Performance Monitoring of PV/T Based Solar Collector for Dual Output

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Abstract
This study aims to focus on the concept of integration of solar air heaters with PV (Photovoltaic) for dual output i.e. thermal and electrical. Conventional solar based collectors either water or air type are used majorly for thermal application. Thus, the integration of PV to the air heaters efficiently utilizes the solar radiation on a wider scale improving the overall output of the system. Thus, the optimized combination of PV and thermal collectors could effectively use same space to serve the dual purpose Present case study investigates the performance comparison of the PV/T air collector with the thermal collector. The transmittance of glass for thermal and PV/T air collector was found to be 87.5% and 4.54%, respectively. The maximum power output of PV/T collector was found to be 128.6 W at 815 W/m^2 with solar panel efficiency of 10.38%. Such collectors find application where low energy standalone applications are desired such as drying, cooling and power generation in off grid areas.

Keywords: *PV/T collector, Efficiency, solar energy, thermal, power*

1.1 INTRODUCTION

Dependency on fossil fuels to cater the need of energy supplies such as coal natural gas and fuel oil for domestic and industrial purposes since centuries is driving the growth of civilization. The deterioration of the global fuel supplies has been the key driving factor to explore the renewable sources of energy for a sustainable future. Moreover, the renewable shift takes long-term economic sense, it is expected that costs of wind and solar energy generation will fall by 47% and 32% respectively by 2040 [1]. In Indian perspective, government policy intends to achieve 175 GW of installed renewable energy capacity by 2022. State government of Gujarat under its solar policy envisages providing clean and sustainable environment to its citizens projected based on the rich availability of solar energy resource of 5.5-6 kWh per sq. m per day, having potential of 10,000 MW of solar generation capacity reducing carbon footprint [2].

Solar Energy utilization can be mainly classified in two ways: solar thermal and solar photovoltaic. Solar thermal technologies have decentralized applications in industrial and commercial applications whereas on the domestic front, solar water heaters are the most widely used technology. Whereas, other innovative areas getting attention in urban and industrial areas are solar concentrating steam generation and air heating and energy efficient solar green buildings. Further, they can sub-divide into cooking, drying, hot water system, desalination and electricity generation applications [3]. Solar photovoltaic however, the conversion for the photovoltaic cells .i.e. silicon-based cells having maximum achievable efficiency of 30% for a band gap of 1.1 eV into electricity for the ideal case given by Shockley and Queisser [4]. Moreover, overheating in the cells raising the panel temperature and decreasing the efficiency of solar PV is the major bottleneck for the solar cells. To overcome this drawback and to increase the photovoltaic and overall efficiency, hybrid solar air heaters (PV/T) have been developed. PV/T collectors serve the dual purpose by recovering the heat for combined electrical efficiency and thermal applications. Thus, PV/T collectors provide an innovative way of converting solar energy thereby increasing in overall system performance and efficiency.

There are different ways of yielding output using PV/T based heating systems namely, i.) PV/T air collector, ii.) PV/T based water collector and iii.) PV/T based concentrator. Water based PV/T collectors are more efficient than air type due to enhanced thermo-physical properties of the heat transfer fluid [5]. Hybrid PV/T air collectors heat the air for domestic space heating purpose and simultaneously generate electricity for other applications where the excess power can be utilized in a better way. Tiwari et. al., estimated the performance of PV module integrated with air duct for Indian climatic conditions and concluded that the significant increase in overall efficiency of PV/T air collector was due to combined output in the form of thermal energy and photovoltaic [6].

Tonui et. al., studied and validated the performance of low cost heat extraction methodology after several modifications in the system comprised of PV/T air system with thin flat metal sheet suspended at the middle or finned back wall of an air channel to achieve higher thermal output and cooling of the PV panel so as to keep the electrical efficiency to an acceptable limit. The model was validated to study the effect of various physical parameters such as channel depth, channel length, and mass flow rate on electrical and thermal efficiency, cooling of the PV and pressure drop for both the systems under study [7]. Raman and Tiwari analyzed the energy and exergy performance of a hybrid photovoltaic air collector with single and double pass for different climatic conditions in India. It was observed that that the energy(electrical &thermal) and exergy efficiencies of double pass PV/T system are higher than single pass systems by 10-12, 40-45 and 13-17%, respectively. The cost of double pass air systems per kWh significantly reduced for all locations compared to cost of single pass air collector per kWh [8].

