases.

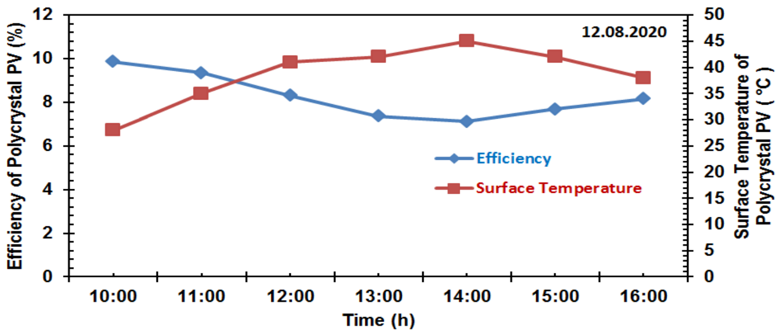

Figure 8. Relation between the efficiency and surface temperature values for polycrystalline solar panel with respect to time.

Power output values of monocrystalline photovoltaic are greater than power output values of polycrystalline photovoltaic with respect to time as shown in Figure 9. The power output values of both photovoltaic increased towards noon.

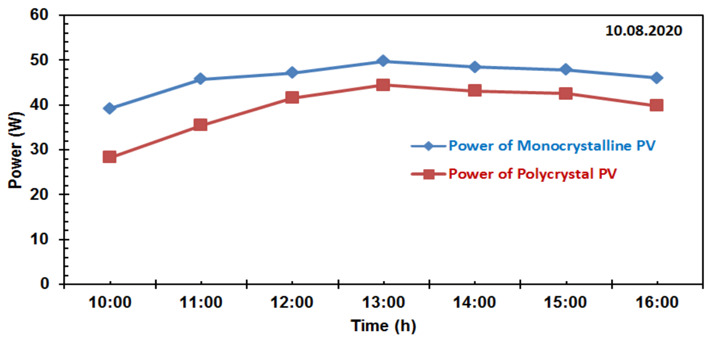

Figure 9. Variation of power values for monocrystalline and polycrystalline solar panel with respect to time.

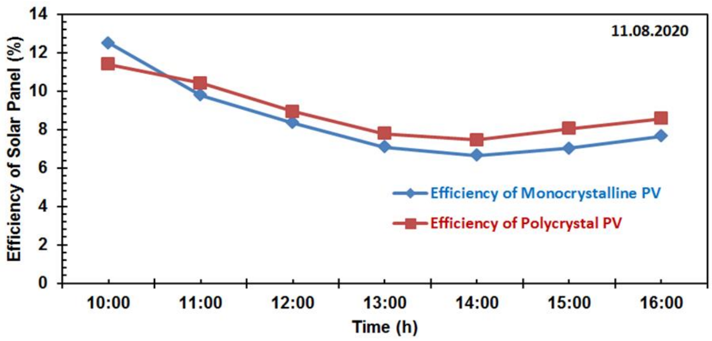

Figure 10. Variation of efficiency values for monocrystalline and polycrystalline solar panel with respect to time.

Efficiency values of polycrystalline photovoltaic are usually greater than efficiency values of monocrystalline photovoltaic with respect to time between the dates of 10.08.2020 and 13.08.2020 as shown in Figure 10. But the efficiency values of monocrystalline photovoltaic are greater than efficiency values of polycrystalline photovoltaic at hour of 10:00. The reason can be that monocrystalline photovoltaic is more adversely affected by temperature. Their efficiency values are close to each other. The reason why efficiency values of polycrystalline photovoltaic are usually greater than efficiency values of monocrystalline photovoltaic is that the area value of monocrystalline photovoltaic is greater than area of polycrystalline photovoltaic. Actually the power output values of monocrystalline photovoltaic are greater than power output values of polycrystalline photovoltaic.

4. CONCLUSION

The performance of 80 W monocrystalline and polycrystalline type panels is investigated in Aydın province conditions. the change of current, voltage for monocrystalline and polycrystalline solar panels are examined and thus the performance of the panels was calculated. The changes related to current, voltage, radiation intensity, panel surface temperature and generated power were obtained by using the measurement setup. The real performance, potential and usability of the panels were observed.

