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PERFORMANCE AND EFFICIENCY OF PHOTOVOLTAIC PANELS IN ERZURUM WINTER CONDITIONS

ERZURUM KIŞ KOŞULLARINDA FOTOVOLTAİK PANELLERİN PERFORMANSI VE VERİMLİLİĞİ

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ABSTRACT

In this study, the efficiency and performance ratios of monocrystalline and polycrystalline type Photovoltaic (PV) solar panels were investigated comparatively under winter conditions in Erzurum province. Within the scope of the research, an experimental system was established using 250W monocrystalline and polycrystalline panels, and measurements were taken in December, January, and February. Current, voltage, and power outputs of the panels were measured, and efficiency and performance ratios were calculated. The results of the study show that the theoretical efficiency of polycrystalline panels is in the range of 13.9-18%, while the efficiency of monocrystalline panels is in the range of 13-17%. The performance ratios of polycrystalline panels were 116%, 94%, and 90% for December 2019, January, and February 2020, respectively. The performance rates of monocrystalline panels were 110%, 91%, and 90% for the same months. These results show that both panel types perform similarly in terms of efficiency, but polycrystalline panels have a slightly higher performance ratio. The results show that both polycrystalline and monocrystalline panels show similar performance in terms of efficiency in winter months, but the polycrystalline panel exhibited higher values in terms of performance ratios. In light of these findings, it is concluded that polycrystalline panels are more suitable for Erzurum winter conditions.

Keywords: Photovoltaic panels, efficiency, performance ratio, winter conditions, Erzurum/Turkey

ÖZET

Bu çalışmada, Erzurum ili kış ayları şartlarında monokristal ve polikristal tip fotovoltaik güneş panellerinin verimlilikleri ve performans oranları karşılaştırmalı olarak incelenmiştir. Araştırma kapsamında, 250W gücünde monokristal ve polikristal paneller kullanılarak bir deney sistemi kurulmuş ve Aralık, Ocak, Şubat aylarında ölçümler alınmıştır. Panellerin akım, gerilim ve güç çıkışları ölçülerek verim ve performans oranları hesaplanmıştır. Çalışmanın sonuçları, polikristal panellerin teorik veriminin %13,9-18 aralığında, monokristal panellerin veriminin ise %13-17 aralığında elde edilmiştir. Polikristal panellerin performans oranları Aralık 2019, Ocak ve Şubat 2020 için sırasıyla %116, %94 ve %90 olmuştur. Monokristal panellerin performans oranı ise aynı aylar için %110, %91 ve %90 olarak gerçekleşmiştir. Bu sonuçlar, her iki panel türünün de verimlilik açısından benzer performans gösterdiğini, ancak polikristal panellerin biraz daha yüksek bir performans oranına sahip olduğunu göstermektedir. Sonuçlar hem polikristal hem de monokristal panellerin kış aylarında verimlilik açısından benzer performans gösterdiğini, ancak performans oranları açısından da polikristal panel daha yüksek değerler sergilemiştir. Bu bulgular ışığında, Erzurum kış şartları için polikristal panellerin daha uygun olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Fotovoltaik paneller, verimlilik, performans oranı, kış koşulları, Erzurum/Türkiye

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INTRODUCTION

The use of renewable energy sources, such as solar energy, has been increasing in recent years as a response to the growing concern about the environmental impact of fossil fuels and the need to reduce greenhouse gas emissions. PV panels are an important technology for converting solar energy into electricity, and the efficiency and performance of these panels are critical factors for their economic viability and long-term sustainability (Jeter, 1981; Chandel and Agarwal, 2017; Shukla et al., 2017; Cuce et al., 2013; Öztürk et al., 2012a).

Erzurum, Turkey, is an area with high solar radiation and a suitable location for PV power plants. However, the performance of PV panels is affected by the weather conditions, particularly in winter. Therefore, it is essential to investigate the efficiency and performance of PV panels under winter conditions (December 2019, January, and February 2020) in Erzurum, Turkey. Farahmand et al. (2021), in their study of the effect of Seasonal Weather and Solar Conditions on PV Panels, showed that the panel efficiency is higher in winter than in summer due to the decrease in air temperature (Farahmand et al., 2021). It has been shown in many studies that the efficiency of PV panels decreases as the temperature increases. For example, theoretical studies show that each 1°C increase in temperature decreases the energy conversion efficiency by approximately 0.3% (Hossain et al., 2020). In this context, it can be considered that lower temperatures in winter conditions can positively affect panel efficiency. However, environmental factors also affect panel performance. For example, dust accumulation can reduce the power output of panels. In one study, uncleaned panels were observed to produce 8-12% less power per month compared to clean panels (Salimi et al., 2019). In winter conditions, snow and ice accumulation can cause similar effects.

The purpose of this study is to investigate the performance and efficiency of monocrystalline and polycrystalline PV panels under winter conditions in Erzurum, Turkey. The study aims to determine the most suitable type of panel for the region in terms of efficiency, performance ratio, and cost, and to provide scientific data to investors for making informed decisions about PV panel investments. Efficiency and performance ratios were compared over the parameters of current, voltage, and power produced by the panel, and the most suitable panel type for Erzurum was determined in terms of efficiency, performance ratio and cost (The average global radiation value of Erzurum is calculated as 4.63 kWh/m^2 -day, the average sunshine duration is 7 hours and the altitude is 1869 m).

The efficiency and performance of PV panels are critical factors for their economic viability and long-term sustainability. The efficiency of a PV panel is a measure of the panel's ability to convert solar radiation into electricity, while the performance ratio is a measure of the panel's actual energy output compared to its theoretical maximum output. Previous studies have investigated the performance and efficiency of PV panels under different weather conditions and have shown that the performance of PV panels is affected by temperature and solar radiation. For example, a study by Parthiban and Ponnambalam (2022) found that the performance of PV panels decreases as the temperature increases, a study by Karafil et al. (2016) found that the performance of PV panels is affected by the solar radiation and According to Brahim et al. (2017) They stated that only less than 20% of solar energy is converted to electricity and more than 50% of incoming solar radiation is converted to heat.

