

Effect of Inclination and Thermoelectric Material on the Performance of Solar PV-Thermo Electric Cooling System

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ABSTRACT

Solar photovoltaic (PV) systems, coupled with thermo-electric cooling, have gained significant attention as an eco-friendly solution. To enhance energy efficiency and reduce the overall environmental impact of energy generation and consumption, it is a viable option. This study investigates the impact of critical parameters, namely inclination angle of solar panels, the type of material used in thermo-electric cooling modules, on the performance of a solar PV-thermo electric cooling system. In this research, the impact of inclination angles (15°, 20°, 25°) and two materials (Bismuth telluride and Peltium telluride) of thermoelectric were considered for this study. A comprehensive series of experiments were conducted to analyze the impact of varying inclination angles of the solar panels and material of thermoelectric cooler. The average incident irradiation, panel temperature and outpower of solar panel variation with time are presented. The optimum tilt angle of the solar panel is observed as 20° and material for thermoelectric cooler is Bismuth telluride. When using Bismuth telluride as a thermoelectric material with 20° tilt angle, the solar panel's temperature decreases by 14% and its outpower is augments by a maximum of 14.5%. The results presented here offer practical guidance for system design and operation, ultimately promoting the widespread adoption of this technology in a more environmentally conscious manner.

Keywords: solar PV, thermo electric cooling system, performance, efficiency, sustainability.

INTRODUCTION

The combination of thermo-electric cooling and solar photovoltaic (PV) systems has shown promise in meeting the growing demand for efficient cooling technologies and renewable energy sources worldwide. Because solar PV systems can capture solar radiation and convert it into electrical power, they have attracted a lot of attention for their potential to reduce greenhouse gas emissions and mitigate climate change (Bassam et al., 2023). At the same time, thermo-electric cooling systems offer an environmentally friendly method for maintaining temperatures in various

applications, from electronics to refrigeration, by employing the Peltier effect to create temperature gradients (Khan et al., 2021).

Recognizing the potential synergies between these two technologies, researchers have increasingly focused on the development of solar PV-thermo electric cooling systems. This integration presents a unique opportunity to not only generate electricity but also to utilize excess heat for cooling, making it an attractive solution for both energy generation and thermal management. To maximize the efficiency and effectiveness of such systems, it is imperative to investigate and understand the influence of key parameters, including

the inclination angle of the solar panels and the type of material used in the thermo-electric cooling modules (Sardarabadi and Passandeh, 2016). The inclination angle of solar panels demonstrates a vital role in capturing the maximum solar irradiance, as it determines the angle at which the panels are oriented relative to the sun's position. By optimizing the panel inclination, it is possible to enhance energy generation and thus increase the overall system efficiency. However, this optimal inclination angle varies depending on geographical location and solar tracking capabilities, making it essential to consider site-specific factors in system design (Srinivasulu et al., 2021).

Simultaneously, the choice of material for the thermo-electric cooling modules profoundly affects the system's performance. Different materials exhibit varying thermoelectric properties, such as Seebeck coefficients and electrical conductivities, which directly influence their ability to convert heat differentials into electrical power. Selecting the appropriate material can significantly impact the cooling efficiency and overall system output (Moafaq et al., 2021).

A 36% increase in electrical output was noted by Bassam et al. (2023) in their experimental investigation of the effects of nanofluid, nano PCM, and the mass flow rate of the fluid on the electrical and thermal efficiency of solar PV thermal systems. With the aid of ANSYS software, Rosli et al. (2021) computationally examined the impact of solar PV thermal systems using nanofluid. They then compared their findings with those of the experiments and saw that the mean average percentage error was 10.31% and 6.67%. In their 2016 study, Sardarabadi et al. (2016) conducted an experimental and computational investigation to examine the impact of three oxide-based nanofluids on the solar photovoltaic system's performance. They discovered that the ZnO-water nanofluid outperformed the other two.

Graphene-based nanofluids were used in studies by Srinivasulu et al. (2021) to study the impact on solar PV thermal systems at 0.5 lpm and 1 lpm flow rates. CuO-water nanofluid was used in experiments by Moafaq et al. (2021) on solar PV thermal systems, and it was found that the system performed better at 2% volume fraction than at 0.5%. In their experimental investigation, Joo et al. (2019) found that alumina-water nanofluid outperforms CuO-water nanofluid in terms of thermal and total efficiency in solar photovoltaic systems.

