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Research Article

Development of a small scale photovoltaic thermal hybrid (PV/T) system for domestic applications in Pakistan

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ABSTRACT

Pakistan, currently grappling with a severe electricity shortage, has witnessed a growing utilization of PV panels for nationwide electrification efforts. Nonetheless, a significant challenge in deploying PV systems lies in the adverse impact of rising ambient temperatures on solar cell performance. In Pakistan, numerous regions experience ambient temperatures surpassing 50ºC, an unfavorable condition for such systems. In the present study, the focus was on mitigating this issue by investigating the impact of cooling on PV panel performance using a Photovoltaic thermal hybrid system (PV/T). The PV/T system was meticulously designed and constructed using locally available resources, and its functionality was tested under Karachi's local conditions. By implementing a water circulation system through the absorber, the study achieved a noteworthy 3.9% enhancement in electrical efficiency. This improvement translated to an additional thermal energy output of 350 Watts, coupled with a commendable thermal efficiency of 56%. Consequently, the overall efficiency of the entire system was augmented. Remarkably, the outlet temperature of the tubing saw an increase of 5°C to 7°C. The results demonstrated that this hybrid PV/T system outperformed the traditional PV system, making it a promising solution capable of catering to both electrical and domestic heating demands.

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INTRODUCTION

Due to the escalating demand for electrical power and the corresponding environmental issues, researchers have begun exploring ecologically friendly alternative energy sources. Solar energy stands out as one of these alternatives due to its abundant availability and environmentally conscious nature. Energy is the measure of

Highlights

- Investigation of the impact of cooling on PV panel performance using a photovoltaic thermal hybrid system (PV/T) was conducted
- PV/T system was tested for Karachi city climate and attained an efficiency of 3.9%
- Water circulation system enabled the enhanced thermal energy output by 350 watts.
- Hybrid PV/T system achieved 56% higher thermal efficiency in comparison to traditional PV system
- The system has an advantage to fulfil electrical and heating needs.

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prosperity of any country in the modern [1, 2] Need of Energy is on rise day by day owing to industrial development and population growth. Whereas the source of energy production remains the same [3]. In result, energy supply is less than energy production causing severe energy shortage in various part of the world. According to estimates 1.2 billion have no access to energy [4] . Which is the main reason behind the poverty across the globe [5]. The demand of Global energy has approximately doubled in the last three decades of 20-th century [6]. In 2020, about 62% of the energy consumption is produced from fossil fuels, 10% from nuclear fuels, and 28% from renewable resources [7].

Energy infrastructure is in ravages. The outdated and ill managed infrastructure is aggrandizing the energy crisis. Moreover, no appreciating efforts have been made to install new capacity of generation [8]. As the world is moving to the use of renewable energy, however, energy generation in Pakistan is primarily 54% from the fossil fuel. Rest is generated from the hydro 29% and only 6 % is produced from the renewable energy. The energy generated from the fossil fuel is not only expensive, but also catastrophic for environmental aspects [9, 10].

Photovoltaic thermal system converts solar radiation into electrical as well as thermal energy. Photovoltaic Thermal System is a hybrid system that consists of PV panels with solar thermal collectors [11]. It uses the available heat energy of the PV system. It allows the water or air flowing through the thermal collector and enables the heat transfer from the PV cells. Due to larger portion of solar energy incident on the collector, energy is efficiently captured [12]. Herrando et al. [13] has discussed different keys areas, for practically making such systems feasible for domestic use, in which efficiency would boost, and overall output will be improved by integrating thermal storage. However, the optimizing channel and flow configuration at the PV module's rear is crucial for enhancing heat transfer rates. Notably, helical fluid flow channels were found to be optimal due to their ability to disrupt thermal boundary layers, resulting in increased heat transfer rates. The review underscores the central role of geometric design in boosting PVT system performance, particularly through enhanced heat transfer rates. The findings provide valuable insights for advancing the efficiency of PVT systems and outline potential avenues for further research [14–16]. Photovoltaic thermal system has been emerged as a new replacement to all the utilities as Solar PV Modules had arisen for 12 V standalone systems. Researchers are utilizing solar PV in different domestic applications [17], and currently the PV/T systems in domestic application is been assessed to enhance the overall efficiency.

Chen et al. [18] in his paper has claimed solar energy being the vital resource for replacing fossil fuel for clean energy production. Since the carbon footprint has increased exponentially, causing climate change. Multiple factors including thermodynamic analysis coupled with economic and environmental effect is considered for study. The overall exergy efficiency was 41% for the proposed system. Emmi et al. [19] in his study discussed the possible arrangements of heat pump and photovoltaic thermal hybrid solar collector (PVT) for residential heating and hot water encouraging integrated building heating. Analyzing air, solar, and ground heat sources, it achieved 14% to 26% higher energy efficiency than a standard air to water heat pump. The systems using air and solar energy resources had an energy efficiency of 3.64, somewhat less than more intricate systems. Kumar et al. [20] in his recent analysis has emphasized the use of Nano fluids and concentrating techniques in solar photovoltaic/thermal (PV/T) systems to enhance their efficiency. A systematic review highlights significant advancements in BSPV/T, particularly with linear Fresnel mirror-based and nanoparticle-laden systems, showing improved overall performance. The study briefly addresses economic, carbon footprint, and environmental aspects, while also identifying future research challenges and directions. Researcher are looking for feasible and very economic system for maximum efficiency, In this paper author has discussed three main points, the first one is performance, secondly Exergy and levelized cost assessment and thirdly economic viability and sun hours [20, 21].