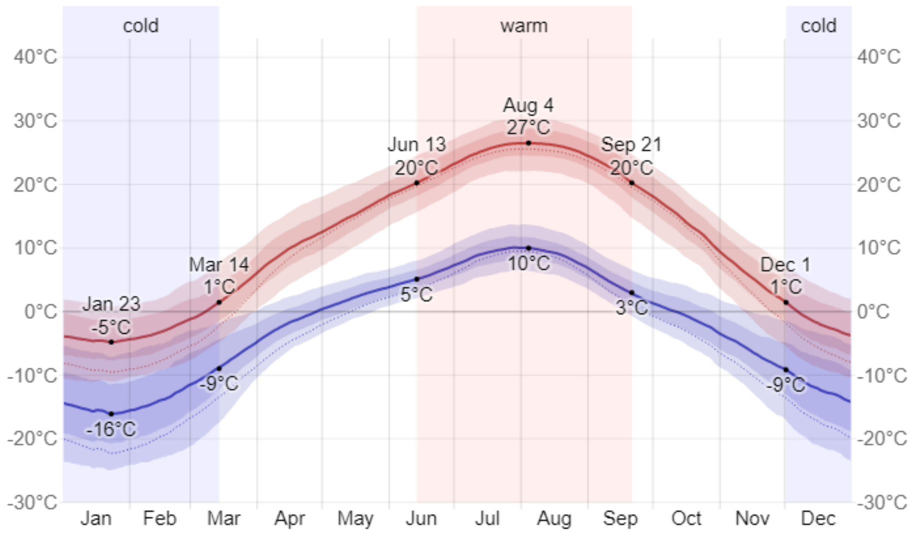

Figure 1. Average High and Low Temperatures in Erzurum Region (Weather Spark, 2023)

Despite the previous studies, the performance and efficiency of PV panels under winter conditions in Erzurum, Turkey, have not been fully investigated yet. Therefore, this study aims to fill this gap in the literature by investigating the performance and efficiency of monocrystalline and polycrystalline PV panels under winter conditions in Erzurum, Turkey. The average low and high temperatures of the Erzurum region and the hourly temperature distribution of the region are shown in Figure 1, Figure 2, and Figure 3.

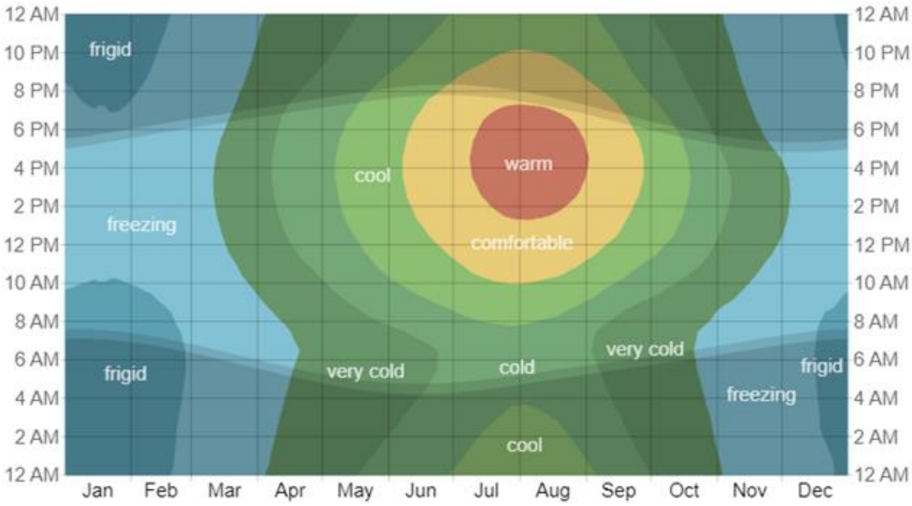

Figure 2. Hourly Temperature in Erzurum Region (Weather Spark, 2023)

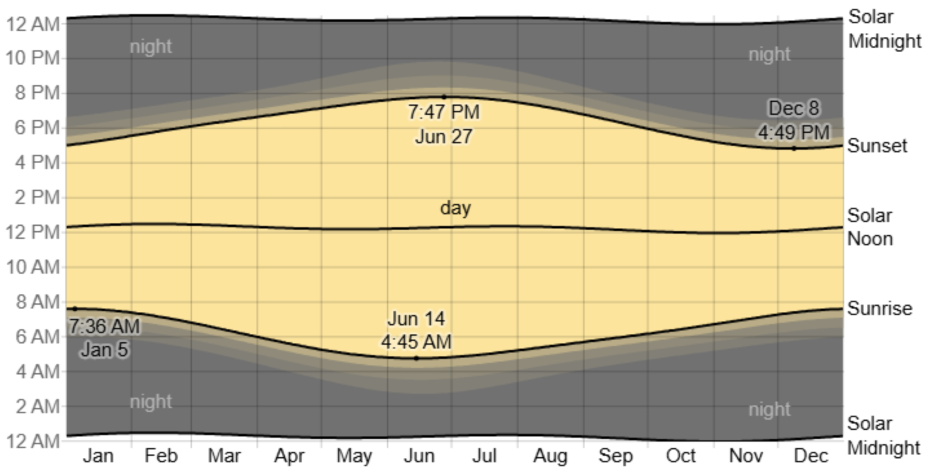

Figure 3. Sunrise and Sunset with Twilight in Erzurum (Weather Spark, 2025)

Solar energy can be used in thermal and electric systems. PV systems are utilized to generate electricity. The working principle of these systems is based on the principle of converting the radiation falling on semiconductor materials into electrical energy. Different panel types are formed due to the type and production method of the semiconductor cells used, and as a result, the efficiencies of the resulting panels are also different (Chauhan et al, 2018; Nadda et al, 2018; Baloch et al, 2015; Öztürk et al, 2012b; Yesildal et al, 2022)

In their study, Fouad et al. (2017) emphasized that it is very important to take into account the installation factors such as cable properties, inclination angle, mismatch effects, fixed/tracking PV mechanisms, and maximum power point when installing the PV systems. Canete et al., (2014) have conducted a comparative study of four different PV module technologies to obtain energy performance under the meteorological conditions of southern Spain over a period of one year.

