International Conference on Mechanical, Industrial and Energy Engineering 2020
19-21 December, 2020, Khulna, BANGLADESH

ICMIEE20-256

Experimental Performance Investigation of a Solar Photovoltaic Thermal (PVT) Collector

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ABSTRACT
Photovoltaic Thermal (PVT) collector is a hybrid technology that produces both thermal and electrical energy simultaneously combining a photovoltaic (PV) cell and solar thermal collector. In this work, the performance of a PVT collector was investigated experimentally. A PVT collector was constructed by incorporating a heat exchanger in a PV cell. Electrical energy from the PVT collector was monitored by flowing cooling water in the heat exchanger. A small portion of solar radiation was transformed into electricity, but the unsettled portion was lost as heat that affected the PV cell's efficiency. Solar radiation intensity, inlet and outlet temperature of cooling water, surface temperature, voltage, and current of PV cell, was measured. The performance of the PVT collector was compared with a PV cell of the same configuration. Experimental results revealed that the output power of the PVT system is greater than that of the PV system and the average output power is approximately 15% higher compared to the PV system. Results also indicated that the surface temperature of the PVT system is 4-5°C lower than that of the PV system.

Keywords: Photovoltaic module, thermal collector, Photovoltaic Thermal(PVT), solar radiation, efficiency.

1. Introduction

Renewable energy is extracted from natural properties that replace themselves in less than a human lifespan without depleting the planet's resources. These resources for instance sunlight, waves, tides, winds, biomass, hydropower, geothermal power and thermal energy gathered in the earth's crust are accessible in one form or another nearly everywhere. They are virtually inexhaustible what is even more important, they produce neither greenhouse gas – which causes climate change – nor polluting emission [1]. Fossil fuels, for instance, natural gas, coal, and oil are available in finite quantities only. As humans keep extricating them, they will be exhausted eventually. Although produced in biological activities, fossil fuels do not replenish as quickly as humans are using them continuously. Energy efficiency is a pivotal step to reduce human impact on climate change and creating a sustainable future of energy. Solar Energy is the uttermost successful, easy to operate, and standard renewable energy. Solar energy is altered into thermal energy in a thermal energy collector and reformed into electrical energy in a photovoltaic energy system. These two systems are incorporated into a photovoltaic thermal collector [2].

The thinking behind the hybrid concept is that the effectiveness of a solar cell is about 6– 15% depending on the distinct solar cell type [3]. Photovoltaic (PV) cells converted a portion of solar energy into electricity and an unconverted portion of solar energy is absorbed in the cell which increased the temperature of the cell. About 80% of the solar energy incident on solar cells is not transformed into electricity, but either reflected or altered to thermal energy. Therefore, the surface temperature of the solar cells increased substantially and the effectiveness of the cells drops significantly due to its increased resistance. About 3–6 % drop per degree centigrade in case of the electricity conversion efficiency [4]. The voltage is extremely reliant on the temperature and an escalation in temperature will reduce the voltage. PVT structures are discovered to capture and transport heat away from the PV module and hence cooling the cells and improving their efficiency by lowering resistance. The electrical productivity of the PV cell can be enlarged by cooling the cell using air or water. Simultaneously, the heat extracted by air or water can be used for various applications such as indoor hot water production, industrial process heating, solar aided cooling, and space heating, etc. The hybrid design does give extra precedence, likewise a reduction of the thermal stresses and consequently, an extended life of the PV module and a stabilization of the solar cell current-voltage characteristics [3]. Solar collectors must have adequate optical performance such that soaking up as much heat as feasible while the thermal storage systems need high thermal space density upholding small scale volume and cheap fabrication cost, exquisite heat transfer rate, and decent long-term robustness. The preference for heat transfer fluid is vital to outline a PVT system. The liquid-based collector systems are virtually more anticipated and reasonable than air-based systems thanks to the higher heat capacity of water.