According to Muniyandy et al. (2022) investigation, the TiO_2 – water nanofluid had a greater electrical efficiency of 19.35% when the system was operating at a flow rate of 1 lpm as opposed to 0.5 lpm. In studies utilizing SiC – water nanofluid to assess the impact on solar PV thermal system performance, Ali et al. (2017) found that there is a 24% increase in electrical efficiency. Sangeetha et al. (2021) carried out experiments to ascertain the impact of water-based nanofluid (MWCNT, Al_2O_3 , and TiO_2 nanoparticles) on the operation of solar PV systems. They found that the electrical efficiency of MWCNT, Al_2O_3 , and TiO_2 was increased by 47%, 33%, and 27%, respectively. The effects of CuO –water nanofluid on solar thermal collectors were studied mathematically and experimentally by Faran et al. in 2023. They found that the maximum improvement in thermal efficiency was 12.01% at 0.2 weight percent of CuO – water nanofluid.

In their experimental study, Khan et al. (2021) found that the hybrid system combining sun photovoltaic cells and thermoelectric generators performed better overall, with an efficiency gain of 17%. Gad et al., (2023) conducted experiments and numerically simulated the solar PV-nano PCM to determine the system efficiency and observed that Panel efficiency is enhanced by 11.9% and 9% respectively. Elavarasan et al., (2022), Aditya et al., (2018) Tirupati and Raja (2023) critically reviewed the past literature based on various parameters like volume fraction of nanofluid, mass flow rate, thermal efficiency, electrical and overall efficiency etc. In order to ascertain the impact of panel temperature on system performance, Charaf et al. (2019) devised a solar PVT cooling system. When Mohsen et al. (2022) used numerical analysis to examine the impact of cooling on solar cell efficiency, they found that cell efficiency increased by 49.42% and 49.17%, respectively. Table 1 summarizes the conclusions drawn from the literature.

Many of the studies in the literature are limited to the solar PV thermal system using circulated cooling system with nanofluid as a cooling medium where as it is used to lessen the solar panel's temperature (Bassam et al., (2023), Joo et al., (2019)). Here in this work, a hybrid system of solar PV coupled with a thermos electric cooler with materials like Bismuth telluride (Bi_2Te_3), Lead telluride (PbTe) to analyze the variation of panel temperature with day timing and corresponding solar PV system output power variation

The purpose of this research is to move further our understanding of how material selection and inclination angles interact in solar PV-thermoelectric cooling systems. By conducting a systematic investigation, we seek to identify the optimal conditions for different scenarios, enabling the design and operation of more efficient and sustainable systems. The world continues to seek innovative solutions to address climate change and energy demands. The findings of this study could influence the development and deployment of solar PV-thermo electric cooling systems for a variety of settings, including off-grid and distant residential and commercial structures (Joe et al., 2019).

EXPERIMENTAL SETUP

Setting up a solar PV-thermoelectric cooling system involves combining photovoltaic (PV) technology with thermoelectric cooling components. Typically, silicon and other semiconductor materials are used to make solar PV panels, which use the photovoltaic effect to directly convert sunlight into electricity. PV panels need to be securely mounted in a way that maximizes exposure to sunlight. Mounting structure is designed to withstand weather conditions and provision for various tilt angles of panel. Thermoelectric cooling module (Bismuth telluride and Peltium telluride) utilizes the Peltier effect, where an electrical current flowing through two different conductors creates a temperature difference. The module's two sides release and absorb heat, respectively, on the hot and cold sides. Typically, heat sinks are positioned between these modules to optimize

heat transfer. The heat that is captured by the thermoelectric cooling module is released using heat sinks. Usually, they are composed of materials like copper or aluminium that have a high heat conductivity. This configuration uses an aluminium heat sink. The various procedures involved in assembling the solar PV-thermo electric cooling system are shown in Figure 1. In Rajam Village in Southern India, these trials were conducted (18.4478°N 83.6617°E). Table 1 displays the PV module specifications.