Sulukan (2020) studied the techno-economic and environmental analysis of a PV system in Istanbul. In this study, research was conducted on a system consisting of PV modules to meet the electricity demand of a campus. The focus of the study was determined as the rooftop usable area, efficiency, inverter efficiency, and temperature effect of the photovoltaic array. At the end of the study, it was evaluated that the greenhouse gas emission was reduced by 93%, and 721.1 tons of crude oil would be saved. Taşçıoğlu et al., (2016) measured the power output of two different technologies, polycrystalline and monocrystalline panels, according to the irradiance in Bursa and stated that as the irradiance increases, the power output also increases, and there is a linear relationship between irradiance and power. As a result of the experimental studies, 87.14 W and 80.17 W power were obtained from the monocrystalline solar panel and polycrystalline solar panel, respectively, under 1001.13 W/m^2 total solar irradiance. It can be observed that all studies have evaluated the performance of different PV technologies under different meteorological conditions and found some variations in performance, efficiency, and output power. But it's important to notice that these studies were carried out under specific conditions, and it's not possible to generalize the results for different regions and climates.

Guenounou et al. (2016) conducted a study comparing the performance of four PV panels with different technologies under natural conditions on the southern coast of the Mediterranean over a period of one year (Figure 4). 4 studies were conducted on panel technology. They compared the data provided by the manufacturer's data sheets and the experimental outdoor data, and found that the data on the data sheets were clearly not taken from real measurements. According to their results, the performance ratio, thin film PV panels (a-Si and l-Si) had the best performance ratio in summer months, while crystalline silicon PV panels (M-Si and Poli-Si) had the best performance in winter months.

Figure 4. Experimental System (Guenounou et al., 2016)

Tossa et al. (2016) measured the current and voltage values of three silicon technologies: a monocrystalline module, two polycrystalline modules, a tandem structure module (amorphous/microcrystalline), and a microcrystalline module under outdoor conditions throughout the year. The results show that the micromorph module performs best at the selected site with an average performance ratio of 92%. The monocrystalline and polycrystalline modules from the same manufacturer both have an average performance ratio of 84%. The second polycrystalline module from another manufacturer strangely shows the lowest average performance ratio (80%) due to both its large series resistance and high maximum power temperature coefficient under operating conditions. Ozden et al. (2017) investigate the performance of three distinct solar systems operating in Central Anatolia under the same meteorological circumstances after four years of operation. Different approaches for calculating input solar irradiance on tilted surfaces are used to calculate performance. These three systems' 44-month average efficiencies are calculated to be 11.86%, 6.40%, and 5.30%, respectively. The performance of a photovoltaic thermal pump (PV/T) combined system, as well as the effects of a newly designed evaporator, have been numerically studied. The highest electrical efficiency of a PV system is 2.5% more than that of a system without a cooling system, and the maximum COP of a heat pump system is 4.75. The combined system's maximum COP value is determined to be 4.3 (Ozakin et al, 2020).

MATERIALS AND METHODS

Experimental System

The study was conducted at Ataturk University Teknokent. The system was designed as an off-grid system containing two different panel Technologies (Figure 5-6). A 4 kWp solar energy system was used, consisting of 8 polycrystalline and 8 monocrystalline panels, 2 inverters (4 kW), and 8 gel batteries (100 Ampers) (Table 1). The system was also equipped with software for real-time monitoring and control. The aim was to measure the performance of two different production technologies in winter months according to Erzurum province conditions (Aras, 2019).

Figure 5. PV Experimental System

Figure 6. Combiner Box

Table 1. Introduction and Technical Characteristics of System Components

System Technical Specifications	
Installed Power	4 kWp
Panel Type	8 pieces 250 W Polycrystalline, 8 pieces 250 W Monocrystalline
Inverter	Smart Inverter 4 kW (2 pieces)
Voltage Measurement	Enda EPV 241A Modbus Voltmetre (4 pieces)
Current Measurement	Enda EPV 241A Modbus Ampermetre (4 pieces)
Automation	PLC Datalogger Ethernet
Meter	Elster A15000 Meter
Battery	100 A Gel Battery (8 pieces)
Supporting Construction	45 m^2

PV Panels

In the study, polycrystalline and monocrystalline solar panels were used. The technical specifications of these panels are given in Table 2.

Table 2. Characteristic Information Provided by The Manufacturer for The Polycrystalline and Monocrystalline Panels

Cell Type:	Polycrystalline	Monocrystalline
Maximum Power (Pm):	250 W	250 W
Maximum Power Voltage (Vmp):	30.3 V	31.64 V
Panel Efficiency:	15.37%	17.8%
Tolerance:	± 3%	± 3%
Panel Dimensions:	1640 x 992 x 40 mm.	1640 x 992 x 40 mm.

Inverter

In this study, the Axpert KS Inverter was used. Two 4 kW Smart Inverters were used, one for monocrystalline panels and one for polycrystalline panels. The inverters used can power any type of equipment, including motor-driven items such as fluorescent lights, fans, refrigerators, and air conditioners in residential or office environments (Figure 7).

