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An Investigation into the Effect of Cooling on the Efficiency of Monocrystalline Solar Panels

Roshan Ajit
Department of Mechanical Engineering
Federal Institute of Science And Technology
Angamaly, Kerala, India
roshan.karlose@gmail.com

Rejeesh C R
Department of Mechanical Engineering
Federal Institute of Science and Technology
Angamaly, Kerala, India
rejeeshcr@fisat.ac.in
ORCID: 0000-0002-9834-365

***Abstract* — This study investigates the impact of temperature variations on the efficiency of two identical 50-watt monocrystalline solar panels, one equipped with active cooling and the other without any cooling mechanism. Conducted in a controlled environment simulating real-world temperature conditions, the experiment compares the panels' power output and overall performance. The panels are exposed to diverse thermal conditions to isolate the effect of temperature on efficiency. Detailed data on electrical output, temperature, and other parameters are systematically collected and analyzed using MINITAB 17 software. The analysis reveals key correlations and trends, providing predictive models that demonstrate how active cooling enhances panel efficiency under varying temperature conditions. These findings offer valuable insights into optimizing solar panel performance, particularly in regions with high thermal fluctuations.**

Keywords - Monocrystalline solar panels, panel efficiency, Active cooling, MINITAB 17.

I. Introduction

Solar panels generate electricity in a clean and sustainable manner, as they rely on the abundant and renewable energy of the sun. The efficiency of solar panels has improved over the years, making them an increasingly popular choice for residential, commercial, and industrial applications. Conversion efficiency represents the percentage of sunlight that a photovoltaic (PV) panel can transform into usable electricity. It is a key performance metric for PV systems, as it indicates the maximum electrical output a panel can achieve under optimal conditions.

A. Efficiency

Solar panel efficiency refers to the maximum percentage of sunlight that a photovoltaic (PV) panel can convert into electricity. Higher efficiency indicates better energy conversion rates. Over time, significant improvements in materials, manufacturing processes, and design innovations have boosted solar panel efficiency. Today, consumer-grade PV panels typically achieve efficiencies ranging from 15% to 23% [1].

In laboratory settings, even higher efficiencies—exceeding 40%—have been reached, although such panels are not yet available for widespread consumer use. These efficiency improvements have contributed to the declining cost of solar energy, making it more affordable and driving its adoption as a clean, renewable energy source.

Temperature plays a crucial role in solar panel performance, particularly affecting voltage and current. As temperature rises, resistance increases, slowing the flow of electrical current and reducing energy output. Conversely, when temperatures drop, resistance decreases, leading to higher energy production. The optimal operating temperature for most solar panels is around 25°C (77°F), which is also the industry standard for testing and rating panels.

To assess how a panel performs in higher temperatures, the temperature coefficient is an important specification. This coefficient reflects the percentage reduction in energy output as temperatures exceed 77°F. For example, a temperature coefficient of -0.36% per degree Celsius (-0.20% per degree Fahrenheit) means that if the panel's temperature rises by one degree Celsius (or two degrees Fahrenheit), its energy output decreases by 0.36%. If the temperature reaches 35°C (95°F), energy production would decline by 3.6% [2].

B. Factors that Affect Efficiency

Temperature: High temperatures can significantly reduce the efficiency of photovoltaic panels, as increased heat leads to higher electrical resistance [3].

Sunlight: The amount of direct sunlight a PV panel receives is the most critical factor in determining its electricity production. Even the most efficient solar panels cannot generate power at night, and output is reduced on cloudy or overcast days [4].

Orientation and Tilt: To maximize sunlight exposure, panels should be oriented toward the sun (typically facing south in the Northern Hemisphere). Their tilt should be adjusted based on latitude, usually between 30 and 45 degrees, to align with the sun's path [5].

Dust, Snow, and Debris: Accumulations of dirt, leaves, snow, and other debris can obstruct sunlight and lower panel efficiency. Regular cleaning is essential to maintain optimal performance [6].

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Panel Age: As photovoltaic panels age, their efficiency gradually decreases. However, high-quality panels can last for over 25 years, often outliving traditional asphalt roofs [7].

Shading: Shadows from trees or nearby structures can drastically reduce panel efficiency. Even partial shading of a single cell in a monocrystalline or polycrystalline panel can negatively impact the overall energy output of the entire panel [8].

C. Conversion Efficiency of Solar Panels

Solar panel efficiency varies significantly between hot and cold environments due to the effects of temperature on photovoltaic (PV) cells. Understanding these temperature-related differences is crucial for determining the suitability of PV panels in different climates and maximizing energy output.