Sarhaddi et al. developed a model for PV/T air collectors to compute the thermal and electrical parameters including solar cell temperature, back surface temperature, air outlet temperature, open circuit voltage, short circuit current, maximum power point voltage, maximum power point current, etc. It was found that the thermal, electrical and overall energy efficiency of PV/T air collector was found to be 17.18, 10.01 and 45%, respectively, done for a specific climatic condition including several operating and design parameters [9].

Kumar and Rosen evaluated the effects of fins in lower air channel, depth of ducts flow rate, packing factor and flow rate on thermal and electrical efficiency for a double pass PV/T air collector with vertical fins. The extended fin area reduces the cell temperature from 82 °C to 66 °C due to better heat removal. The drop in cell temperature due to higher packing factor yielded more electrical output for the system [10]. Hegazy compared the designs for single and double pass collector over air flow pattern over the absorber plate and beneath it on both sides of absorber for thermal, electrical, hydraulic and overall efficiencies. He concluded that the increase in thermal efficiency was observed due to higher mass flow rate whereas, the air flowing over the absorber had the lowest performance and comparatively less power generation from PV at lower flow rates [11]. Beccali et al. analyzed the energy and economic performance standard single glazed and hybrid PV/T collectors for desiccant based cooling applications in hot and humid climate. The overall increase in system efficiency of hybrid PV/T system was observed by 18% due to power generation from PV along with thermal energy [12].

II. MATERIAL AND METHODOLOGY

Setup and Instrumentation

Experimental setup consists of i) solar thermal collector with toughened glass, ii) solar thermal collector with PV. The graphical representation of the following system is as highlighted in Fig.1. The system consists of collector box, glass cover (toughened and PV integrated toughened glass- 5 mm), black painted absorber sheet and insulation (glasswool-50 mm thick). Absorbers in both the collectors were made of same material and kept at the middle of top cover and insulated bottom plate. Air flows between the glass and absorber sheet in thermal collector and between the solar cells and absorber sheet in PV integrated thermal collector.

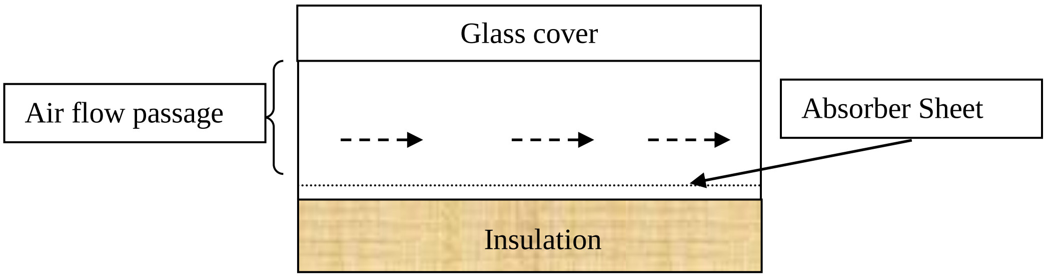

Fig. 1: *Schematics of Solar Air Collector*

Pyranometer was used for measuring solar radiation (Make: Kipp & Zonen), platinum resistance temperature sensors (RTD) PT1000 (Make: Sigma Instruments) was installed at various places to measure ambient and air temperature. Datalogger (Model: Data Taker, DT-85) was used for continuously monitoring data for logging temperature and solar radiation. Hot wire anemometer (Make: KIMO) with digital display was used for air velocity measurement. Wireless PV analyzer (Make: Solmetric) was used to record the electrical performance parameters of the PV manually. Temperature and radiation were monitored throughout the day to check the overall performance of the collector.

Experimental Methodology

Experiments were done using both the collectors simultaneously between 9:30 am and 4:30 pm. The global solar radiation was also measured at the similar inclination of 35°C and observed in the range of 300-925 W/m^2 during the experiments under natural convection mode. The wind speed and ambient temperature, near the experimental area, were between 0.08-0.10 m/s and 33-35°C respectively. Transmittances of cover glass of solar thermal collector and PV integrated glass cover were measured as per the BIS standard IS12933 (Part 2: 2003) clause no: 5.1. Tests were performed on the collectors and temperature data was collected using a continuous data monitoring system at specified intervals having a software interface and system was analyzed. The electrical parameters such as voltage, current, power efficiency were also measured for PV integrated collector using PV analyzer. The pictorial view of the conventional and PV integrated solar collector along with necessary arrangements is shown in Fig.1. Specifications of the collectors used for experimentation with and without PV are listed in Table 1.