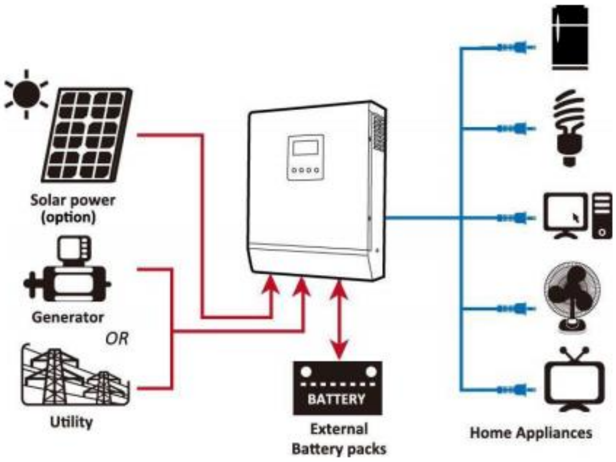

Figure 7. Inverter

The working and display panel shown in the figure below is the front panel of the inverter. This panel includes three indicators that show the working status and input/output power, four function buttons, and an LCD screen.

Current Voltage Meter

4 Enda EPV 241A Modbus Voltmeters, 2 for the output of polycrystalline and monocrystalline panels, and 2 for the output of polycrystalline and monocrystalline battery groups, and 4 Enda EPV 241A Modbus Ampermeters, 2 for the output of polycrystalline and monocrystalline panels and 2 for the output of polycrystalline and monocrystalline battery groups, were used to measure the current and voltage of the circuit. These ammeters and voltmeters have the ability to communicate with ModBus RTU protocol (Figure 8).

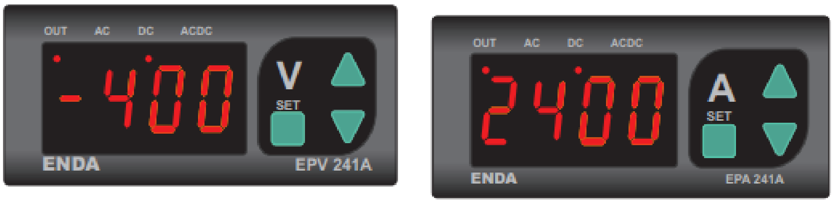

Figure 8. Enda EPV 241A Modbus Voltmeter and Ampermeter

Automation

Data from the system was recorded through a PLC Datalogger data recorder, remote access was provided to the system, and data was saved in a SQL database. Through the provided connection, the system's status was remotely monitored, alarms were set, and the list of data to be collected was controlled (Figure 9).

Figure 9. PLC Datalogger

Figure 10. Station Data Map

On the page that we entered with our username and password, the first thing that appears is the station data map showing the location and status of our test system (Figure 10).

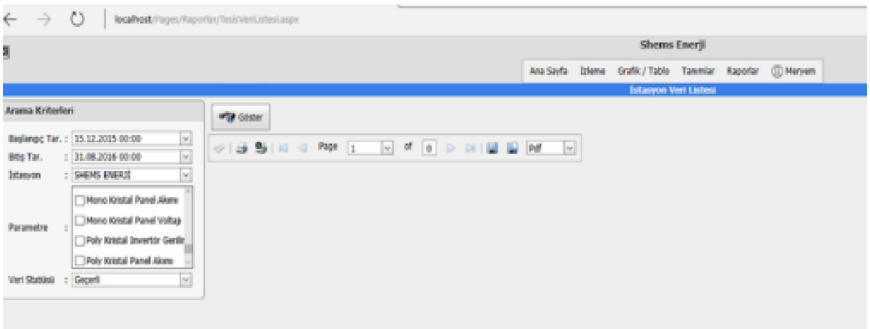

Figure 11. Station Data List

By selecting the parameter we want to see through the station data list, the read values of that parameter are examined (Figure 11).

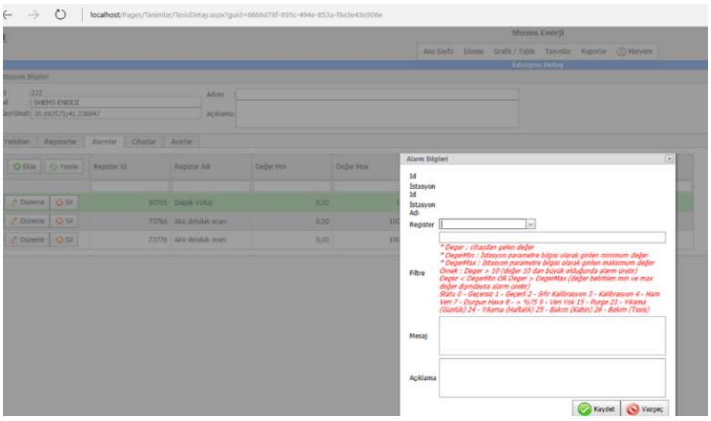

Figure 12. Station Alarm Definition

We set an alarm by specifying the range of values we want on the Station Alarm Definition page, and otherwise, we could be notified via the alarm (Figure 12).

Counter

The equipment that can measure the consumed or produced electrical energy is called an electricity meter or simply a meter. To put it briefly, the electricity meter measures the power and the time this power is applied. For this reason, the unit of measurement is Wh (Watt hour). The total energy produced in the system was measured by the Elster A15000 Counter.

Battery

8 gel batteries of 12V 100A were used in the experimental system. Gel batteries have a longer life than other batteries. Gel batteries are batteries with deeper discharge characteristics compared to other batteries. Gel batteries can discharge up to 20% without any problems.