RESULTS AND DISCUSSION

Experiments were conducted during the month of June 15th 2023 to July 14th 2023 and average values are taken into consideration. Average solar irradiation (W/m^2) during the day between 8 AM to 4 PM is shown in Figure 2. Average solar irradiation received is taken in y-axis and the time from morning to evening is taken in x-axis. It is observed that at 8 AM, irradiation is $500 W/m^2$ and it gradually increases up to $850 W/m^2$ at around 12:00 PM and again gradually decreases and at 4 PM irradiation is close to $300 W/m^2$. This pattern is similar to bell-shaped curve and it is

Table 1. Specifications of PV module

Dimension	400 mm × 450 mm × 20 mm
Maximum power	10 W
Op-circuit voltage	21.2 V
Short circuit voltage	0.58 A
V_{mp} , I_{mp}	18 V, 0.55 A

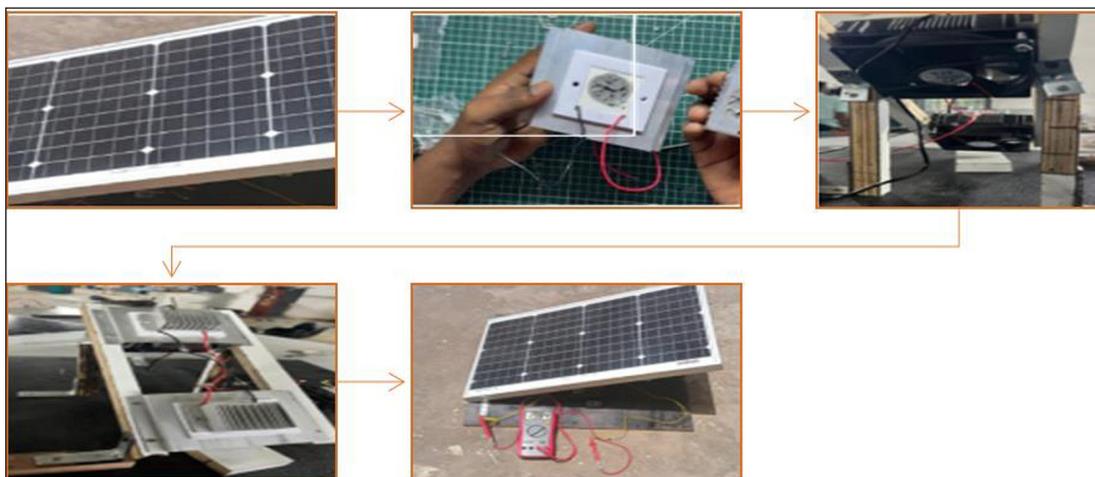


Figure 1. Sequential steps of assembling the solar PV-thermo electric cooling system

influenced by factors such as the angle of the sun, atmospheric conditions, and seasonal variations. The width of the curve around the peak indicates the duration of peak irradiance. In regions with clear skies and minimal cloud cover, the peak irradiance period may be relatively brief, whereas in areas with variable weather patterns, it may extend over a longer duration. Air pollution, humidity, and cloud cover are examples of atmospheric factors that can affect variations in solar irradiation. The amount of solar energy that reaches the Earth’s surface can be diminished or increased by several factors, which can cause variations in

irradiance levels throughout the day. The temperature of solar panel with time for various tilt angles (15°, 20°, 25°) without any thermoelectric cooler is shown in Figure 3. It indicates the heat absorbed by the panels from solar radiation and ambient environmental conditions.

The graph illustrates how the temperature of solar panels changes throughout the day, influenced by factors like intensity of solar irradiation, atmospheric temperature, and airflow around the panels. Panel temperature typically rises gradually from sunrise, peaks during midday when solar radiation is highest, and then decreases towards

