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Enhancing solar photovoltaic panel performance in india's tropical climate: an experimental study on the influential effects of optical filters

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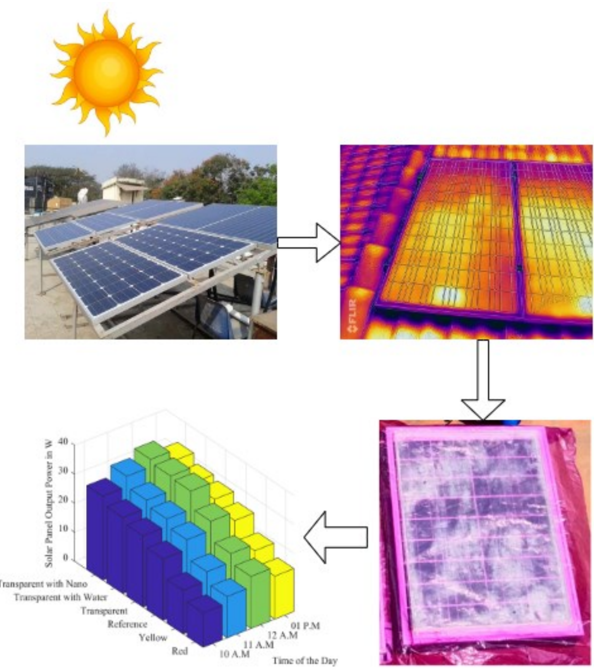
Graphical abstract



Abstract

Due to the increasing global energy demand and consequent climate change from burning fossil fuels, researchers are getting more focused on renewable energies as a potential solution to the world's energy problems. Solar energy is a prominent form of sustainable energy. The solar photovoltaic power generation system's electrical performance is negatively influenced by several factors, including the impact of solar irradiance, incident angle, temperature, dust accumulation on the top of the solar cell, cracks in the solar panel, shadowing, shunt resistance, solar cell materials, load mismatch, maintenance and cleaning schedule, spectral mismatch loss, and cable loss. The direct environmental factors that have the biggest impact on efficiency are the effects of sun irradiance and temperature. This empirical investigation examined the impact of optical filters on the electrical efficiency of a 40W polycrystalline solar PV panel in India while considering real-time ambient conditions. Through the utilization of an optical filter, the solar PV panel's temperature is diminished, hence enhancing the output power of the solar panel. Based on the experimental findings, the utilization of a transparent plexiglass sheet equipped with a coolant system installed on the solar panels leads to a drop in the average operating temperature of the solar PV module by up to 6°C. Additionally, the output power is enhanced by up to 10W in comparison to the reference solar panel's output performance.

keywords: Performance of solar panel, optical filter, solar irradiance effect, temperature effect, optical effect

Nomenclature

A	Solar PV panel surface area in m^2
G	Solar irradiance in W/m^2
V_{oc}	Open Circuit Voltage in V
V_{max}	Maximum output voltage of the Solar PV panel in V
I_{max}	Maximum output current of the Solar PV panel in A
P_{max}	Maximum output power of the Solar PV panel in W
I_{sc}	Short Circuit Current in A
α	Temperature coefficient of I_{sc} in %/ºc
γ	Temperature coefficient of P_{max} in %/ºc
ß	Temperature coefficient of V_{oc} in %/ºc
T_{mod}	Temperature of Solar PV module in ºc

1. Introduction

Worldwide environmental change, energy security, and likely weariness of petroleum products have pulled in sustainable power innovation advancement. Roughly 80%

of energy utilization on the planet is from petroleum derivatives, which adds to environmental change (Lebbi *et al*. 2020; Bos *et al*. 2018). Using sustainable power innovation is important because of its lessening effect on ecological debasement and limitless asset accessibility. Aside from being manageable, sun-powered energy represents the greatest sustainable power asset (Muthu and Ramadas, 2022; Kelmendi *et al*. 2019; Joseph *et al*. 2019). Sun-based energy reaping using solar photovoltaic (PV) frameworks for creating power is thoroughly examined as one of the likely business sectors in environmentally friendly power. Power creation through the change of sun-oriented radiation into power emerges because of photovoltaic impact. Energy transformation using solar PV advancements doesn't cause genuine ecological difficulties when contrasted with customary force age sources, for example, petroleum derivatives. The current transformation effectiveness of solar PV frameworks is approximated at various efficiencies running somewhere between 7 and 40% (Kirmani *et al*. 2018; Aquib *et al*. 2020).