Lately, there has been additional attention in discovering a new method to expand the efficiency of these systems. Numerous experimental efforts have been performed for this occasion by changing the collector structure; types of photovoltaic cells; implementing a concentration approach; and utilizing various working fluid for example water, air, and

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nanofluids. Despite the structural design being a crucial factor to have an effective system, the design alterations in a PVT system are quite restricted. For instance, the thermal efficacy of a sheet-and-tube collector is about 2% less than that of other sorts of collectors present such as free flow, channel, and twin-absorber [5]. Teo et al. [6] progressed a hybrid system with a parallel array of uniform airflow secured to the back surface to cool the PV cell & found an upsurge of electrical efficiency from 8-9% to 14%. Bahaidarah et al. [7] evolved a PV water-cooled hybrid system using a solar thermal collector on the back side of the panel. The fusion structure decreased module temperature by about 20% heading a growth in PV module efficiency by 9%. Cuce et al. [8] studied the consequences of passive cooling on the performance of silicon photovoltaic cells for numerous radiation stipulation using an aluminum heat sink for eradicating waste heat from the panel. Investigational outcomes showed that the PV cell furnished with fins delivered more electrical energy than without fins because of its lower cell temperature. Kordzadeh [9] investigated for boosting the system operation by cooling PV cells with a thin film of water flown on the PV surface. It obtained better electrical efficiency due to lowering surface temperature as well as reflection loss.

Power generation from PV cells is getting renewed focused in Bangladesh as solar energy is an immaculate and renewable source of energy. The renewable energy development targets of Bangladesh ask for an extra 3,100 MW of RE capacity to be installed by 2021. 54% of the fresh capacity will be delivered by solar energy [10]. Abundant solar radiation is available in Bangladesh to generate power. However, the limited land area is the main constrain to solar power generation. So, expanding the efficacy of the PV cell is vital to maximize energy output and to reduce land utilization. In this work, the implementation of a PVT system is inspected in the climate of Bangladesh. The enhancement of output in comparison with a PV system of the same capacity is also investigated.

2. Experimental Procedure

The experimental procedure has been established to study the effect of forced water cooling on a solar photovoltaic panel.

2.1 Construction of a PVT collector

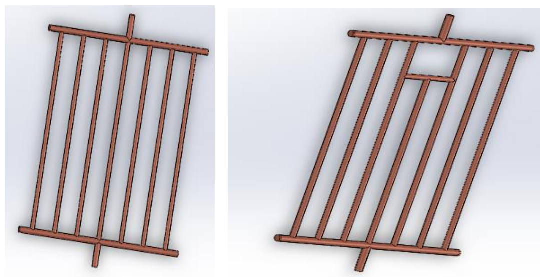
A PVT collector is a mixture of a solar PV cell and a thermal collector. To construct a PVT collector, a 50W PV cell was selected and table 1 shows the specification of the solar panel. Based on the dimensions of the PV cell, a sheet and tube type heat exchanger was designed and constructed. A heat exchanger with parallel circular tubes connected between two header sections is selected for this work and table 2 represents the selection parameters of the collector design is. The schematic illustration of the heat exchanger is shown in Fig. 1(a) and the design of the heat exchanger is slightly modified to accommodate the electrical output of the PV cell as shown in Fig. 1(b). For the construction, the copper tube was used due to its superior thermal conductivity over other conventional tube materials. Two different sizes of copper tubes have been used in this work. Tube size 3/4" was used for the header sections, while tube size 5/8" was used for parallel tube banks.

Table 1 Specification of Solar panel

Manufacturer Company	Genetic Solar
Model No	GP(P) 50W
Dimensions	540mm*720mm*30mm
Maximum Power(P_{max})	50 Wp
Tolerance of P_{max}	0± 3%
Rated Voltage(Vmp)	18V
Rated Current (Imp)	3.1 A
Open Circuit Voltage(Voc)	21.6 V
Short Circuit Voltage(Isc)	2.78A
Maximum System Voltage	1000V

Table 2 Selection parameters of the collector design

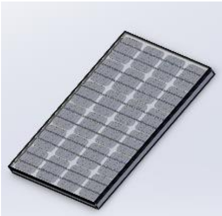
Parameter		Type/Dimension
Collector Types		Direct Flow
Absorber Material		Circular Hollow Copper Tubes
Absorber collector module	Raiser tubes	7 channels with 28 inch X 5/8 inch [L, D]
	Header tubes	2 channels with 21 inch X 3/4 inch [L, D]
Method of Joining		Welding