As discussed in literature, Photovoltaic thermal technology is the emerging field for researchers to optimize and scale up the existing systems. Keeping in view, through this research article a small scale PV/T system is developed for domestic applications in Pakistan. Integration of thermal system with PV standalone system will give an opportunity to store thermal energy for future purpose, ultimately increasing the overall efficiency. However, Thermal system is also assessed for thermal efficiency through heat transfer techniques are adopted by integration of fins. In the end the overall comparative study of PV system and PV/T system is carried out.

MATERIALS AND METHODS

Experimental Setup

The experimental setup developed for the present study is shown in Figure 1. The system was assessed with normal standard conditions. The readings recorded are given below. Furthermore, the specifications for the PV plate are given in Table 1.

- Air mass 1.5 spectrum (AM1.5) for terrestrial cells
- Intensity of 1000 W/m^2
- Wind velocity 1 m/s
- Ambient Temperature 25 °C

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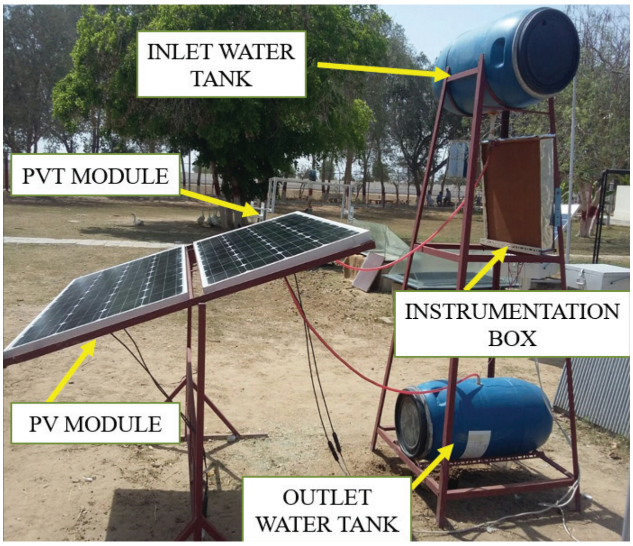

Figure 1. Experimental setup.

Table 1. Specifications (PV Module)

Brand	GH Solar
Rated maximum power	150 W
Power output tolerances	± 3%
Module efficiency	18%
Voltage at P_{mpp}	18 V
Current at P_{mpp}	8.33 A
Open circuit voltage V_{oc}	21.6 V
Short circuit current I_{sc}	8.75 A
NOCT (Nominal operating cell temperature)	46±2 °C
Temperature coefficient of P_{mpp}	0.45% /°C
Encapsulation materials	Ethylene vinyl acetate (EVA)
Weight (kg)	12.5
Dimensions (cm)	147.6 * 68 * 3.5

Absorber Plate

The material of the plates was selected as copper owing to its high thermal conductivity The Copper Absorber plates has dimension of 1.21 m * 0.60 m with thickness of 0.54 mm. Absorber plate provides the medium of heat transfer between the panel and water flowing in the tubes.

Absorber Tube Design

The design of tubes was done as a Continuous flow absorber design due to the fact that it causes the enhanced thermal efficiency and also its easiness in the fabrication. Round hollow tubes were fabricated so that they can acquire maximum thermal energy. Continues flow was achieved for a specific time limit in the copper tubes. The specifications of copper tube are (outside diameter: 9.5 mm, wall thickness: 0.65 mm and thermal conductivity: 386 W/m^2) and is shown in Figure 2.

PV/T Collector

PV/T collector is made up of the copper absorber plate, copper tubing and fixture, as shown in the Figure 3. The system includes the absorber plate with the surface of the PV panel, fixture with two channels for locating the absorber plate, and two holding clamps which produce required contact force in order to maintain the required contact between the plate and PV cells. Asbestos material was used as an insulation of fixture.

Experimental Procedure

The system was set up at Hamdard University, located at coordinates 25°N and 67°E. The modules were angled at

Figure 2. Absorber plate (Copper).

Figure 3. Absorber plate attached with PV module.

-5° to maximize sun exposure in May. During the experiment, measurements were taken for solar energy, ambient temperature, humidity, and wind speed. Data was collected hourly from 9:00 to 16:00. The initial temperatures of the panel's front and back surfaces were gauged using an infrared thermometer. Water circulation through the suction tubes was controlled by a valve, which could be adjusted to either half a turn resulting in 0.01 kg/s (equivalent to 0.013 liters/s), or a full turn leading to 0.03 kg/s (equivalent to 0.025 liters/s). Inlet and outlet water temperatures were monitored with a thermocouple. To assess the impact of water circulation on the panel's surfaces, temperature readings were taken again using an infrared thermometer. For experimental purposes, a 50 W DC load was separately connected to both the PV and PV/T systems, based on the specific experimental configuration. Load current and voltage were measured using multimeters in parallel and series connections. The PV/T module was positioned with a separation of 3.5 cm and connected to absorption tubes that were 15 meters long. Water flow through the pipes was maintained at 0.03 kg/s (0.025 liters/s) by setting the valve to full rotation.