The main conclusion can be summarized as follows:

- The highest power output is obtained from the monocrystalline panel as 49.74 W at 13 o'clock in August.
- The maximum efficiency rate of the monocrystalline panel is found to be 13.94%. While the average efficiency of the monocrystalline panel is obtained as 8.13%.
- The maximum efficiency of the polycrystalline panel is obtained as 12.13%, whereas the average efficiency of the polycrystalline panel is obtained as 8.52%.

This study has provided fundamental data on the monocrystalline solar panel should be preferred in systems to be installed in Aydın. It has been shown that in order to increase the performance and efficiency, the panels should be designed considering environmental conditions. This research can be considered as a reference guide to possible studies on energy analysis of solar panels in Aydın and will contribute to the literature.

Turkey is in a position that is dependent on foreign energy and imports energy. In order to prevent this situation and contribute to the national economy, investors should be directed towards alternative energy sources and these resources should be encouraged. Thus, environmental pollution will be prevented by moving away from fossil fuels. It is predicted that this study will be a reference to possible studies on energy analysis of solar panels in Aydın.

ACKNOWLEDGEMENT

This study was funded by Aydın Adnan Menderes University Scientific Research Projects (BAP) with project number MF-17024. The authors would like to acknowledge the support provided by BAP commission and staff.

REFERENCES

1. Al-Rousan, N., Isa, N.A.M., Desa, M.K.M., “Advances in solar photovoltaic tracking systems: A review”, Renewable and Sustainable Energy Reviews, Vol. 82, Pages 2548–2569, 2018.

2. Taşçıoğlu, A., Taşkın, O., Vardar, A., “A power case study for monocrystalline and polycrystalline solar panels in Bursa city”, Internatıonal Journal of Photoenergy, Vol. 2016, Issue Article ID 7324138, Pages 1-7, 2016.

3. Zaraket, J., Aillerie, M., Salame, C., “Standards and testing experiments for a photovoltaic module”, Journal of Energy Procedia, Vol. 199, Issue 1, Pages 702-708, 2017.

4. Hafez, A.Z., Soliman, A., El-Metwally, K.A., Ismail, I. M., "Tilt and Azimuth Angles in Solar Energy Applications - A review", Renewable and Sustainable Energy Reviews, Vol. 77, Pages 147-168, 2017.

5. Er, Z., Rouabah, Z., Kızılkan, G., Orken, A.T., “Standards and testing experiments for a photovoltaic module”, European Journal of Science and Technology, Special Issue, Pages 12-15, 2018.

6. Alaaeddin, M.H., Sapuan, S.M., Zuhri, M.Y.M., Zainudin E.S., Faris M. AL-Oqla. “Photovoltaic applications: Status and manufacturing prospects”, Journal of Renewable and Sustainable Energy Reviews, Vol. 102, Pages 318-332, 2019.

7. Senthil Kumar, M., Balasubramanian K.R., Maheswari L., “Effect of temperature on solar photovoltaic panel efficiency”, International Journal of Engineering and Advanced Technology, Vol. 8, Issue 6: Pages 2593-2595, 2019.

8. Ogbulezie, J.C., Njok, A.O., Panjwani, M.K., Panjwani, S. K., “The impact of high temperature and irradiance source on the efficiency of polycrystalline photovoltaic panel in a controlled environment”, International Journal of Electrical and Computer Engineering, Vol. 10, Issue 4, Pages 3942-3947, 2020.

9. Shafique, M., Luo, X., Zuo, J., “Photovoltaic-green roofs: A review of benefits, limitations, and trends”, Journal of Solar Energy, Vol. 202, Pages 485-497, 2020.

10. Chander, S., Purohit, A., Sharma, A., Nehra, S.P., Dhaka, M.S., “A Study on Photovoltaic Parameters of Monocrystalline Silicon Solar Cell with Cell Temperature”, Journal of Energy Reports, Pages 104-109, 2015.

11. Tiwari, G.N, Shyam A.T.,” Handbook of Solar Energy Theory, Analysis and Applications”, Springer, Berlin, 2016.