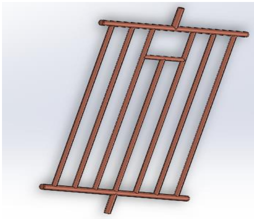
(a) Basic Model (b) Modified Model

Fig.1 Schematic diagram of the heat exchanger

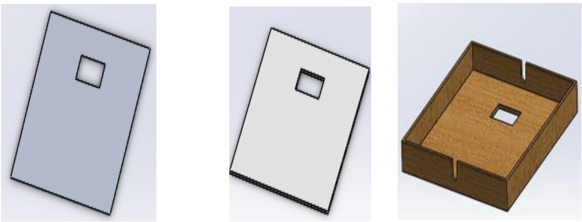
The heat exchanger was secured to the backside of the PV cell to absorb heat directly from the cell. Another side of the heat exchanger was attached to the Aluminum sheet to maximize the heat absorption. To minimize the heat loss from the collector a cork sheet has been used. Then the combined system was installed in a wooden frame to prevent it from any external effect. The detail of the PVT is shown in Fig. 2



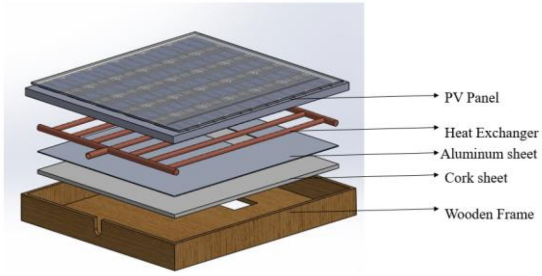
(a) PV Panel



(b) Heat Exchanger



(C)Aluminium sheet (d) Corksheet (e)Wooden Frame



(e) components layer by layer

(f)Final assembly with a solar stand

Fig.2 Different Steps to prepare a solar Photovoltaic Thermal Collector

2.2 Experimental Setup

An experimental setup was constructed to investigate the performance of the PVT collector. The schematic diagram of the experimental setup is shown in Fig.3. It contains a circulation pump, a water to air heat exchanger, and a PVT collector. A PV cell of the same configuration was installed parallel to the PVT collector to obtain the same weather condition for comparison of their performance. The experimental arrangement was installed on the roof of the New Academic Building of Khulna University of Engineering & Technology, Khulna (22.8456° N, 89.5403° E), and the elevation of the roof was 18.3 m from the ground level. Both of the collectors were installed facing towards the south at an angle of 23.5° with the horizontal surface. A photograph of the experimental setup is shown in Fig. 4. A circulation pump (Manufacturer: Gazi pump, 0.5 HP) was used to deliver water in the inlet section of the PVT collector. Then the water went around the thermal collector attached beneath the panel and absorbed the heat and flowed through the outlet section. A water to air heat exchanger was used to cool the water coming from the outlet section of the PVT. Then the cool water was sent back to the inlet section again through a pump. T-type thermocouples were installed in the inlet section, outlet section and panel surfaces to measure temperature. A pyranometer (Manufacturer: Hukseflux) was installed to measure solar radiation intensity. All the thermocouples and pyranometer are connected to a data logger (Campbell Scientific, Inc). The data logger was used to monitor and store the data with time. Two multimeter dataloggers (Manufacturer: Hantek) are used to compute the voltage and current of PVT and PV cells.