Solar energy has the most potential to replace fossil fuels as a renewable energy source. Solar energy is currently receiving much attention and is essential to providing clean, sustainable energy. One of the most difficult problems the world is facing is global warming. The primary source of various pollutions that endanger the environment and reduce the availability of scarce conventional energy sources such as coal, oil, and diesel is now the production of electricity. Coal, natural gas, petroleum, and other fossil fuels account for about 63% of the world's electrical production. Finding alternate energy sources has become necessary because of this. Solar energy makes up approximately 3% of renewable energy sources.

Solar photovoltaic, or PV, cells use sunlight to generate power instantaneously. Semiconductors like silicon and gallium are unique materials used to produce solar PV cells (Green *et al*. 2018; Green *et al*. 2019; Mousa *et al*. 2021; Cariou *et al*. 2021). When sunlight hits the solar cell, the semiconductor material absorbs a particular portion. This absorbed energy allows a few electrons to flow freely. However, various factors reduce the efficiency of solar cells (Abdelaziz *et al*. 2020; Sahli *et al*. 2018). Only 10% to 25% of the solar energy absorbed may be transformed into electricity using solar photovoltaic cells; the remaining solar energy (over 70%) is wasted as heat loss. This will cause the solar PV module to overheat, which lowers solar PV efficiency (Venkateshwara and Sreejith, 2018). Only a few local studies have been made on the effect of optical loss on the degradation of solar cell efficiency (Gupta and Bajpai, 2014; Chowdhury and Chowdhury, 2018). However, it is a serious issue as it reduces the electrical efficiency of solar cells by 40%. The author developed a theoretical strategy to enrich the solar PV/Thermal systems performance using water as an optical filter (Babu *et al*. 2018). The researcher (Abio Moacir *et al*. 2018) developed a dynamic method to assess the solar PV/Thermal system's performance and confirmed it with experimental findings. Future renewable technology will benefit greatly from using water, air, and nano fluid-based PV/T systems, demonstrating positive and encouraging outcomes.

An enhanced heat dissipation system boosts the efficacy of solar energy systems (Khanna *et al*. 2018; rajvikram and Leoponraj, 2018). The solar cell's temperature experienced a drop of 5.4 percent and 11 percent, respectively, when it was subjected to a heat sink cooling system that utilized forced and natural airflow convection over the heat sink. The solar cell's efficiency and output rose by 8% and 16% when it was forced to cool with a heat sink cooling system (Ilse *et al*. 2018). This study examines the heat adjustment of a photovoltaic (PV) panel by employing phase change material, through the utilization of a simulated analysis (Srikumar and Saibabu, 2020). When the phase change material is completely melted and the temperature of the solar panel rises rapidly, the rate at which heat is extracted by the phase change material (PCM) falls. Hence, the author postulates that utilizing a PCM with a melting point that is relatively low, close to room temperature, would enable the sustained cooling of solar photovoltaic (PV) systems at lower temperatures. However, this would necessitate a larger quantity of PCM to have the desired cooling effect on the PV panels. The study (Chairma and Ramadas, 2022) employs chemical coating techniques, namely aluminum oxide-tantalum pentoxide-aluminum oxide, as antireflective agents. By adding this antireflective compound, the temperature was decreased from 53.8°C to 48.2°C, resulting in a 14% increase in efficiency. A build-up of dust on solar panels can reduce their electrical performance by as much as 40%. Multiple research studies have been conducted on the elimination of dust effects (Rashid *et al*. 2023; Benghanem *et al*. 2016). The efficiency of solar PV panels can be enhanced by implementing dust cleaning techniques, which effectively reduce both dust accumulation and panel temperature (Nabil *et al*. 2022; Haris *et al*. 2023).