In hot environments, PV panels typically operate less efficiently because high temperatures negatively affect the cells' performance. As temperatures rise, the panel's output voltage decreases, leading to lower power generation. For each degree Celsius above 25°C (77°F), solar panel efficiency usually drops by 0.3% to 0.5%. This reduction can be substantial in regions with extreme heat, such as deserts or tropical areas. In such climates, it is advisable to select PV panels with a lower temperature coefficient and to implement cooling systems or adequate ventilation to minimize heat-related efficiency losses.

Conversely, cold environments can enhance solar panel efficiency, as lower temperatures improve PV cell performance. The cooler conditions increase output voltage, boosting overall power generation. Monitoring the behaviour of solar modules under varying temperature conditions involves measuring both the voltage and current produced as the panel's temperature changes [9].

The efficiency of the solar panel can be calculated using the equation,

$$\eta = \frac{I_m V_m}{RA} * 100\% \qquad \text{---- Eqn 1}$$

I_m – Measured Current
V_m – Measured Voltage
R – Solar Irradiance
A – Area of the Solar Cell

As the temperature of a photovoltaic (PV) panel rises above 25°C (77°F), its efficiency typically declines due to the temperature coefficient, which quantifies the reduction in output power for each degree Celsius above the reference temperature (commonly 25°C). When temperatures increase, the semiconductor materials within PV cells become more conductive, leading to a greater flow of charge carriers. This increased conductivity reduces the voltage generated by the panel, ultimately lowering its overall efficiency.

Some PV panels are equipped with heat dissipation features designed to counteract the negative impact of high temperatures. Passive cooling techniques and improved ventilation have proven effective in maintaining PV panels closer to their optimal operating temperatures, helping to sustain better performance in hot conditions.

Thermal Loss is a significant challenge in the field of solar energy. It is observed that solar panel performance is sensitive to temperature changes and as temperature increases beyond a threshold limit, the efficiency of the solar panel tends to decrease [10-12]. When solar panels become hotter, the electrical resistance of the semiconductor materials within the panel increases. Higher resistance makes it more difficult for electrons to flow through the material, leading to a drop in electrical current. Therefore, maintaining the temperature between certain values is crucial in achieving high efficiency.

II. EXPERIMENTAL

This study employs two 50W Loom Solar Panels to investigate the influence of temperature on solar panel performance. The research aims to understand the impact of temperature variationson the voltage and current output of the panels. Additionally, an active cooling system is employed, where the temperature of the solar panels is systematically reduced by 5°C every hour during the experimental period. The study involves the use of a multimeter to measure the voltage and current at various hours of the day, providing a comprehensive analysis of the panels' behaviour under changing temperature conditions.

A. Experimental Set up

The experimental setup involves exposing the solar panels to sunlight and measuring their electrical characteristics using a multimeter at different hours of the day. Simultaneously, two thermometers are employed to measure the temperature of the solar panels. The unique aspectof this experiment lies in the controlled cooling mechanism, where the temperature of the panels is intentionally reduced by 5°C every hour. This setup allows for a systematic examination of the solar panels' performance under varying temperature conditions.

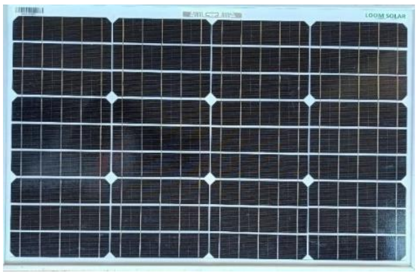

Fig. 1. Loom 50W Solar Panel (Area – 0.285 m^2)

TABLE 1. PV panel Specifications

wattage (Wp)	50 watts
voltage at max power	20.0 volts
current at max power	2.25 amps
open circuit voltage	25.36 volts
short circuit current	2.40 amps
Number of Cells	36

The solar panels are exposed to sunlight for an entire day, with data on voltage, current, and temperature recorded at regular intervals. After sunset, the panels are retrieved, and the next day the process is repeated for seven days. The deliberate reduction of the solar panel temperature by 5°C every hour introduces a dynamic element, simulating real-world scenarios where solar panels might be subjected to fluctuating temperature conditions. This iterative process ensures a thorough analysis of the panels' performance over an extended period.

A multimeter is used to measure both voltage and current output from the solar panels, providing detailed insights into their electrical characteristics. Simultaneously, the two thermometers recorded the temperature of the panels throughout the experiment. This dual data collection approach enables a comprehensive understanding of the relationship between temperature and electrical performance.

To derive meaningful conclusions from the collected data, a regression analysis is conducted using MINITAB 17 Software. This statistical tool is employed to identify trends, patterns, and correlations between the variables, allowing for a robust assessment of the impact of temperature on the solar panels. Regression analysis will help in quantifying the relationship between temperature variations and the electrical output of the panels, providing valuable insights into the effectiveness of the cooling mechanism in enhancing overall solar panel performance.