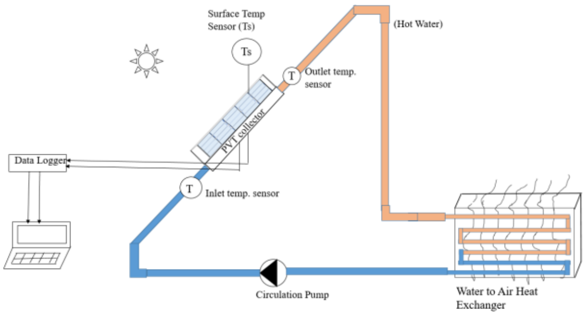


Fig.3 Schematic diagram of PVT setup

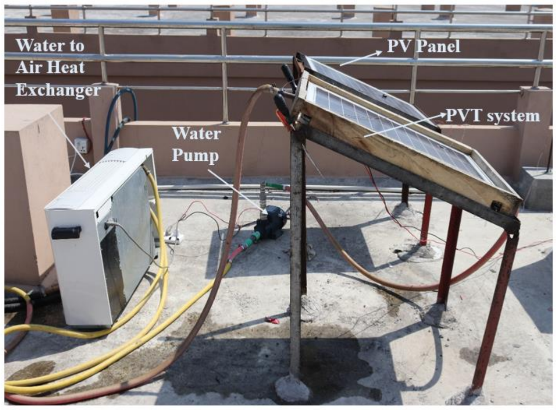
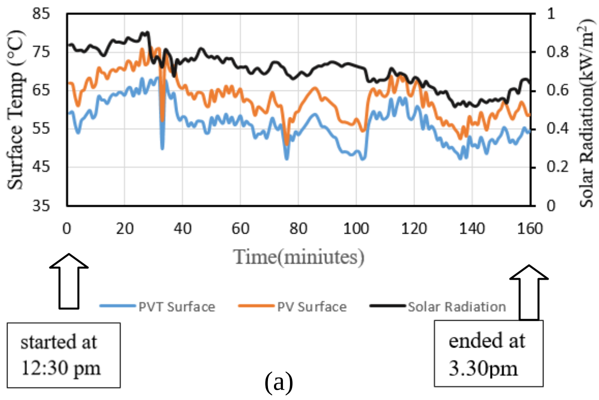


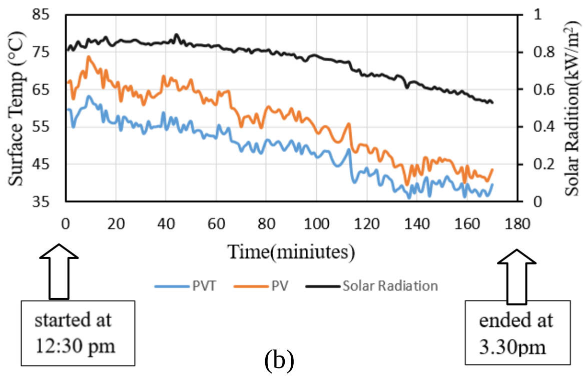
Fig.4 Experimental Setup of PVT and PV

3. Results and Discussion

The experiments were conducted by exposing PVT and PV systems to the same solar radiation condition. From the experimental, the surface temperatures, the inlet and outlet temperatures of the thermal collector, current, and voltage of the PVT and PV system, and solar radiation intensity were monitored simultaneously and stored every minute. The experiments were performed for two days from 09/03/2020 (12:30 pm to 3.10 pm) to 10/03/2020 (12.30 pm to 3.20 pm). The variation of surface temperatures of PVT and PV system with time along with solar radiation intensity is shown in Fig. 5 for the days mentioned above. The surface temperature of the PVT system is approximately 4-5 °C lesser than that of the PV system. It demonstrated that by using a thermal collector, a substantial reduction in the surface temperature in a PVT system can be accomplished compared to that of a PV system.



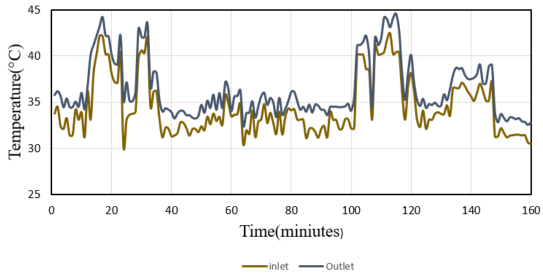
(a)



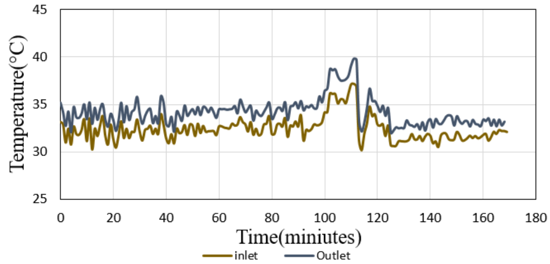
(b)