RESULT AND DISCUSSION

Experiments were conducted for three days with each setup. Experimental results obtained for each setup are discussed in this section.

Experimental Results with Setup conducted on Day 1

Figure 4 illustrates the temperature profile during the day. Temperature was measured on different points on the front surface of the system. These results indicate a gradual increase in temperature with time up to 12 noon and afterwards both parameters: temperature and insolation were found to decrease gradually. Maximum temperature of the front panel surface was recorded to be 72.5 °C without flow of water and the same was noticed to be lowered to 66.5 °C

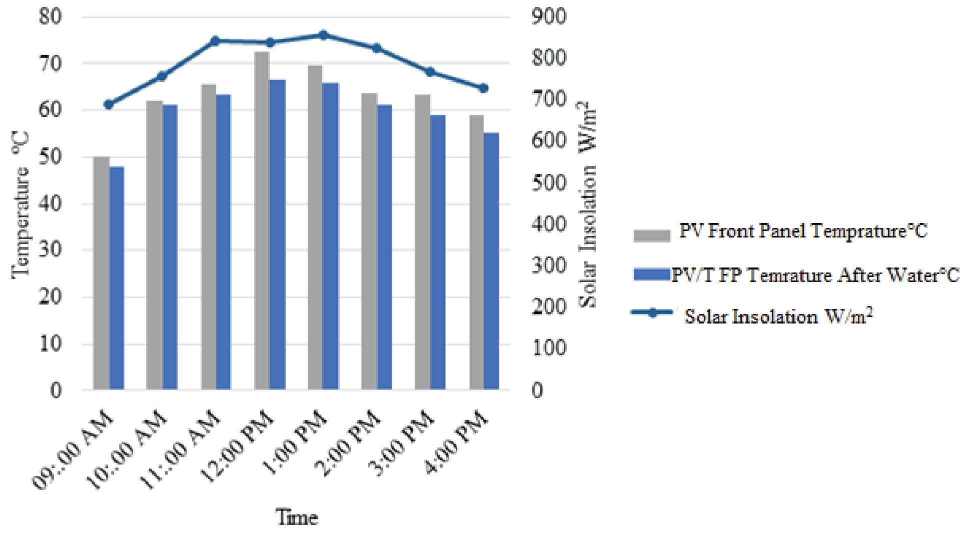

Figure 4. Temperature profile at front surface of PV/T module.

by the flow of water at the same instant of time that is 12 pm, and hence a decrease of 6 °C was achieved in the surface temperature of the panel due to water circulate.

Figure 5 illustrates the temperature profile during the day. Temperature was measured on different points on the rear surface of the system. These result exhibit similar trend as was observed at front panel surface. Maximum temperature of the rear panel surface was recorded to be 80.5°C without flow of water and the same was noticed to be lowered to 77°C by the flow of water at the same instant of time that is 12 pm, and hence a decrease of 3.5°C was achieved in the rear surface temperature of the panel due to water circulation. Maximum change in rear surface temperature of 3.5°C was also observed at 12 pm. Average solar insolation was recorded as 788.5 W/m².

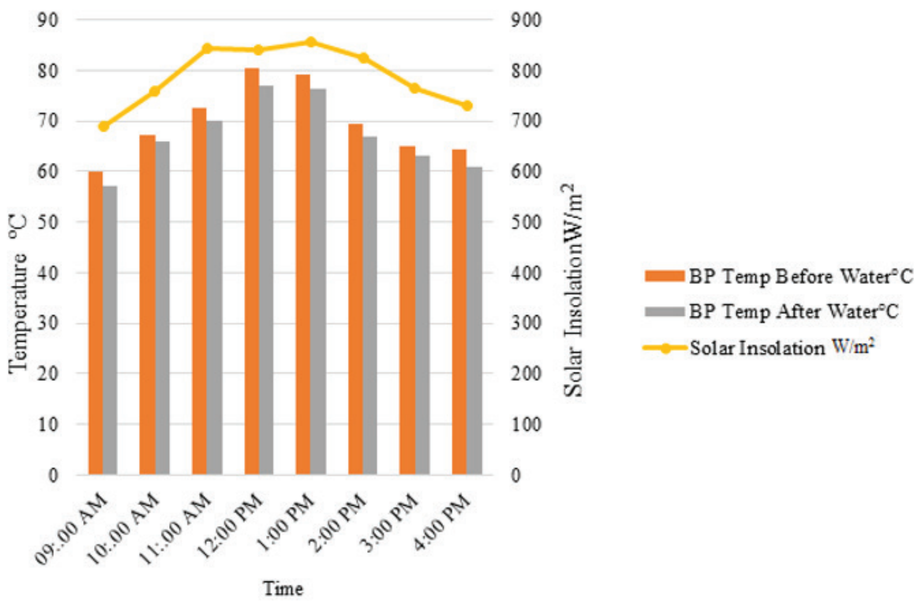

Figure 5. Temperature profile at rear surface of PV/T module.