Experiment Procedure:

The measurements were taken in December 2019, January, and February 2020, during winter months, in Erzurum province, at an appropriate slope angle, between 9:00 AM and 5:00 PM, every minute. The purpose is to assess the performance of two distinct manufacturing technologies in relation to the winter circumstances in Erzurum region. As a result of these measurements, daily average data was collected to create current-voltage graphs, and monthly average data was used to calculate the system's efficiency and performance ratio by month, and charts were drawn (Aras, 2019).

In the application, a PV experimental system was used, with an inverter system with AC output, and two different types of solar panels with 250 W power each, and an off-grid system containing two separate panel technologies. Measurements were taken in the winter months in Erzurum. The energy generated was used to illuminate the corridor of Ata Teknokent Building.

To determine the amount of electricity generated by the solar panels, an electrical measurement equipment comprised of Voltmeters and Ammeters was used in the scope of the study. The electrical measurement equipment was used to determine the current and voltage values produced by the solar panels. The data in the system was recorded with a PLC Datalogger and written to a SQL database through a remote connection. Instant data acquisition can be achieved through remote connection. The power, efficiency, and performance ratios were calculated with the current and voltage values obtained.

Determination of Panel Efficiency:
Panel efficiency can be calculated using equation 1 below.

$$\eta sys = \frac{P}{AxG} \times 100 \quad (1)$$

η : Panel efficiency (dimensionless)
P: Instant power output (W)
A : Surface area of the panel (m^2)
G: Solar irradiance (Standard Test Conditions (STC) solar irradiance is 1000 W/m^2)

Calculation of Performance Ratio:

$$P.R. \;=\; \eta sys/\eta stc \quad (2)$$

$$\eta stc = (P_{stc}/AxG_{stc}) \times 100 \quad (3)$$

These equations are used to calculate the efficiency and performance ratios.
Where;
η_{sys}: System panel efficiency (dimensionless)
η_{stc}: Panel efficiency under standard test conditions (dimensionless)
P: Instant power output from the system (W)
A : Surface area of the panel (m^2)
G: Solar irradiance intensity (Solar irradiation intensity under standard test conditions (STC) 1000 W/m^2)
*P*stc: Power output (W) under standard test conditions

RESEARCH FINDINGS AND DISCUSSION

Evaluation of Solar Radiation by Power Output

The results of this study, as illustrated in Figure 13, demonstrate that the solar radiation values recorded on sunny and partly cloudy days during the three winter months exhibit peak values in the afternoon. Additionally, it is observed that as the months progress, the peak values of solar radiation increase. This can be attributed to the increase in solar incidence angle. The results also show that the peak values of solar radiation fluctuate based on the cloudiness throughout the day. The solar radiation values approach zero at sunrise and sunset, and these findings are in line with previous studies in the literature (Başoğlu et al, 2015b; Başoğlu ve Çakır, 2015a). In conclusion, this study provides a detailed analysis of the solar radiation values in Erzurum province during the winter months and highlights the potential of solar energy in the region. The results indicate that solar radiation values are at their highest during the afternoon hours and increase as the solar incidence angle increases. Furthermore, the study shows that cloudiness affects the solar radiation values during the day. These findings can be used as a reference for future solar energy projects in the region and for choosing the appropriate solar panel type for the region. It is important to note that the results of this study are based on measurements taken during the winter months, and future studies could be conducted to include other seasons to have a more comprehensive understanding.

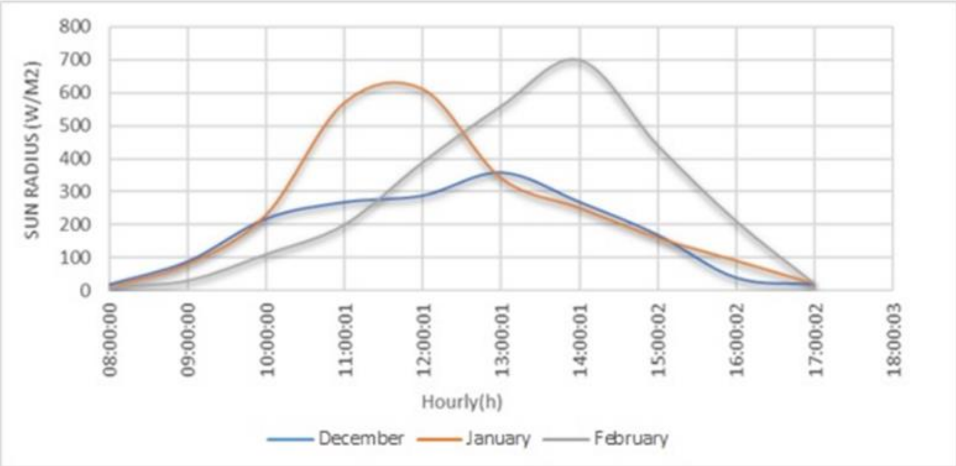

Figure 13. Hourly Solar Radiation Graph

Evaluation of Panel Power According to Solar Radiation

Figure 14. illustrates the evaluation of the panel output power at various times based on the solar radiation value recorded at that time. The analysis shows that there is an approximate linear relationship between solar radiation and panel output power. The equation of this line is found to be y = 0.0731x + 182.97. As the panel power increases, it is observed that solar radiation also increases. The results obtained are in agreement with the literature (Mirzaei and Mohiabadi, 2017; Al-Ghezi vd., 2022).