Fig.5 Variation of the surface temperatures and solar radiation intensity with time (a) for March 9, 2020 (b)for March 10, 2020

Fig.6 shows the deviation of the inlet and outlet temperature of the PVT collector along with time during the test period. The average inlet and outlet temperatures of PVT on the 9th and 10th are 34.72°C, 36.6°C and 32.43°C, 34.5°C, respectively. The outlet temperature rises as water after absorbing heat from the PV panel finally discharges through the collector's outlet. The distinction in temperature between the inlet & outlet of the collector is shown in Fig.7. The graph shows that the outlet temperature is greater than the inlet temperature of about 2°C. The difference in outlet and inlet temperature implies more heat is being shifted to the collector due to rising cell temperature rise over time**.**

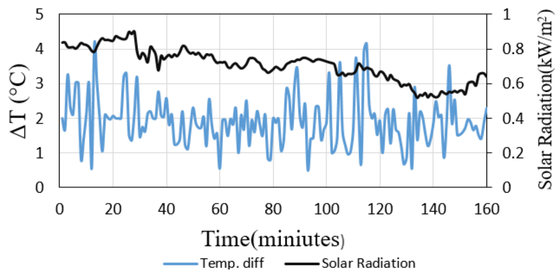


(a)

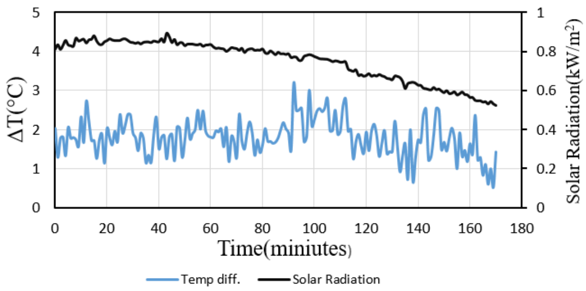


(b)

Fig.6 Deviation of inlet and outlet temperature with time (a) March 9, 2020 (b) March 10, 2020



(a)



(b)

Fig.7 Deviation of the temperature difference with time (a)for March 9, 2020 (b)for March 10, 2020,

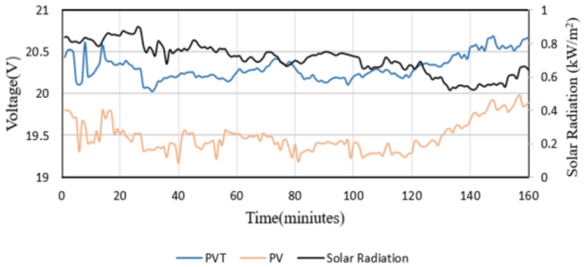
The experimental results of the electrical parameters for the PVT and PV are shown in Figs.8-10. The output voltage and current of PVT and PV system were measured using multimeter dataloggers and the output power was calculated by using Eq. (1). The efficiency of PVT and PV system was calculated by Eq. (2) -(3). Where G is incident radiation on the solar cell which is obtained from the pyranometer.

$$P=V*I \quad (1)$$

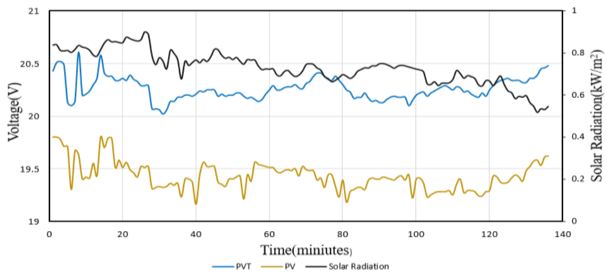
$$\eta_{PVT}=\frac{P_{pvt}}{G} \quad (2)$$

$$\eta_{PV}=\frac{P_{pv}}{G} \quad (3)$$

By utilizing a solar thermal collector, an upsurge in efficiency was observed for all cases considered. Fig.8 showed the variation of voltage with time and solar radiation. According to the manufactures catalog, the open-circuit voltage can be up to 21V. Even though during the peak voltage, solar irradiance was not the maximum. This showed how cell temperature takes part in a significant role in setting up the open-circuit voltage of solar cells. Thus, additional cooling is essential for enhanced electrical performance. In this experiment, the average output voltage of PVT and PV system for 9th and 10th March is found 20.25V,19.42V, and 20.20V,19.54 V respectively.