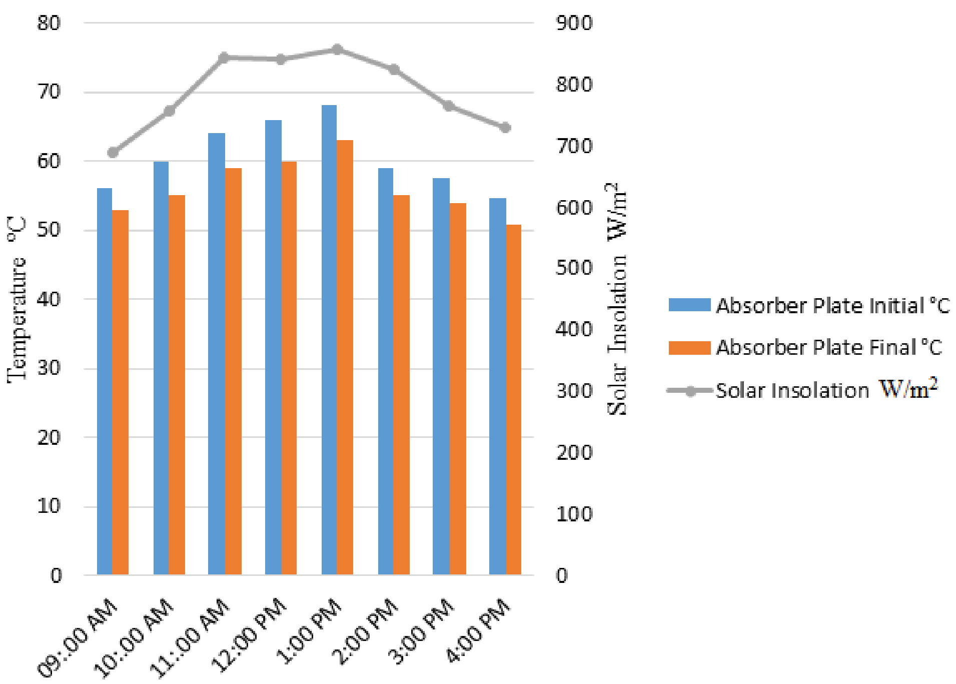

Figure 6. Temperature profile of absorber plate.

Figure 6 shows the temperature observed from tube of absorber plate measured during the day. The maximum decrease in the temperature of the absorber plate was 6°C at 12 pm which dropped the absorber plate temperature from 66°C to 60°C. However, the maximum temperature of the absorber plate reached 68°C which was dropped to 63°C after the circulation of water at 1 pm.

Figure 7 shows the inlet and outlet water temperature flowing through the tubes. The maximum increase in the temperature of the water was 6.6°C which was recorded at 1 pm by increasing the initial water temperature from 35.5°C to 42.1°.

Figure 8 shows the thermal and electrical efficiency of the PV/T module. The thermal efficiency was found to increase with time and reached to the maximum level of 80.96% at peak hour with corresponding electrical efficiency of 8.88%.

Figure 9 shows the comparison of electrical efficiency between PV and PV/T. From the figure it is clear that cooling of the system results in improvement performance of the system, there was an overall increase of 3.9% in the electrical efficiency of PV/T system. However, the maximum difference of 7.59% in the electrical efficiency of PV/T and PV module was observed at 3 pm.

Experimental Results with Setup conducted on Day 2

Figure 10 illustrates the temperature profile during the day. Temperature was measured on different points on the front surface of the system. These results shows a gradual increase in temperature with time up to 12 noon

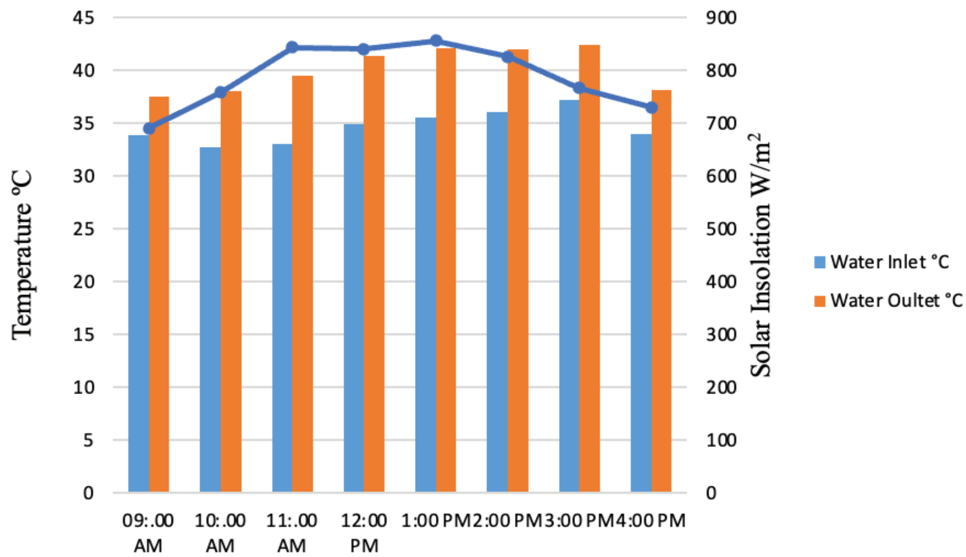

Figure 7. Temperature change of water flowing through the tubes.