This research study examines the influence of optical filters on the electrical efficiency of solar photovoltaic (PV) module power-generating systems. The first portion describes the test location's geographical information and the investigational setup. The second portion explains the design of optical filters and nanofluid coolant preparation. The third section deals with efficiency improvement techniques by reducing the consequence of temperature on the solar PV module's performance.

2. Materials and methods

2.1. Overview of the testing location

The proposed endeavor conducted an experimental study at R.M.K. Engineering College in Kavaraipettai, Gummudipoondi, Tamilnadu, India. With a surface area of 1189 km^2, Chennai is the fourth-largest city in India (Longitude: 80.270186°E and Latitude: 13.0836939°N). The tropical climate of Chennai has distinct rainy and dry seasons. Its proximity to the coast and geographical equator means that it experiences little discernible temperature changes. For most of the year, the weather is hot and muggy. Chennai experiences 27.9°C (82.1°F) on average temperature per year. Rainfall averages 1014 millimeters, or 39.9 inches, per year. February has a precipitation of only 0.4 inches (9 mm), making it the least rainy period of the entire year. The month of November experiences the highest precipitation, averaging 228 mm or 9.0 inches. The test site's geographic features are described in Table 1, together with the daily average solar irradiance and monthly atmospheric temperature data [23], which are shown in Figures 1 and 2, respectively.

Table 1: Geographical details of the test site

Test Location	R.M.K. Engineering College
Village	Gummidipoondi
Location's State	Chennai, Tamil Nadu, India.
Longitude at the test site	80.141°E
Latitude at the test site	13.358°N

Table 2: Description of Solar PV panel Parameter

Mechanical and Thermal Characteristics		Electrical Characteristics	
Solar Cells per Module (units) /Arrangement	3	I_{sc} - Short Circuit Current in Amps	2.22
Length (L) x Width (W) x Thickness (T) in mm	430*665*35	V_{oc} - Open Circuit Voltage in Volts	22.5
Weight in kg	3.2	P_m - Nominal Maximum Power in W	40
Temperature coefficient of I_{sc} (α) in %/ºC	0.0681	I_{mp} - Current at Maximum Power Point in A	2.08
Temperature coefficient of P_{max} (γ) in %/ºC	-0.3845	V_{mp} - Voltage at Maximum Power Point in V	19.25
Temperature coefficient of V_{oc} (ß) in %/ºC	-0.2941	Module Efficiency in %	16

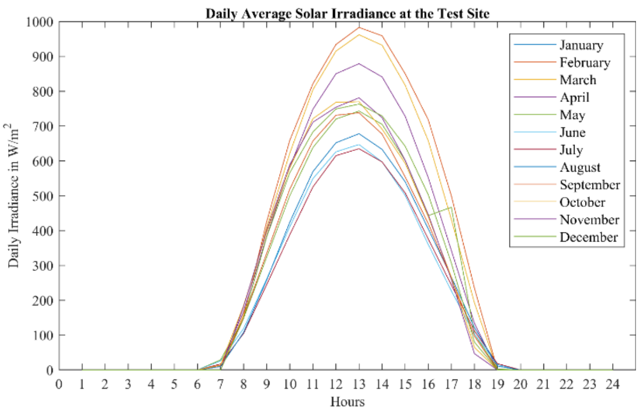


Figure 1. Test Location's Daily Average Solar Irradiance

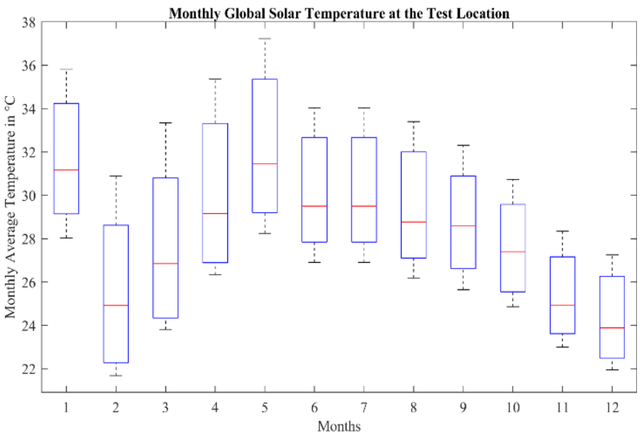


Figure 2. Monthly Solar Temperature at the Test Site

Figure 3. Picture of the Experimental Hardware Configuration.