B. Operating Conditions

The testing location is in Perumbavoor, Ernakulam. The ambient temperature and irradiance are updated frequently. The water used for cooling is at room temperature. The solar panels are placed on the ground without an inclination angle. Testing is done for 7 days.

C. Efficiency Calculation

The climate was partially sunny throughout the 7 days. The readings were taken for 11 hours, from 8:00 am to 06:00 pm. The maximum voltage generated and the time of measurement was noted for both the panels. The maximum panel temperature was also noted. The readings of panel 2 (active cooling) were taken only after reducing the panel temperature by 5°C.

TABLE 2. Efficiency Calculation

	Without Cooling	**With Cooling**
Day 1	Avg. Voltage = 22.67 V Avg. Current = 2.01 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 11.42%	Avg. Voltage = 22.86 V Avg. Current = 2.03 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 11.63%
Day 2	Avg. Voltage = 22.55 V Avg. Current = 1.95 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 11.02%	Avg. Voltage = 22.63 V Avg. Current = 1.97 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 11.17%
Day 3	Avg. Voltage = 22.44 V Avg. Current = 1.85 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 10.40%	Avg. Voltage = 22.54 V Avg. Current = 1.86 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 10.50%
Day 4	Avg. Voltage = 22.26 V Avg. Current = 1.96 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 10.93%	Avg. Voltage = 22.31 V Avg. Current = 1.98 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 11.07%
Day 5	Avg. Voltage = 22.03 V Avg. Current = 1.83 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 10.10%	Avg. Voltage = 22.03 V Avg. Current = 1.85 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 10.21%
Day 6	Avg. Voltage = 22.42 V Avg. Current = 1.95 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 10.95%	Avg. Voltage = 22.53 V Avg. Current = 1.98 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 11.18%
Day 7	Avg. Voltage = 22.24 V Avg. Current = 1.87 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 10.42%	Avg. Voltage = 22.50 V Avg. Current = 1.89 A Irradiance = 1.4 kWh/m^2 Area = 0.285 m^2 Efficiency = 10.65%

III. RESULTS AND DISCUSSION

Linear, quadratic, and cubic regression models were considered for analysis. It was found thatthe cubic model gave the best fit and most accurate predictions. Therefore, a third-degree polynomial (cubic) regression model was used with the panel temperature as the predictor (X)and the efficiency of the solar panel as the response (Y). Two models are generated for "with cooling" and "without cooling".

A. Regression Analysis

Regression Analysis is implemented for both models (without cooling & with cooling).

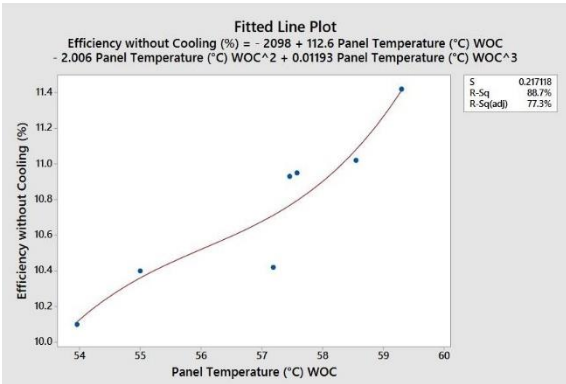

Fig. 2. Best Fit for Efficiency Without Cooling

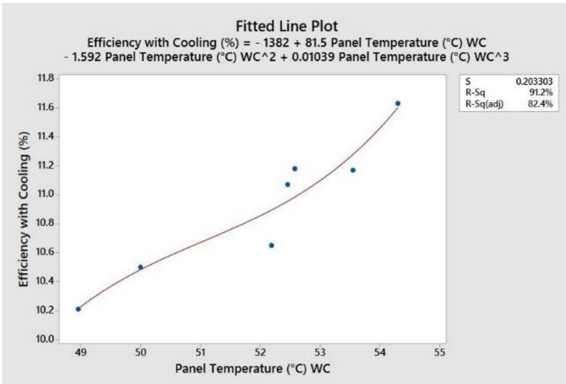

Fig. 3. Best Fit for Efficiency With Cooling

a) Regression analysis for efficiency without cooling

A regression equation was generated with (F (3,3)= 7.83 and P = 0.063), with an R^2 value of 88.7%.

The regression equation is

$$\textit{Efficiency without Cooling (\%)} = -2098 + 112.6X - 2.006X^2 + 0.01193X^3$$

b) Regression analysis for efficiency with cooling

A regression equation was generated with (F (3,3)= 10.37 and P = 0.043), with an R^2 value of 91.2%.