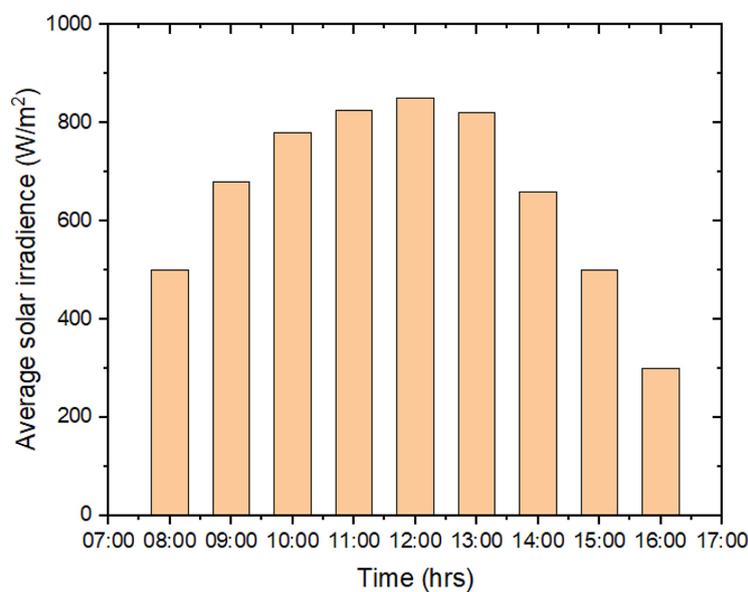


Figure 2. Average solar irradiance during day time

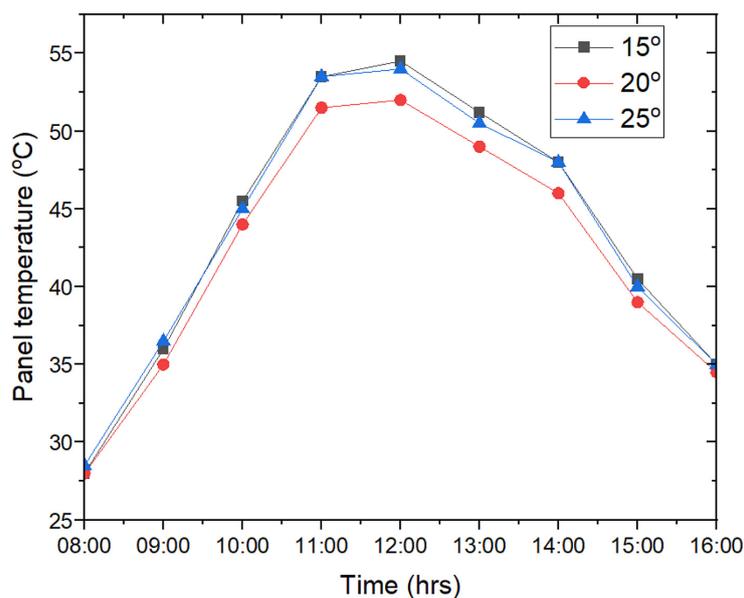


Figure 3. Panel temperature with day time at various tilt angles without TEC

sunset. Panels tilted at different angles receive solar radiation differently, affecting the amount of heat they absorb and consequently their temperature. It has been noted that the panel’s minimum temperature is reached at a 20° inclination and its highest temperature is reached at a 15° inclination. Solar photovoltaic (PV) cells’ efficiency and performance can be negatively impacted by high panel temperatures. Elevated temperatures can increase electrical resistance, reduce the efficiency of energy conversion, and accelerate degradation over time. Analyzing panel temperature variations helps in optimizing panel orientation

and tilt angles to mitigate these effects and improve overall system performance.

Figure 4 depicts the temperature of panel in the presence of a thermoelectric material, Bismuth telluride (Bi_2Te_3) with time for various tilt angles of the panel (15°, 20°, 25°). It has been noted that when thermoelectric material is coupled, the panel’s maximum temperature decreases. The greatest temperature drop for a tilt angle of 20° occurs at 12:00 PM. The panel’s electrical efficiency will increase as its temperature drops.

Figure 5 depicts the temperature of panel in the presence of a thermoelectric material, lead