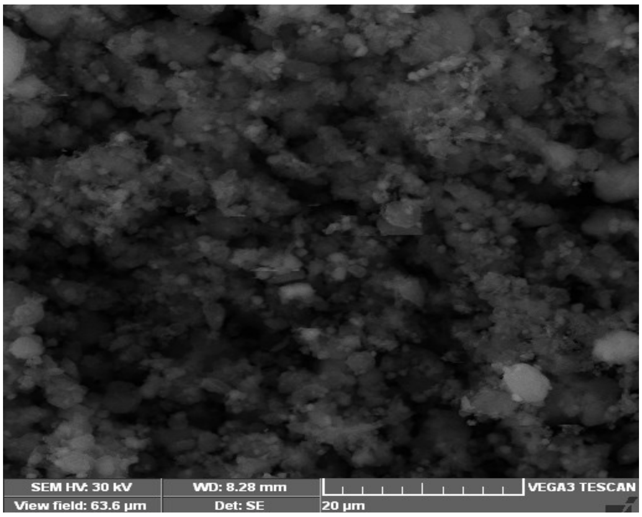


Figure 4. SEM Image of Al2O3 Nanofluid

2.2. Overview of the experimental configuration

The present configuration is employed to assess the decline in performance of the solar photovoltaic (PV) module. The experimental configuration of the proposed approach is shown in Figure 3. Two 40W polycrystalline solar panels are used in the experimental system's hardware configuration to compare its performance with and without efficiency improvement methods. In Table 2, the electrical properties of solar panels are listed.

2.3. Design of optical filter

The optical filter in solar PV power generating systems restricts unwanted infrared radiation within the wavelength range of 1100 to 2500 nanometers. Since this wavelength does not contribute to the solar cell's electrical production, its presence can lead to unnecessary overheating of the solar module. This experiment looked at how different colored plexiglass materials influenced the solar photovoltaic (PV) system's performance. Plexiglass is a thermoplastic substance that possesses exceptional strength against impact and modulus of elasticity. It is primarily selected as an optical filter because of these characteristics. Furthermore, it possesses a weight that is 50% less than that of glass, is impervious to moisture, exhibits durability, and is well-suited for many transparent structural uses.

Moreover, it possesses a weight that is 50% less than that of glass, is impervious to moisture, exhibits durability, and is well-suited for numerous transparent structural uses. Additionally, it possesses exceptional optical transparency and exhibits remarkable resistance to temperature fluctuations and a wide range of chemicals. The solar PV module's top surface was encased in a 0.430 x 0.665 m plexiglass sheet. A piece of plexiglass is placed on the solar panel's surface to evaluate its impact on the system's overall efficiency. The performance of solar panels with and without colored plexiglass sheets is then compared using a comparative analysis. The transmission ratio of plexiglass sheets exhibited variation depending on the material's color, which was assessed using a UV-visible spectrometer. The transmission ratios of various color plexiglass sheets are provided in Table 4.

Table 3: Description of Measuring Devices in Hardware Setup [23]