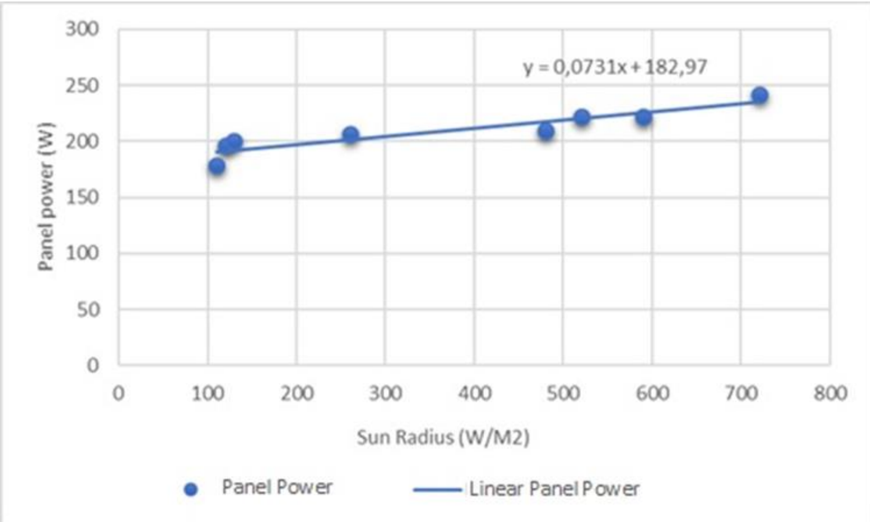

Figure 14. Panel Power-Solar Radiation Graph

The results of this study show that there is a linear relationship between solar radiation and panel output power (Al-Ghezi vd., 2022). This finding is significant because it demonstrates that the panel's output power increases as the solar radiation values increase. This information can be used to optimize the performance of PV systems by adjusting the orientation and tilt angle of the panels to maximize solar radiation.

Additionally, this study also provides an equation that can be used to estimate the panel output power based on the solar radiation values. This can be useful for predicting the performance of PV systems in Erzurum province. It is worth noting that the results of this study are based on the measurements taken during the winter months, and further studies could be conducted to include other seasons to have a more comprehensive understanding of the relationship between solar radiation and panel output power in Erzurum province.