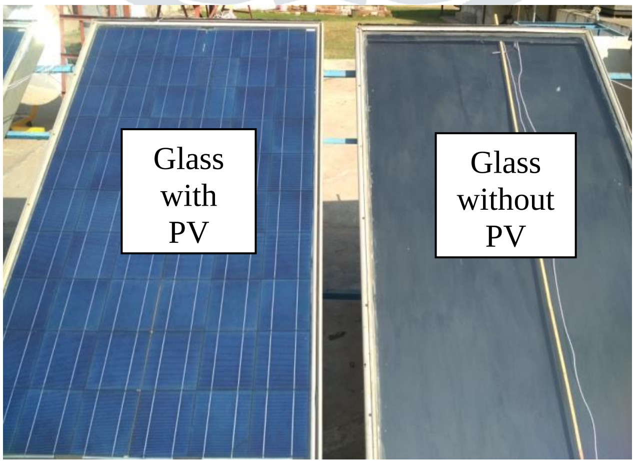

Fig. 1: *Experimental Setup for Solar Collector with and without PV*

***Table1:** Specifications of collectors*

Sr.No.	Parameter	Value
1	Dimension of collectors	1.00 m X 2.10 m
2	Area of the collectors	2.1m^2
3	Area of PV glass	1.48 m^2
4	Rating of the PV panel	150W
5	No. of cells in PV panel	60 (2.5W each)

III. RESULTS AND DISCUSSIONS

Thermal Performance

Transmissivity of collector glass with and without PV was measured using pyranometer during solar noon time and was found to be 87.5% and 4.54% respectively. The average temperature values in the flat plate thermal collector with toughened glass and PV integrated toughened glass were found to be 89°C and 67°C respectively. The hot air temperature in the PV integrated thermal collector was measured ~30% lower than flat plate thermal collector. Due to higher transmittance, thermal performance of the conventional collector can be seen higher than the PV integrated collector, as it allows higher radiation to be reached at the absorber plate and gain heat. It has to be noted that glass used for both the collectors are same and lower transmittance resulted due to PV cell integration. The low transmittance of the PV integrated glass leads to lower thermal performance of the PV integrated thermal collector.