Instruments	Rating and Range	Application
SM – 206: Solar power meter	Range: 01-3999w/m^2 (btu)	Solar irradiance/intensity measurement
	Resolution: 0.1 w/m^2	
	Size (L XWXH): 132 X 60 X 38 mm	
	Operating temperature and humidity: 0.25s/ time	
	Accuracy: ±5%	
	Weight: approx.150g	
MAS830L: MASTECH Multimeter	DC voltage: 200 mV/2V /20 /200 V /1000 V ± 0.5%	Solar panel output current and voltage measurement
	Accuracy: ± 0.5%+3	
	Resolution: 0.1mV/ 1mV/10 mV/ 0.1 V	
	DC Current: 10A	
	Accuracy: ± 3.0%+3	
	Resolution: 10mA	
	Resolution: 1kΩ	
	Accuracy: ± 1.0%+5	
Rheostat (Resistive load)	Pure Resistive loads with the variable node Resistance: 10 Ω	Resistive load for solar PV panel output voltage and current measurement.
	Single-tube single-wire wound	
	Current: 10A (maximum)	
DC ammeter (MECO SMP48)	DC Current: 20A	Solar panel output current measurement
	Accuracy: ± 0.5% of FSD	
	Resolution: 0.001	
DC Voltmeter (MECO SMP96)	DC Voltage: 200V	Solar panel output voltage measurement
	Accuracy: ±0.5% of FSD	
	Resolution: 0.001	
Canyearn (C01) Infrared Forehead Thermometer	Measuring distance: 3cm-5cm	Solar panel temperature measurement
	Accuracy: ± 0.2°C to ± 0.4°F	
	Measurable Range : 32.0°C - 42.9°C	
	Response Time: 10s ± 1s	

Table 4. Transmission Ratio of Different Colors of Plexiglass Sheets

Plexiglass sheet	Transmission Ratio
Transparent	97
Red color	80.38
Yellow color	95.37
Green color	72.95

Table 5. Thermophysical Properties of Al_2O_3 Nanofluid

Concentration	Specific heat of Al_2O_3	Density of Al_2O_3	Thermal Conductivity of Al_2O_3	Viscosity of Al_2O_3
%	J/kg K	kg/m^3	W/mk	Ns/m^2
0.2%	3493	1178	0.6972	8.453 x 10^{-4}
0.4%	3298	1164	0.7165	8.673 x 10^{-4}

2.4. Design of optical filter with nanofluids

This section describes the design of an optical filter with nanofluids for solar panel temperature cooling purposes. Al_2O_3 / water acts as a nanofluid coolant for this temperature-cooling purpose. There are two ways to create nanofluids.

1) Single-step method: In this process, steady nanofluids are created by directly vaporizing and condensing Al_2O_3 nanoparticles in the base fluid (water).

2) Two-step method: In a two-step operation, nanoparticles are first created before being introduced to the base fluid and stabilizing using a variety of techniques.

The morphological structure of nanofluid is analyzed by using SEM analysis which is shown in Figure 4, physical properties of nanofluid is listed in Table 5.

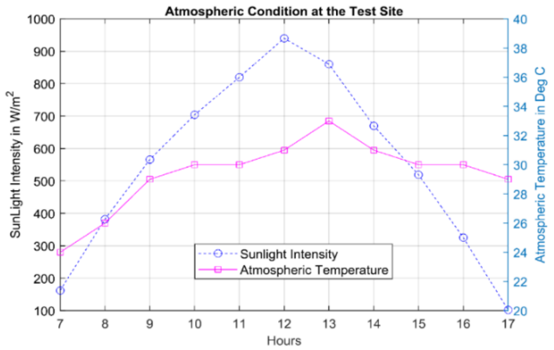


Figure 5. Environmental Condition of Test Site During Test Period

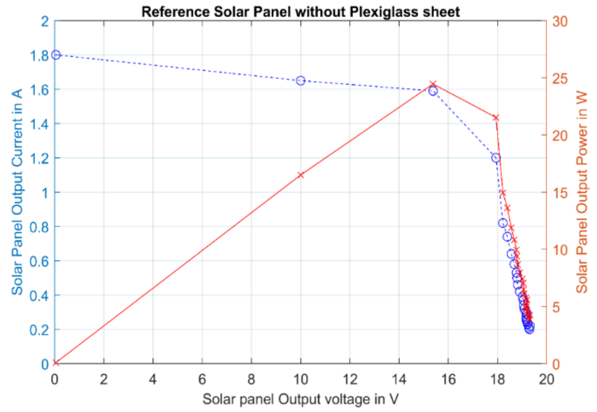


Figure 6. Characteristics of Current-Voltage (I vs V) and Power-Voltage (P vs V) in Solar Panels of reference solar panels