Evaluation of Panel Power Output by Month

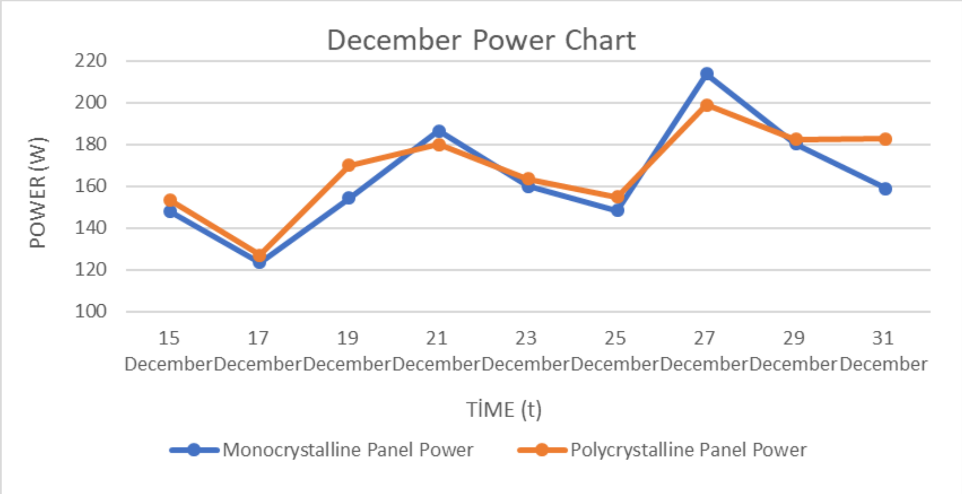

Figure 15. Panel Power Output in December

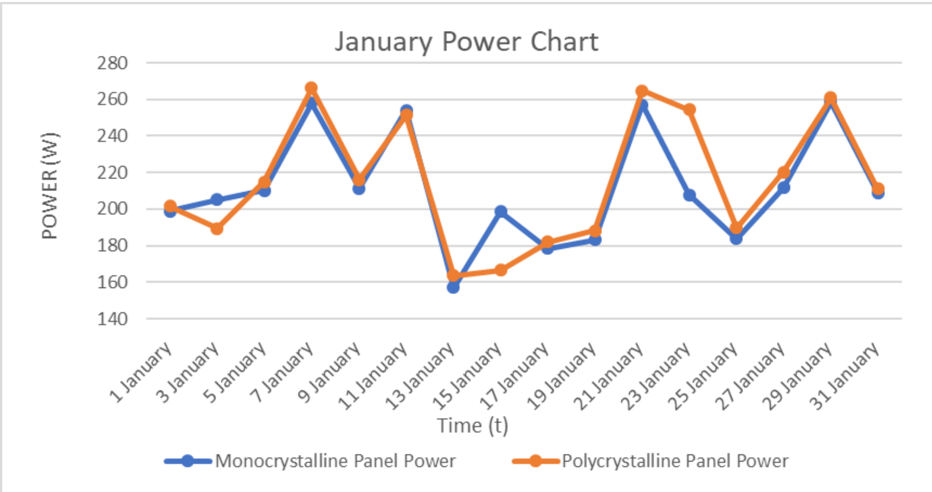

Figure 16. Panel Power Output in January

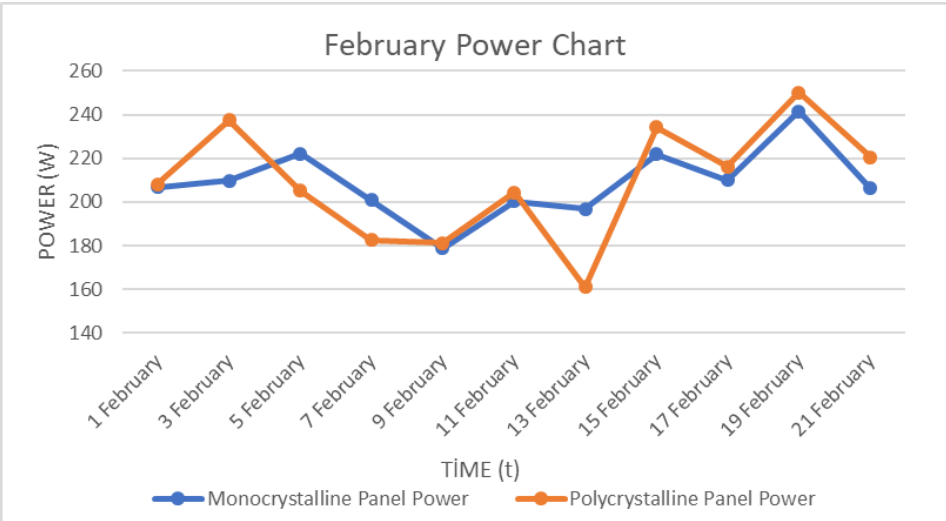

Figure 17. Panel Power Output in February

Figures 15, 16, and 17 present the power output graphs obtained from the experimental studies for the months. As shown in the graphs, the highest power values were obtained in the month of January. The average power output for monocrystalline and polycrystalline panels was 163.7 W and 168.1 W, respectively, in December; 211.4 W and 215 W in January; and 208.6 W and 209.2 W in February. Factors such as the number of sunny days, cloudiness rate, operating temperature, radiation intensity, as well as the reflection property of snow, were also observed to be effective in the results. The data is very close to each other, but there are some days when they change. However, it was determined that the power of polycrystalline panels is higher than that of monocrystalline panels on average for all three months. (Başoğlu et al, 2015b). The results obtained are in agreement with scientific studies.

The study results show that the power output of polycrystalline panels is higher than monocrystalline panels in the winter months of Erzurum. This information can be useful for investors who are considering PV panel investments in Erzurum, Turkey, and can help them to make more informed decisions about which type of panel to invest in.

Furthermore, the results also indicate that the power output is influenced by the number of sunny days, cloudiness rate, operating temperature, radiation intensity, and the reflection property of snow.

Evaluation of Panel Efficiency by Month

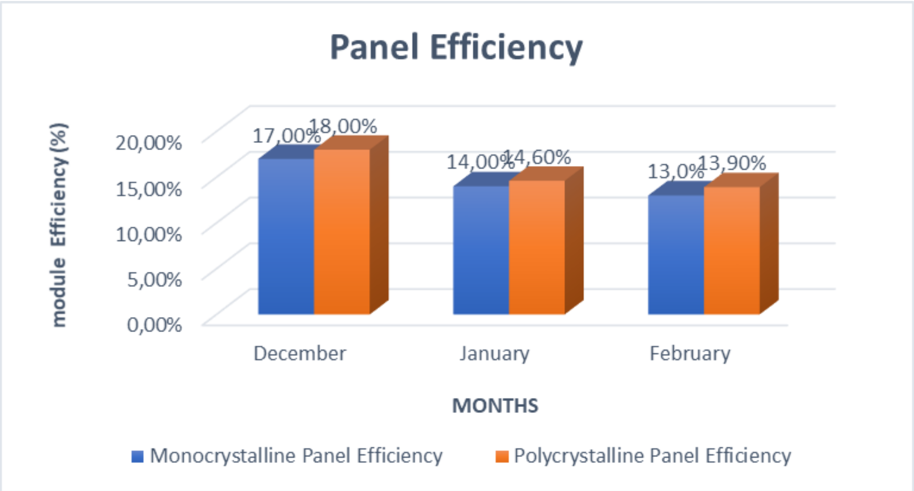

Figure 18. Average Panel Yield Per Month

Figure 18 compares the calculated efficiency values of polycrystalline and monocrystalline panels in the months of December, January, and February. The efficiency calculations were made using the hourly horizontal solar radiation values obtained from the Meteorological Institute, and the vertical solar radiation values were calculated taking into account the tilt angle of the panels. Based on the experimental data, it was determined that the average panel efficiencies for Erzurum province in the winter months were highest in December with values of 17% and 18% for monocrystalline and polycrystalline, respectively, and lowest in February with values of 13% and 13.9% for monocrystalline and polycrystalline, respectively. The efficiency values of solar panels are very similar, and it was determined that the polycrystalline panel type has an approximately 1% higher efficiency value than the monocrystalline panel type for three months (Guenounou et al., 2016; Başoğlu et al, 2015b; Başoğlu ve Çakır, 2015a). The study results show that the efficiency of polycrystalline and monocrystalline solar panels is very close to each other in the winter months of Erzurum. However, the efficiency of polycrystalline panels is slightly higher than monocrystalline panels. This information can be useful for investors who are considering PV panel investments in Erzurum and can help them to make more informed decisions about which type of panel to invest in.

Additionally, these results indicate that the efficiency of the panels is influenced by the solar radiation values, tilt angle of the panels, and weather conditions of the region. Further studies can be conducted to include other seasons and to investigate the effect of other factors such as temperature and shading on the efficiency of the panels.