The regression equation is

$$\textit{Efficiency with Cooling (\%)} = -1382 + 81.5X - 1.592X^2 + 0.01039X^3$$

B. Confirmation of Regression Analysis

The regression analysis predicted maximum values for efficiency without cooling at a panel temperature of 59.30°C. The regression analysis predicted maximum values for efficiency withcooling at a panel temperature of 54.30°C. To calculate the measured efficiency, the readings are taken at a panel temperature of 59.30 and 54.30°C.

TABLE 3. Measured Values at Given Temperatures

Without Cooling @59.30 ^{0}C			Without Cooling @54.30 ^{0}C		
Voltage (V)	Current (A)	Efficiency (%)	Voltage (V)	Current (A)	Efficiency (%)
23.18	1.96	11.38	23.22	1.99	11.58

TABLE 4. Measured and Predicted Values

	Panel 1 Efficiency (%) (without cooling)	Panel 2 Efficiency (%) (with cooling)
Measured Values	11.38	11.58
Predicted Values	12.83	12.92

It was found that the predictions were accurate with variations less than ± 2% for temperatures of 59.30°C and 54.30°C. Therefore, the predictions suggest that the regression analysis can successfully predict the values for maximum efficiency at given temperatures.

IV. Conclusion

The temperature's impact on solar panel efficiency underscores the need for effective management strategies. High temperatures can decrease efficiency due to increased resistive losses and altered semiconductor properties. Regression analysis provides accurate predictions with a variation of ± 2% and can successfully predict the values for maximum efficiency at given temperatures. The tilt angle and shading also make a huge difference in the efficiency ofa solar panel. It's essential to implement solutions such as proper cooling mechanisms and innovative panel designs to optimize solar panel performance. Ongoing research aims to develop panels that can withstand temperature variations, paving the way for a more efficient and sustainable use of solar energy. Addressing these challenges is crucial for maximizing the potential of solar power and advancing our transition to cleaner, renewable energy sources.

References

[1] Luque, A. (2011). Will We Exceed 50% Efficiency in Photovoltaics?. Journal of Applied Physics, 110(3).

[2] Khan, J., & Arsalan, M. H. (2016). Solar Power Technologies for Sustainable Electricity Generation–A Review. Renewable and Sustainable Energy Reviews, 55, 414-425.

[3] Thong, L. W., Murugan, S., Ng, P. K., & Sun, C. C. (2016). Analysis of Photovoltaic Panel Temperature Effects on its Efficiency. System, 18(19).

[4] Zhang, H. L., Et Al. "Concentrated Solar Power Plants: Review and DesignMethodology." Renewable and Sustainable Energy Reviews 22 (2013): 466-481.

[5] Pringle, A. M., Handler, R. M., & Pearce, J. M. (2017). Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture. Renewable and Sustainable Energy Reviews, 80, 572-584.

[6] Kazem, H. A., Chaichan, M. T., Al-Waeli, A. H., & Sopian, K. (2020). A Review of Dust Accumulation and Cleaning Methods for Solar Photovoltaic Systems. Journal of Cleaner Production, 276, 123187.

[7] El Helow, D. (2018). Performance of Green Roof Integrated Solar Photovoltaics in Toronto. University of Toronto (Canada).

[8] Ogbomo, O. O., Amalu, E. H., Ekere, N. N., & Olagbegi, P. O. (2017). A Review of Photovoltaic Module Technologies for Increased Performance in Tropical Climate. Renewable and Sustainable Energy Reviews, 75, 1225-1238.

[9] El Achouby, H., Zaimi, M., Ibral, A., & Assaid, E. M. (2018). New Analytical Approach for Modelling Effects of Temperature and Irradiance on Physical Parameters of Photovoltaic Solar Module. Energy Conversion and Management, 177, 258-271.

[10] Vijayakumar, V., Manu, N. S., Vasudevan, M. C., Kiran, M. V., & Rejeesh, C. R. (2021). Phase change materials for improved performance and continuous output in stepped solar stills equipped with HDH. *Materials Today: Proceedings*, *47*, 5064-5068.

[11] Rejeesh, C. R., Anoob, J., & Chinmayakrishan, G. (2017). Impact of Using Liquefied Natural Gas for Transportation in the City of Cochin: A Review. *J. Altern. Energy Sources Technol*, *8*(3), 29-35.

[12] Batista, R. C., & Rajendran, R. C. (2023). Computational analysis of thermal performance augmentation in helical coil heat exchangers via CuO/water nanofluid. *Power Eng. Eng. Thermophys*, *3*(2), 139-149.