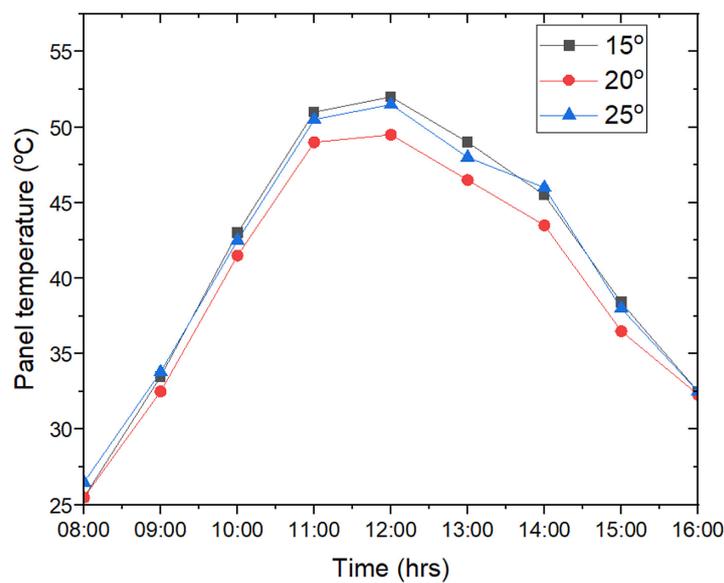


Figure 4. Panel temperature with daytime at various tilt angles for Bi_2Te_3

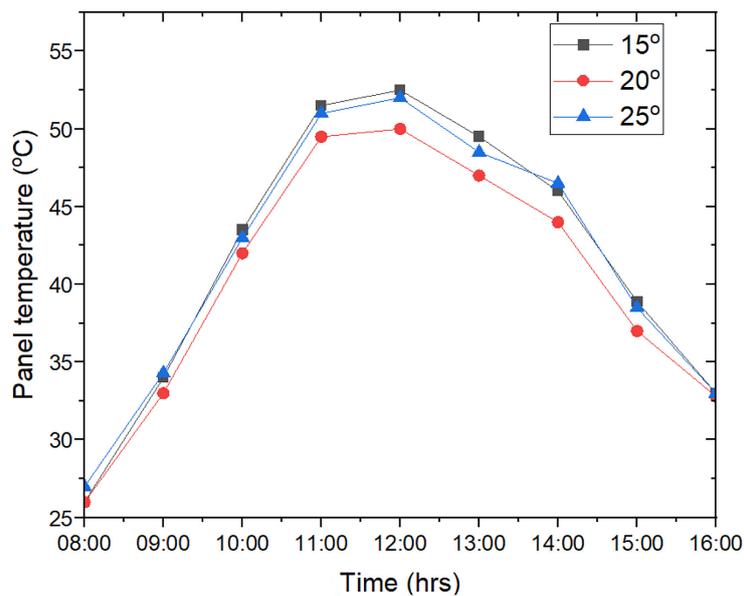


Figure 5. Panel temperature with day time at various tilt angles for PbTe

telluride (PbTe) with time for various tilt angles of the panel (15°, 20°, 25°). It has been noted that when thermoelectric material is coupled, the panel’s maximum temperature decreases. At 12:00 PM, the maximum temperature decrease at a tilt angle of 20° is 3°. The comparison of the panel temperature with time without thermoelectric cooler and Bismuth telluride and lead telluride for 20° tilt angle is shown as histogram chart in Figure 6. It has been noted that, in comparison to other situations, solar panels using bismuth telluride have a lower temperature.

The solar panel’s open circuit voltage (V) and current (A) were measured using a digital multi-meter. The power output of the panel is calculated by multiplying the observed voltage by the measured current. Figure 7 illustrates how the output power varies over time for various solar panel tilt angles (15, 20, and 25°) in the absence of any thermoelectric material.

It is observed that the output power of the panel is increases till 12:00 PM and then decreases gradually up to 4:00 PM as the current follows the similar trend and voltage follows almost

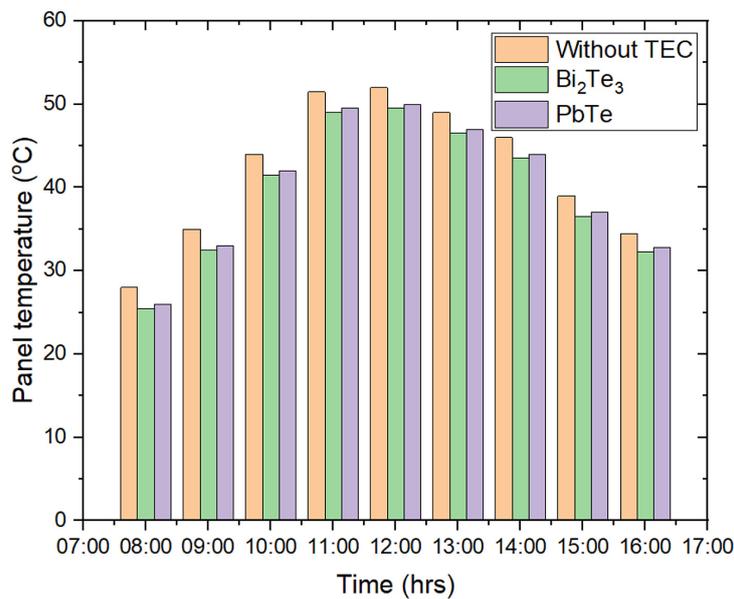


Figure 6. Panel temperature at 20° tilt angle for without TEC, and with TEC (Bi₂Te₃, PbTe)