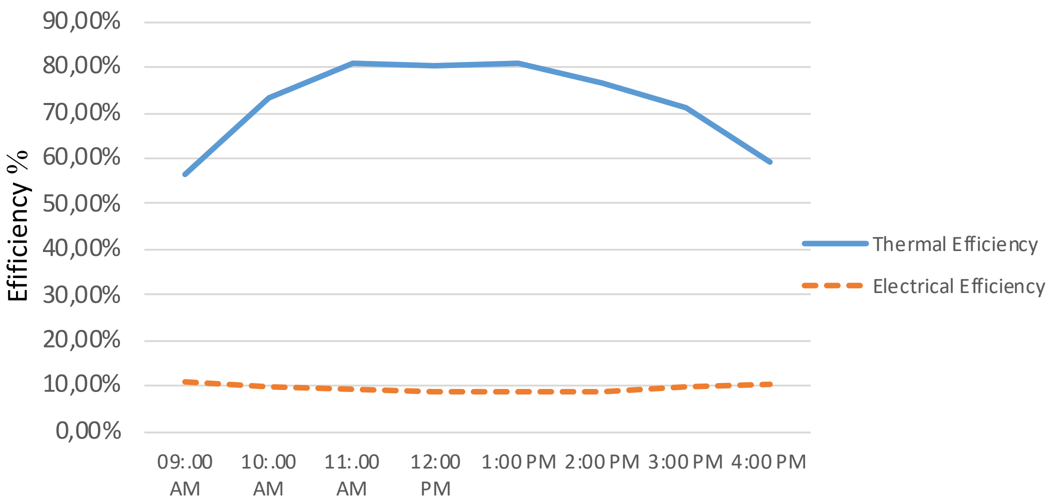

Figure 8. Thermal and electrical efficiency of PV/T.

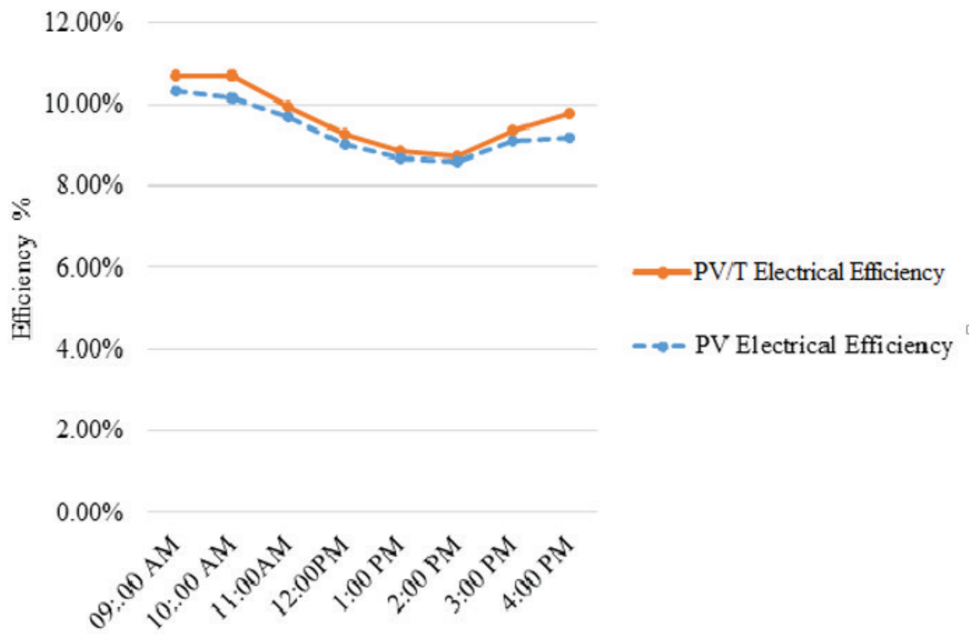

Figure 9. Comparison of PV and PV/T electrical efficiency.

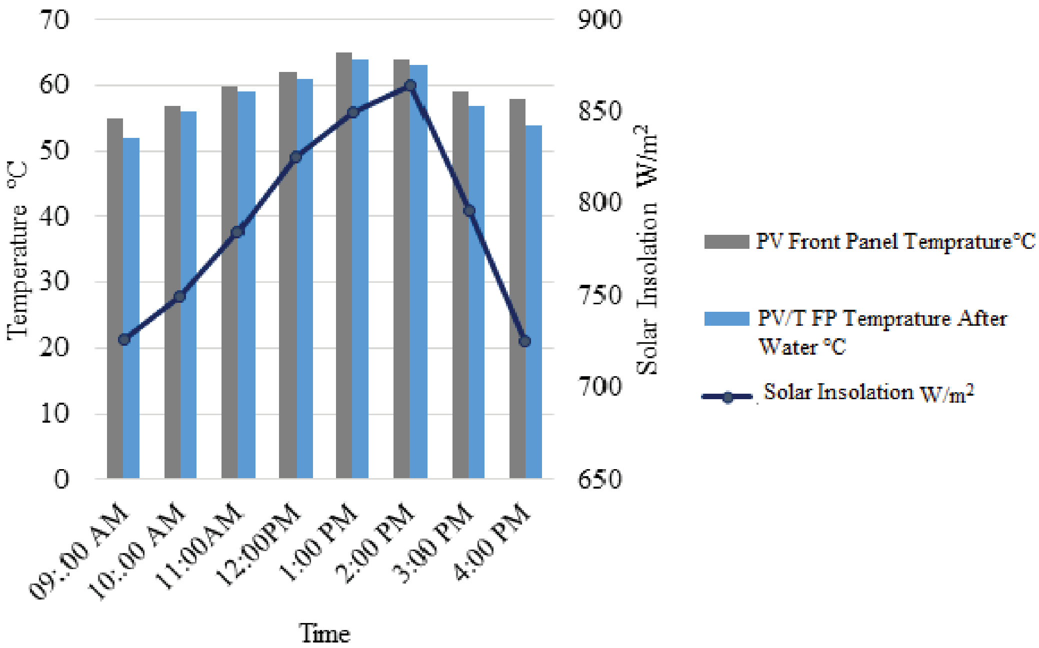

Figure 10. Temperature profile at front surface of PV/T module.