(a)



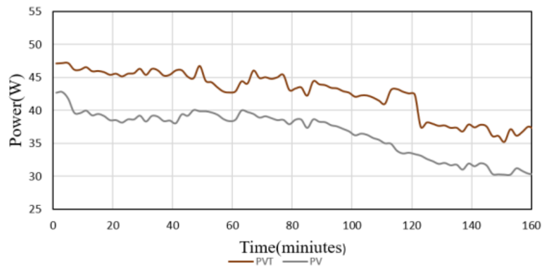
(b)

Fig.8 Variation of output voltage and solar radiation intensity with time (a)for March 9, 2020 (b)for March 10, 2020

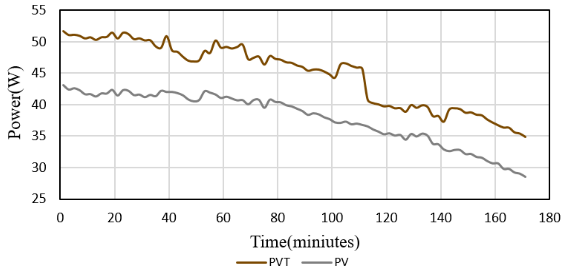
Fig.9 showed the variation of the output power of PVT and PV system. The output power of the PVT system is upper than that of the PV system over the entire testing period. The power generated by the PVT system is superior due to its lower surface temperature compared to that of the PV system as both panels are exposed to nearly the same solar irradiance. The average output voltage of PVT and PV system for 9th and 10th March is found 43.15W,37W and 45.8W,38.7W respectively.

The average output power of the PVT system for the 9th and 10th March is 14.14% and 15.74% higher than that of the PV system respectively. The variation of efficiency of PVT and PV with time is shown in Fig.10.

As expected, PVT is more efficient due to its cooling effect produced by the thermal collector. The average efficiency of the PVT system is 17.23% and 18.45% higher than that of the PV system for the above-mentioned testing days.

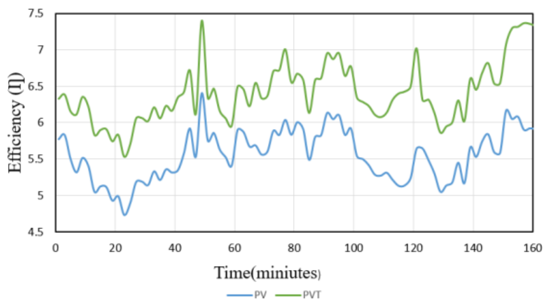


(a)



(b)

Fig.9 Variation of power with time in (a)for March 9,2020 (b) for March 10,2020



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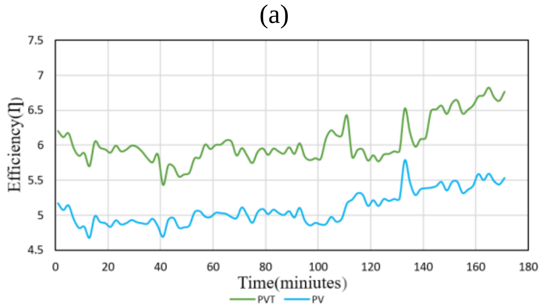

(b)

Fig.10 Variation of efficiency of with time (a)for March 9, 2020(b) for March 10, 2020

4. Conclusion

An experimental investigation was performed in this work to examine the performance of the PVT system in comparison with a PV system. The circulation of the cooling water in the thermal collector reduced the surface temperature of the solar cell. Experimental results showed that the surface temperature of the PVT system is 4-5°C lower than that of the PV system. This cooling effect significantly enhanced the electrical output of the PVT system. The average output power of the PVT system is approximately 15% higher than that of the PV system. This higher output of power enhanced the efficiency of the solar cell.

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NOMENCLATURE

V: Voltage, V
P: Power, W
I: Circuit, A
T: Temperature, °C
G: Solar irradiation, W
η: Efficiency