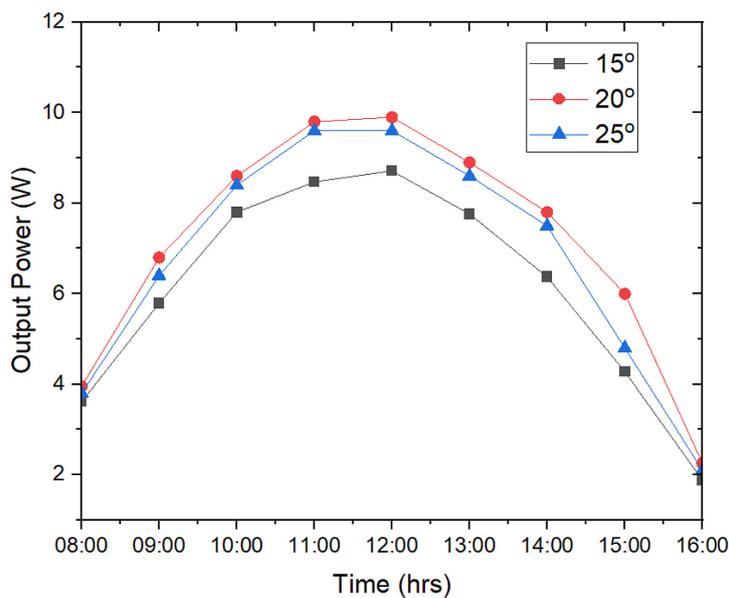


Figure 7. Output Power with day time at various tilt angles without TEC

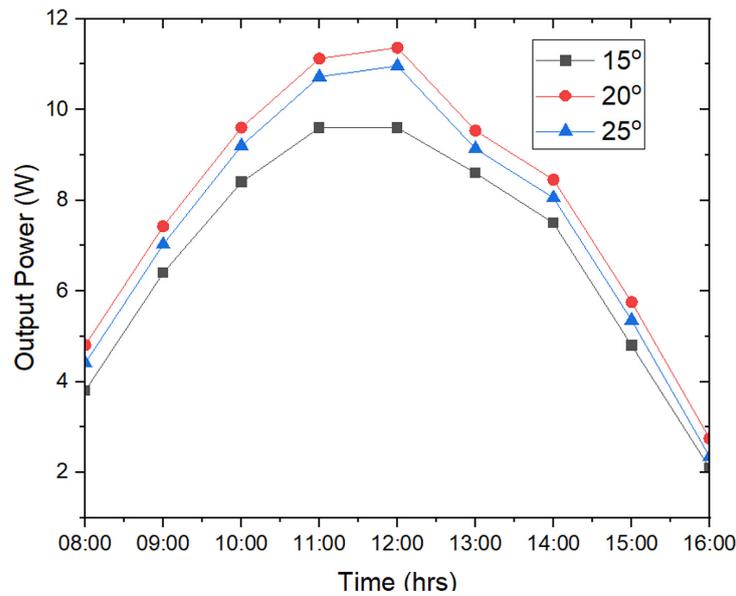


Figure 8. Output power with day time at various tilt angles for Bi₂Te₃

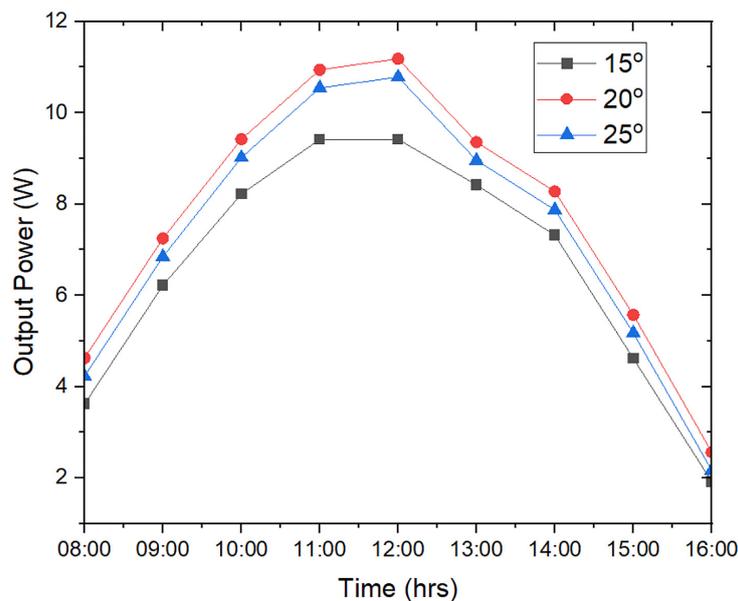


Figure 9. Output power with day time at various tilt angles for PbTe

constant till the maximum power voltage point. It is also identified that the output power is maximum in case of 20° tilt angle. Figure 8 illustrates how the output power varies over time for various solar panel tilt angles (15°, 20°, 25°) using Bismuth telluride (Bi₂Te₃), a thermoelectric material. It is observed that the output power of the panel is increases till 12:00 PM and then decreases gradually up to 4:00 PM. Output power is maximum in the case of 20° tilt angle.

Figure 9 illustrates how the output power varies over time for various solar panel tilt angles

(15°, 20°, 25°) using Lead telluride (PbTe), a thermoelectric material. It is observed that the output power of the panel is increases till 12:00 PM and then decreases gradually up to 4:00 PM. Output power is maximum in the case of 20° tilt angle.

The comparison of the output power of solar panel with time without thermoelectric cooler and Bismuth telluride and lead telluride for 20° tilt angle is shown as histogram chart in Figure 10. It is observed that with Bismuth telluride, output power of solar panel is maximum among other cases.