Table 6: Performance of Solar PV module with Different Plexiglass sheets

Plexiglass sheet Type	G= 700W/m²			G= 820W/m²			G= 940W/m²			G= 860W/m²		
	V_{MAX}	I_{MAX}	P_{MAX}	V_{MAX}	I_{MAX}	P_{MAX}	V_{MAX}	I_{MAX}	P_{MAX}	V_{MAX}	I_{MAX}	P_{MAX}
Clean	14.97	1.42	21.20	14.39	1.71	24.54	15.38	1.80	27.68	14.59	1.69	24.67
Red	13.90	0.86	11.90	14.10	1.01	14.26	14.83	1.21	17.94	14.20	1.04	14.80
Yellow	14.10	1.07	15.02	14.30	1.27	18.17	14.91	1.42	21.17	14.40	1.31	18.90
Transparent Sheet	14.39	1.70	24.50	15.10	1.79	27.10	18.48	1.81	33.45	15.40	1.78	27.40
Transparent with water Coolant	14.00	1.87	26.20	14.05	2.06	28.90	16.00	2.125	34	14.50	1.97	28.6
Transparent with Al_2O_3 Coolant	14.05	2.06	28.90	15.48	2.10	32.51	16.01	2.19	35.10	15.60	2.02	31.45

Table 7: Thermal Performance of Solar PV Module with and without Transparent Plexiglass Sheets

	Solar Panel Front Surface Temperature			
	G= 700W/m²	G= 820W/m²	G= 940W/m²	G= 860W/m²
Reference Solar Panel	38.6	41.2	44.9	46.4
Solar Panel with Transparent Plexiglass Sheet	34.2	37.5	40.9	42.8
Transparent Sheet with water Coolant	32.9	36.1	38.2	40.1
Transparent Sheet with Al_2O_3 Coolant	31.2	34.9	36.4	38.3

3. Results and discussion

The following section examines the findings of investigations carried out on January 10, 2023. Figure 5 depicts the distribution of solar light that is absorbed by the tops of the solar panels, along with the temperature of the surrounding environment, during the duration of the test day, which spans from morning 07 AM to evening 5 PM.

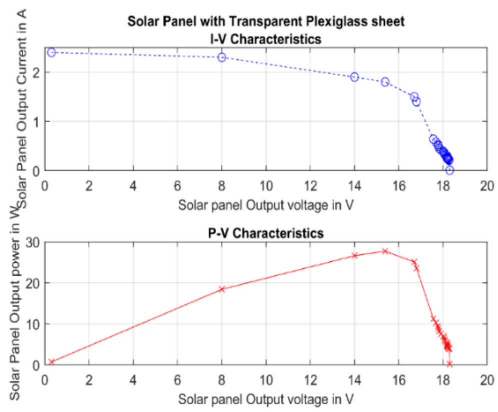


Figure 7. Current (I) versus Voltage (V) and Power (P) versus Voltage (V) Characteristics of Solar Panels with Water Coolant Setup

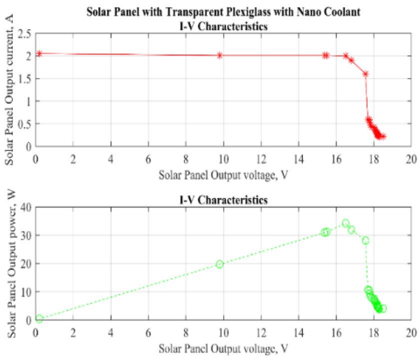


Figure 8. Characteristics of Current (I) versus Voltage (V) and Power (P) versus Voltage (V) in Solar Panels with Transparent Plexiglass with Nanofluid Coolant

The experimental investigation has been done with solar PV panels with different color plexiglass sheets like red color, yellow color, and transparent sheets, and the results are compared to clean reference solar PV power generation system. The test was carried out in four different time intervals (10 A.M, 11 A.M., 12 A.M., and 1 P.M.) with solar irradiance of 700W/m^2, 820W/m^2, 940W/m^2, and 860W/m^2 respectively on the test day and the results were listed in Table 6. Due to the optical filtering of plexiglass sheets, the solar panel's temperature was reduced which is reported in Table 7 and a comparative study is displayed in Figure 11.