and afterwards both parameters were found to decrease gradually. Maximum temperature of the panel surface was recorded to be 65°C without flow of water and the same was noticed to be lowered to 64°C by the flow of water at the same instant of time that is 1pm, and hence a decrease of 1°C was achieved in the surface temperature of the panel due to water circulation. However, maximum change in surface temperature of 4°C was observed at 4pm decreasing the front panel temperature from 58°C to 54°C respectively.

Figure 11 illustrates the temperature profile during the day. Temperature was measured on different points on the rear surface of the system. These results exhibits similar trend as observed at front panel surface. Maximum temperature of the rear panel surface was observed to be 72°C

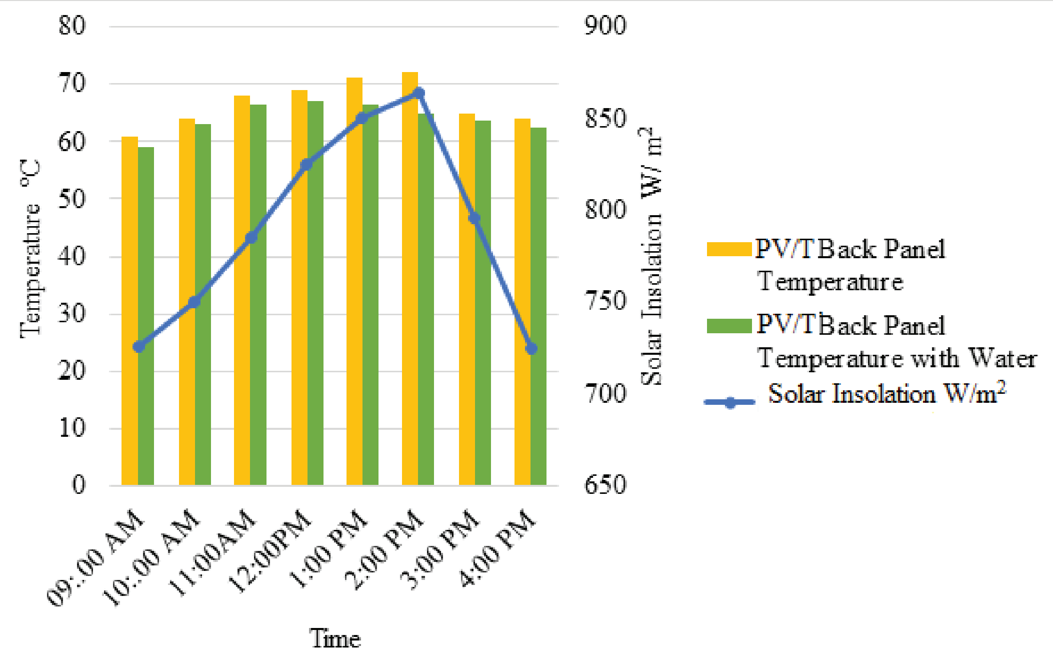

Figure 11. Temperature profile at rear surface of PV/T module.

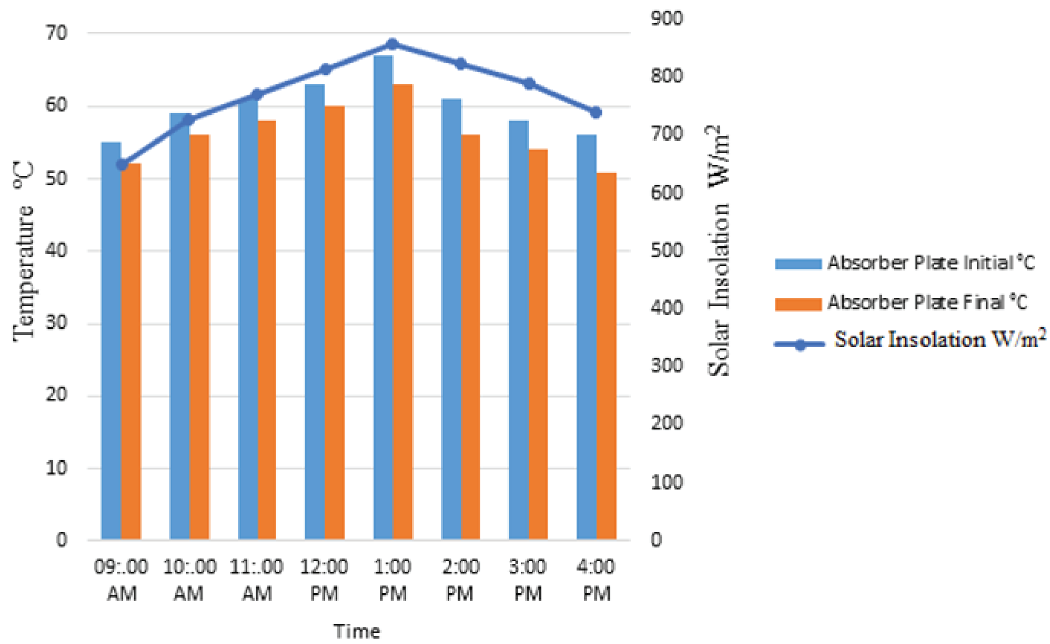

Figure 12. Temperature profile of absorber plate.