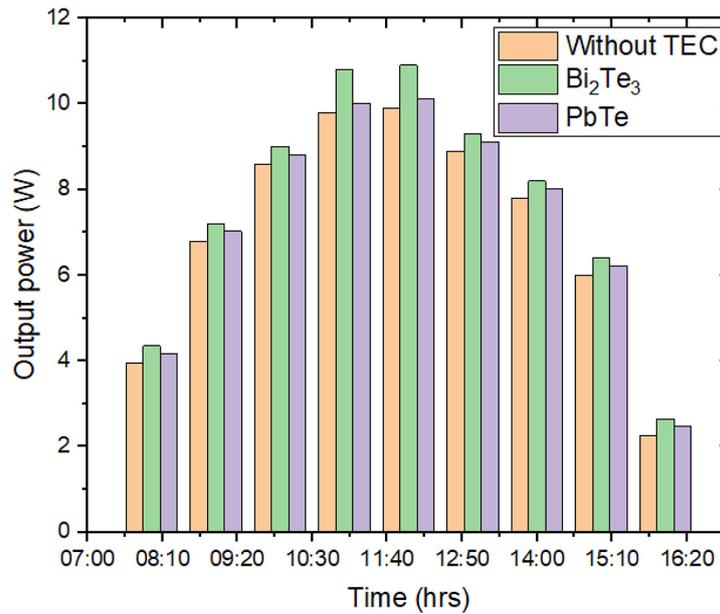


Figure 10. Output power at 20° tilt angle for without TEC, and with TEC (Bi₂Te₃, PbTe)

CONCLUSIONS

In conclusion, the combination of solar PV and thermo-electric cooling offers a promising pathway towards sustainable energy solutions and efficient temperature control. The findings of this study underscore the significance of thoughtful system design, accounting for location-specific factors, and material selection, as listed below:

- the solar panel's temperature drops when thermoelectric material is coupled;
- thermoelectric materials increase the solar panel's output power;
- it is noted that the solar panel tilts at an optimal angle of 20°;
- without thermoelectric material, the temperature of the solar panel is lowered by a maximum of 8% at a 20° tilt angle;
- using bismuth telluride, the solar panel's temperature can be lowered by up to 14% at an angle of 20°;
- without the use of thermoelectric material, the solar panel's output is increased by a maximum of 9.2% at a 20° slant;
- at a 20° inclination, Bismuth telluride can increase the solar panel's output power by up to 14.5%.

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