Evaluation of Performance Rate by Month

Figure 19 shows the calculated performance ratios of the panels for the months. The performance ratio, which is a percentage, was calculated using the panel efficiencies and the standard conditions specified in the manufacturer's catalogs, using Equation 2. The standard test conditions used a solar radiation constant of 1000 W/m^2. The results of the calculations indicate that the highest performance ratio was achieved in December with values of 110% and 116% for monocrystalline and polycrystalline panels, respectively, and the lowest performance ratio was in February with values of 84% and 90% for monocrystalline and polycrystalline panels, respectively. Başoğlu et al. (2015b) analyzed the energy performance of three different PV module technologies (ci-si, mc-si, cd-te) in Kocaeli, located in northwestern Turkey, between October 2013 and December 2014. The study determined the performance ratios of the panels as 82.05%, 83.8%, and 89.76%, respectively. The research indicates that the energy performance of different PV module technologies varies depending on environmental and climatic conditions, as well as disruptive factors such as shading and pollution, and location. The experiments show that the performance ratio of the polycrystalline panel is higher than the other panel, and it is in agreement with the literature (Canete et al., 2014; Başoğlu et al, 2015b). In some cases, the efficiency of polycrystalline panels can be improved. For example, coating with hydrophobic SiO_2 nanomaterial can increase the efficiency of polycrystalline panels by up to 15% (Alamri et al., 2020). Additionally, keeping the panel surface clean is crucial. Regularly cleaned panels can achieve up to 15% higher efficiency compared to dusty panels (Alamri et al., 2020). Moreover, a study conducted in arid regions observed that under high solar radiation conditions, polycrystalline panels were less affected by temperature increases and experienced less power loss compared to monocrystalline panels (Benghanem et al., 2023). According to the study conducted by Mirzaei and Mohiabadi (2017), Temperature measurements have enabled the evaluation of the impact of ambient temperature on the performance of PV modules under real operating conditions. Performance ratio (PR) analyses indicate that, due to the different light absorption and thermal characteristics of each PV module, polycrystalline modules exhibit higher PR under high temperatures during the summer months. However, despite similar irradiation conditions, monocrystalline modules demonstrate higher PR during non-summer months. Consequently, it has been determined that under the semi-arid climate conditions of Iran, polycrystalline solar modules are more suitable for use in summer, while monocrystalline modules are more efficient during non-summer periods. Panel efficiency may vary depending on environmental conditions, temperature, and solar radiation levels. Although monocrystalline panels are generally more efficient, polycrystalline panels can perform better in regions with high temperatures and intense solar radiation. Therefore, regional conditions should be considered when selecting panels (Benghanem et al., 2023; Selvaraj et al., 2023).

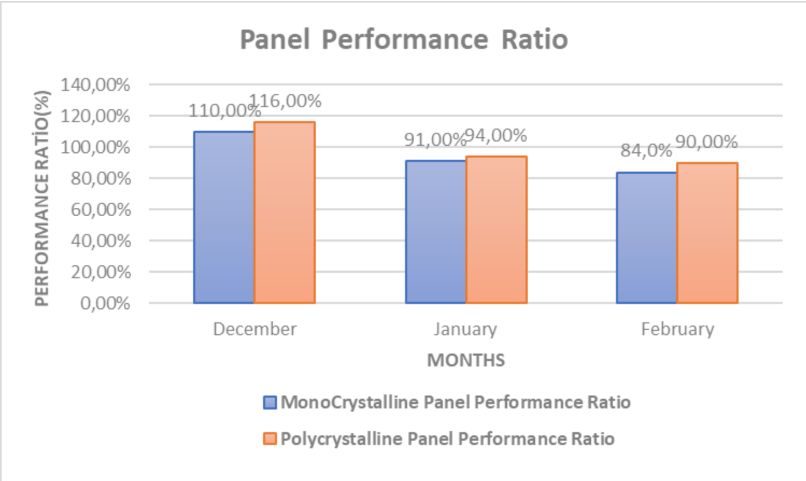

Figure 19. Average Performance Rate Per Month

The study results show that the performance ratio of polycrystalline solar panels is higher than monocrystalline solar panels. The results also suggest that the performance ratio of the panels is affected by the solar radiation, solar panel efficiency, and weather conditions of the region. These differences can be explained by the different performance of the modules depending on the operating temperature (Sharma et al., 2013; Makrides et al., 2012). Further studies can be conducted to include other seasons and to investigate the effect of other factors such as temperature and shading on the performance ratio of the panels.

CONCLUSIONS AND RECOMMENDATIONS

In Erzurum Province, the efficiency of 250 W solar panels was tested. Within the framework of efficiency and cost analysis, the research sought to identify the most efficient panel type for Erzurum province. The measurements were made in a real environment and took into account parameters such as the climatic conditions of the region (cloudiness rate, number of sunny days, outdoor temperature, etc.), solar radiation intensity, and operating temperature.

The results of the research indicate that the highest power outputs were obtained from the polycrystalline panel in January. Solar radiation and panel output power have been found to have an almost linear relationship. The theoretical efficiency of the monocrystalline panel, which is typically 15% to 18%, was found to be in the range of 13-17% as a result of the experimental study. The theoretical efficiency of the polycrystalline panel, which is typically 14% to 16%, was found to be in the range of 13.9%-18%. The performance rates of the monocrystalline panel were calculated as 110%, 91%, and 84% for December, January, and February, respectively. The performance rates of the polycrystalline panel were calculated as 116%, 94%, and 90% for December, January, and February, respectively.

Based on these results, it was determined that the average panel yields for the winter months of Erzurum province are quite high. It was also determined that the polycrystalline panel would be more suitable for Erzurum winter conditions due to its higher efficiency and performance rates. It is worth mentioning that the results of this study are based on the measurements that were taken during the winter months of December 2019, January, and February 2021, future studies could be conducted to extend the measurements and include other seasons in order to have a more complete understanding of the PV panels performance in Erzurum.

In conclusion, this study provides valuable data for investors considering PV panel investments in Erzurum, Turkey. The results indicate that both polycrystalline and monocrystalline panels performed similarly in terms of efficiency during the winter months, but polycrystalline panels had a slightly higher performance ratio and lower cost. This data can help investors to make more informed decisions about which type of panel to invest in, and can also provide insight into the potential return on investment for different types of panels in the region.

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