without flow of water and the same was noticed to be lowered to 64.9°C by the flow of water at the same instant of time that is 2 pm, and hence a decrease of 7.1°C was achieved in the rear surface temperature of the panel due to water circulation. Therefore the maximum change in rear surface temperature of 7.1°C was observed at 2 pm, decreasing the front panel temperature from 72°C to 64.9°C. The average solar insolation was recorded as 790 W/m$^{2.}$

Figure 12 shows the temperature observed from the plate of the absorber plate measured during the day. The maximum decrease in the temperature of the absorber plate was 7°C at 1 pm which dropped the absorber plate temperature from 65°C to 58°C.

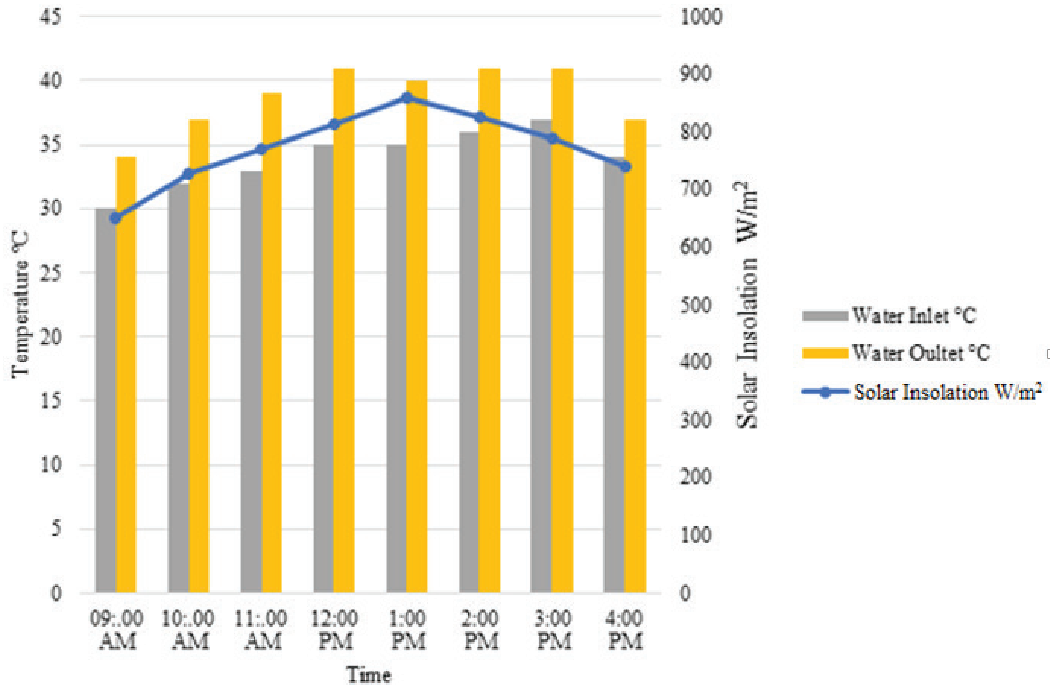

Figure 13. Temperature change of water flowing through the tubes.

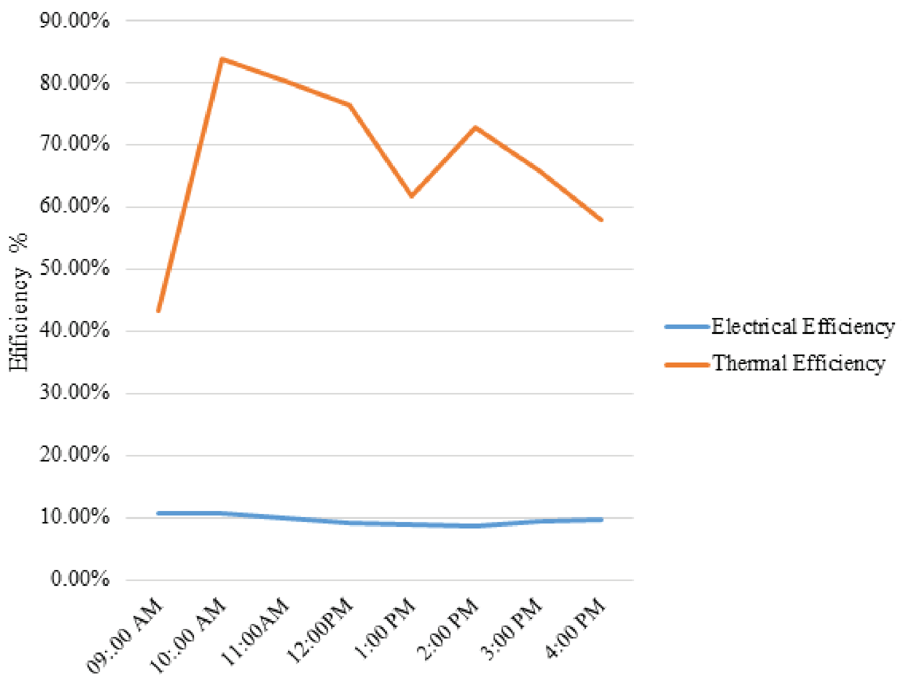

Figure 14. Thermal and electrical efficiency of PV/T.