Figure 6 displays the I-V and P-V curves of standard solar panels when exposed to solar irradiation conditions of 800W/m^2. Figure 7, Figure 8, Figure 9, and Figure 10 show the I-V and P-V characteristics curves of solar panels with different color plexiglass sheets, such as transparent with water coolant, transparent with Al_2O_3 / water coolant, red, and yellow. These curves were obtained under solar irradiation conditions of 800W/m^2. The electrical properties of the solar panel, such as its current, voltage, and power, are compared and displayed in Figures 11, 12, 13, and 14. These statistics illustrate the solar panel's performance with and without various plexiglass coverings.

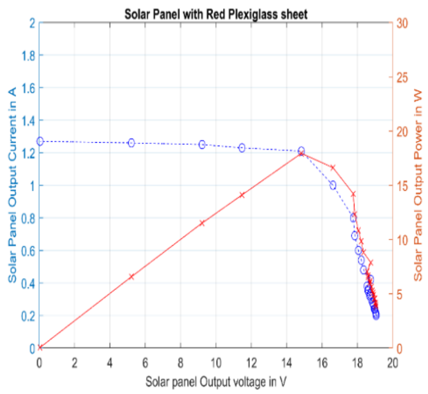


Figure 9. Characteristics of Current-Voltage (I vs V) and Power-Voltage (P vs V) in Solar Panels with Red Plexiglass

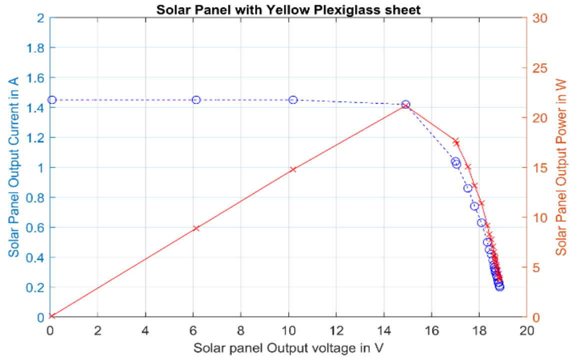


Figure 10. Characteristics of Current-Voltage (I vs V) and Power-Voltage (P vs V) in Solar Panels with Yellow Plexiglass

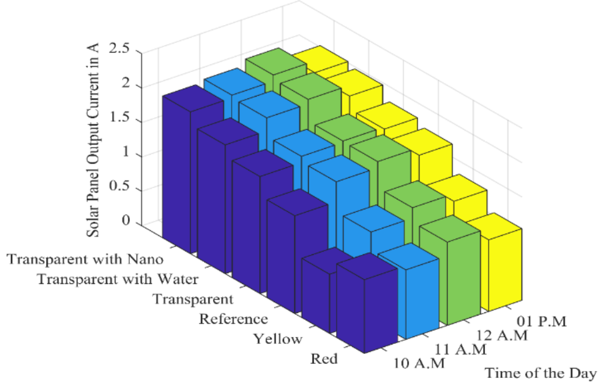


Figure 11. Comparison of Solar PV Module Output Current with and without Various Plexiglass Sheets

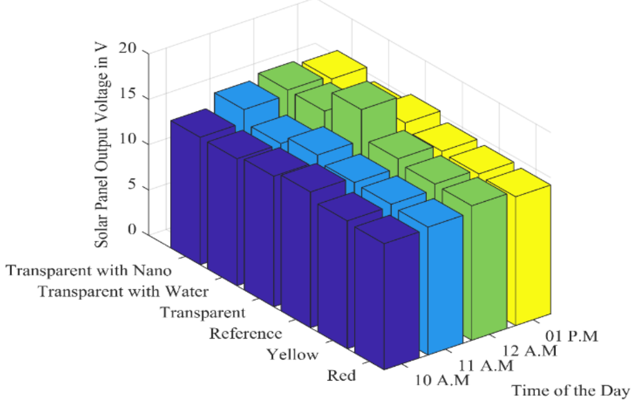


Figure 12. Comparison of Solar PV Panel Output Voltage with and without Different Plexiglass Sheets