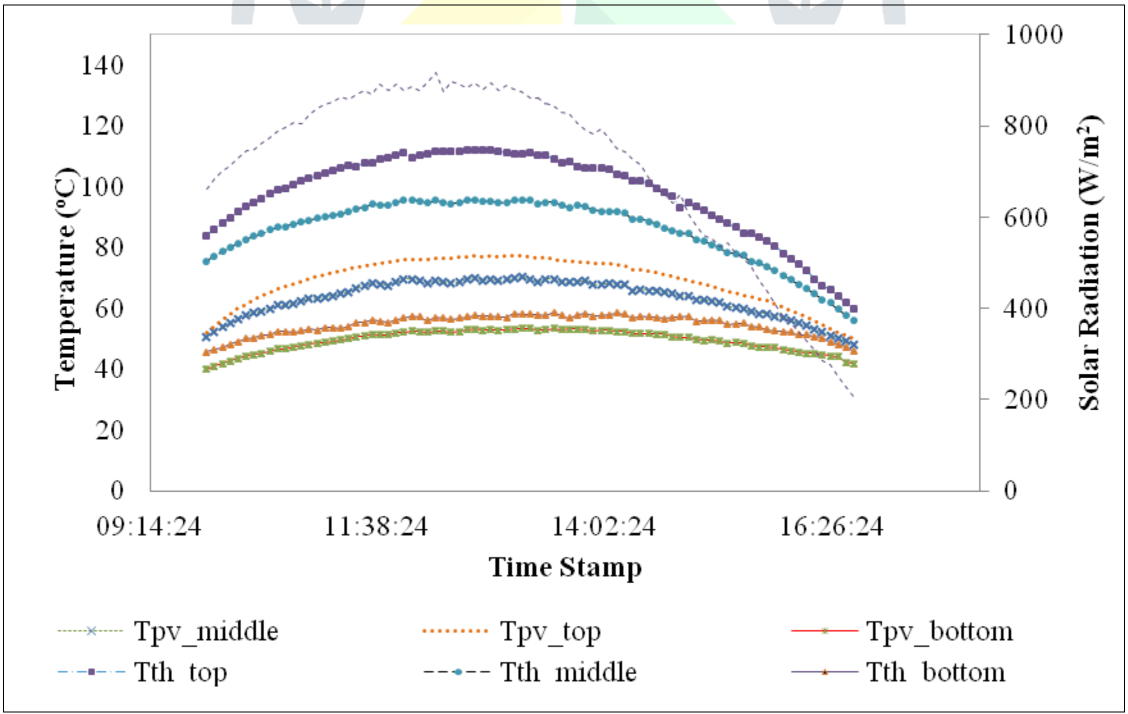

***Fig.2:** Performance of different solar collectors for thermal output.*

where, T_{pv}= Temperature of hot air in Solar PV/T collector

T_{th}= Temperature of hot air in Solar thermal collector

Electrical Performance

The electrical performance of the PV integrated thermal collector under diverse radiation values is plotted in Fig. 3. Variation in the measured short circuit current and power output for different radiation values is given in Table 2. The maximum power output from the PV integrated solar collector was measured about 128.6 W at 815 W/m^2 with solar panel efficiency of 10.38%. As seen in Fig.3, the efficiency decreases on increasing the radiation as open circuit voltage (V_{oc}) decreases. The drop in V_{oc} can be seen a result of increasing cell temperature at higher solar radiation.

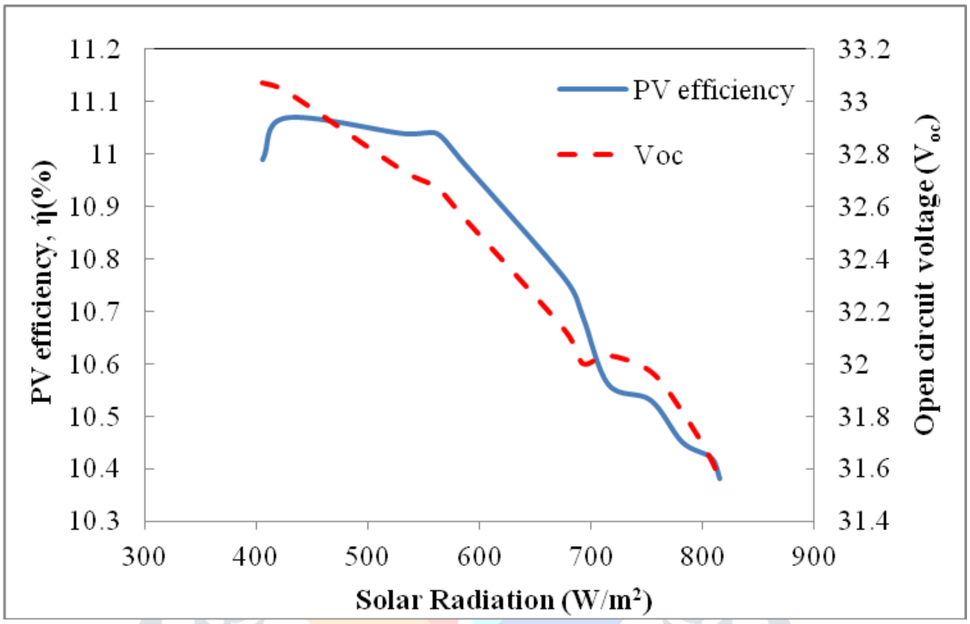

Fig .3: Electrical performance of PV integrated collector glass

As observed the power output from the system is linearly dependent with the solar radiation, short circuit current and power output increases at an average temperature of 45^{o}C.

Table 2: Variation in electrical parameters of PV integrated collector at different radiations

Radiation (W/m^2)	P_{max} (W)	I_{sc} (A)
405	67.74	2.77
426	71.74	2.94
532	89.27	3.74
562	94.30	3.98
587	98.02	4.19
677	110.80	4.95
692	112.54	5.07
715	114.85	5.21
753	120.54	5.50
782	124.11	5.77
808	127.89	6.03
815	128.61	6.09

IV. CONCLUSIONS

The thermal and electrical performances of the collectors were studied and compared. The temperature achieved in the conventional solar air collector was observed significantly higher than the PV integrated collector. However, PV integrated panel provides electrical output in addition to the thermal energy and by retrofitting such hybrid collectors for heating, cooling and power application. The experiments were performed under natural convection mode. In forced convection mode, the performance may vary and has to be investigated in detail at different air flow rates. The solar based PV/T solar collectors are promising alternative for low-energy applications. Such collectors with dual output application are thus useful for people living in remote areas, where grid connectivity is intermittent or not available.

ACKNOWLEDGEMENT

The authors are grateful to Indian Council of Agriculture (ICAR), Government of India under the component of AICRP on energy in agriculture and agro-based industries for providing financial support for this project.

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