Figure 13 shows the inlet and outlet water temperature flowing through the tubes. The maximum increase in the temperature of the water was 6°C which was observed at 12 pm by increasing the initial water temperature from 36°C to 42°C.

Figure 14 shows the thermal and electrical efficiency of the PV/T module. The thermal efficiency was found to increase with time and reached to the maximum level of 85.6% at peak hour with corresponding electrical efficiency of 9.76 %.

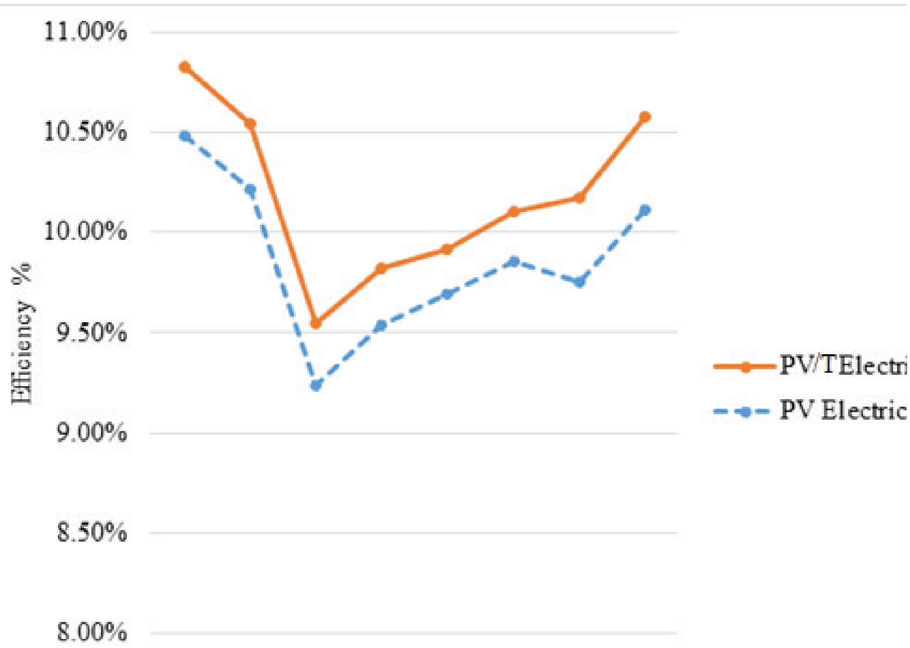

Figure 15. Comparison of PV and PV/T electrical efficiency.

Figure 15 shows the comparison between PV and PV/T electrical efficiency. From the figure it is clear that cooling of the system results in improvement of the performance of system. There was an overall increase of 3.4% in the electrical efficiency of PV/T system. The maximum difference in the electrical efficiency of PV/T and PV module was observed as 9.76 % and 9.19% respectively at 4 pm.

CONCLUSION

The study produced notable results for the solar thermal system. The front panel surface temperature unveiled a significant decrease of 4 °C, indicating competent heat dissipation. Moreover, the thermal collector with 3.75 cm absorber tubes outperformed the one with 7.5 cm tubes at a higher flow rate of 0.03 kg/sec. At uttermost solar insolation, the system achieved a remarkable maximum thermal efficiency of 84%. Additionally, the water detailed a significant maximum temperature difference of 14°C, indicating efficient energy conversion. Notably, the electrical efficiency of the PV/T system was enhanced by up to 3.9%. These findings highlight the system's potential for sustainable and efficient utilization of solar energy. The Study provides useful way of reducing the cost of energy generation, which will greatly benefit the country in the current energy crisis of the country. PV/T systems offers comprehensive solution to the energy crisis in comparison to traditional PV/T systems. This is because it generates both electricity and thermal energy. Hence, it has higher efficiency than traditional PV systems. They also produce energy on cloudy days as well and therefore provide energy continuously during whole year. Furthermore, Due to combination they require less space for higher energy generation. However, it has high installation cost in comparison to traditional PV systems. Also, maintenance cost increases due to amalgamation of two systems. Additionally, it has a potential of reducing reliance on conventional energy resources thereby contributing to lower greenhouse gas emissions. Lastly, it can be used as an educational tool to spread awareness regarding the sustainable energy solution. However, it has certain limitations such as it is influenced by changing weather conditions and time, which causes the inconsistent performance. Secondly, the energy generated by the PVT system is not efficient as the electrical energy generated by conventional resources. Also, the excessive heat of solar energy causes its reduced lifespan. The future suggestions include the study at larger scale in order to meet the growing challenges of energy. Moreover, the system must be improved and commercialized to make it widely accessible to the public.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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