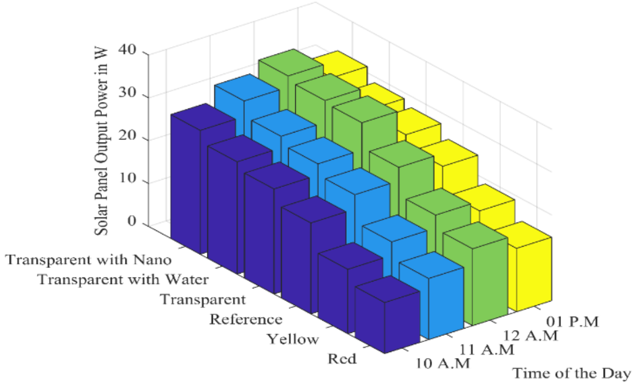


Figure 13. Comparison of Solar PV Panel Output Power with and without Different Plexiglass Sheets

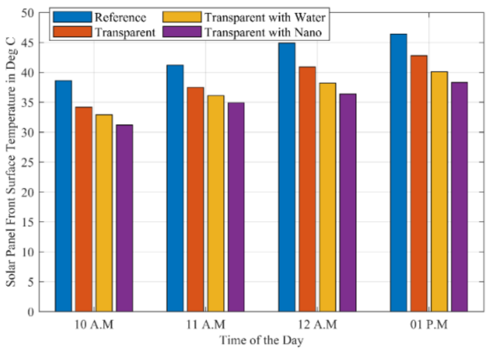


Figure 14. Effect of Transparent plexiglass Sheet on Solar Panel Surface Temperature

3.1 Discussion

The experimental investigation revealed that the use of a plexiglass sheet as an optical filter on the top side of the solar PV panels had a substantial impact on the overall electrical efficiency of the solar PV power generation system. The plexiglass sheets act as an optical filter which reduces the infrared radiation from the sun's intensity. The solar panel's output power is increased as a result of reducing its temperature by blocking infrared radiation. As seen in Figure 14, it is proved that the solar panel with transparent plexiglass sheet with nanofluid coolant reduced the solar panel front surface temperature up to 6°C compared to the reference solar panel power generation system. The primary cause of the temperature drop is the plexiglass sheet's absorption of heat produced by the solar PV panel. The surface temperature for two various experimental conditions of the solar PV modules at various points of the day is shown in Table 7. For comparison, the average temperatures of the front surface of a solar PV module with and without a transparent sheet with a nanofluid coolant setup are taken and it proved that with a nanofluid coolant, the average temperature reduces from 42.8°C to 35.2°C, respectively. Because of the temperature cooling effect, the Transparent plexiglass sheet-mounted solar panel output power increased by an average of 8W more compared to the reference solar panel.

4. Conclusions

The temperature effect is one of the most predominant efficiency losses in solar PV panel power generation systems. When the temperature of the solar PV module increases, the output power decreases. According to the investigation of the experimental findings reported here, it is proved that solar PV panel's efficiency declines as their temperature rises. To enhance the overall efficiency of the solar PV panel power generation system, an optical filter setup is mounted on the top of the solar panel surface. The findings of this experiment demonstrated that lowering the temperature can be accomplished by placing a plexiglass sheet on the solar PV module's front surface. By using a transparent plexiglass sheet, the unwanted infrared wavelength in solar irradiance is blocked, which reduces the temperature effect on the solar panel, so the output power of the solar panel improved by up to 10W compared with the reference solar panel.

Ethical approval

Not Applicable

Consent to participate

Not Applicable

Consent to publish

Not Applicable

Authors contributions

Conceptualization, Methodology, Resources, Formal analysis, investigation, and Writing–original draft preparation was carried out by Ms.K.R. CHAIRMA LAKSHMI; Supervision, Formal analysis, and Visualization was carried out by Bharath Singh J, N Padmavathi, and M. Dinesh Babu

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Competing Interests

The authors declare that there is no competing interest

Availability of data and materials

Not Applicable

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