Performance Evaluation of Hybrid PVT Air Collector. A Comparative Approach

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ABSTRACT

In the recent past, Photovoltaic systems have gained a lot of interest to fulfill the electricity requirement by converting sunlight directly into electricity. One of the major problems in PV module is the derating of their efficiency due to rise in cell temperature which is the strong function of ambient temperature. The issue can be resolved by converting the PV module into hybrid photovoltaic thermal collector. Here, the performance of two photovoltaic modules is compared experimentally on different days. One PV module has been converted into hybrid PVT air collector by installing the air duct at the backside of module while the second is simple PV module. The hybrid PVT air collector is found to be more efficient than the simple one with maximum thermal and electrical efficiencies of 65.6% and 14.8% respectively. The hybrid PVT is technically sound in fulfillment of both electrical and low-grade heat requirement. The economic feasibility has been found by a case study where the comparison between hybrid PVT and electrical heater is made. It is concluded that PVT is more economically beneficial with a low payback of just 8 months.

1. INTRODUCTION

Electricity requirement is exponentially increasing throughout the societies. A tremendous amount of energy is fulfilled by every nation to make a progress in every field. The short fall of electricity in our country, Pakistan is around 5 GW since the past few years. [1]. Due to which, people of Pakistan are looking towards PV systems for fulfillment of electricity. The major issue associated with PV is that they are able to convert only 15 to 20 % of sunlight into electricity while the rest of energy just increases the cell temperature [2] which ultimately results in the decrement of PV efficiency [3]. The electrical efficiency of the PV module can be increased by using the cooling system at the back side of the panel which ultimately transforms the PV into hybrid PVT collector. The hybrid system is able to produce both electricity and heat from a single component. In short, PV is combined with the solar thermal collector by replacing the glass [4]. The system does not only increase the electrical efficiency but also reduces the space requirement for fulfillment of both electricity and heating demand which ultimately makes the system technically as well as economically beneficial. [5]. Sultan [6] made a comprehensive review of different PVT collectors and concluded that PVT technology is technically sound and a more research will make this technology more efficient and cost effective. Kalogirou [7] has analyzed PVT system by TRANSYS and revealed that polycrystalline cell is more electrically efficient than that of amorphous one but the heat generation from polycrystalline is low. Ibrahim [8] assessed the performance of air, water and combined air water-based PVT systems and concluded that the system has a life of around 25 years. Tiwari [9] modelled PVT air collector and revealed that the total efficiency is around 56.30% at 0.01 kg/s. Nazri [10] theoretically modelled and examined, how the fluid outlet temperature varies by varying the rate of fluid flow and sun intensity and reported the negative effects. Sarhaddi [11] modelled the system electrically as well as thermally and concluded that the modelled is in good agreement with the experimental results reported in the previous literature. Khelifa [12] performed the mathematical modelling of PVT water collector by FLUENT and revealed that the PV cell temperature greatly decreased by around 18% due to the flow of water through the backside of the panel. Zohri [13] did the mathematical modelling of PVT air collector by incorporating fins in the air duct and concluded that the electrical efficiency of the system was 14% with 43% thermal efficiency while the fluid outlet temperature was found to be $41.39^{o}\ C$. Kasaeian [14] did the experimental study to check variation of electrical and thermal efficiency by using the forced convection for a single pass system and found the electrical efficiency varies from 12-12.4% while the thermal efficiency varies from 15-31%. Jakhar [15]

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performed the numerical study to check the utilization of PVT system with Earth air heat exchanger for Las Vegas city of U.S. and Ajmer city of India and revealed that with ducting system the cell temperature is reduced down to 43.4 °C for Las Vegas which was previously 54.3 °C, while for Ajmer city, the cell temperature was dropped down to 44.2 °C while without ducting system it was found to be around 54.5 °C. For both the cities the air flow rate was maintained at 0.053 kg/s. Slimani [16] comparatively studied four different configurations of PVT collector which were simple PV module, traditional PVT air collector, glazed PVT air collector and double pass glazed PVT air collector and revealed that the average efficiencies for the studied system were 29.63%, 51.02%, 69.47% and 74% respectively.

From the above discussions, one can conclude that hybrid PVT air collector is very impressive technology. Here, the performance of simple PV and hybrid PVT is experimentally evaluated on different days. The performance evaluation includes the determination of electrical as well as thermal efficiency. Financial viability of PVT collector is also checked by considering a case study in which the PVT and electrical heater are compared.

2. METHODOLOGY

The electrical power of simple PV and PVT collector are determined experimentally. The specs of both the panels studied are presented in table 1 and 2. One panel is converted into hybrid PVT air collector by installing the wooden duct at the backside of the panel. Two fans are used to force the air into the duct while the two fans are installed at the top of duct to collect the air from the duct. Two fans force the cold ambient air into the duct, when the air comes in contact with the hot surface of the panel, due to temperature difference, heat transfer will occur. Panel will lose heat while the air will gain heat. Hot air will be collected from the fans attached at the top side. To enhance the overall heat transfer, installation of fins in the duct has also been done as shown in Figure 1. The modules were placed at angle of 25° equal to the latitude of the Karachi to capture the maximum energy from sun. The actual PVT air collector is shown in figure 2.

Table 1: Simple PV panel Specs

P_{rated}	150.00 Watts
V_{OC}	22.16 Volts
I_{SC}	9.79 Amps
Nominal Operating Cell Temperature	48.0 ˚C
C_T	0.48%/◦ C

Table 2: Hybrid PVT panel specs

P_{rated}	150.00 Watts
V_{OC}	23.61Volts
I_{SC}	8.89 Amp
Nominal Operating Cell Temperature	48 ◦ C
C_T	0.48%/◦ C

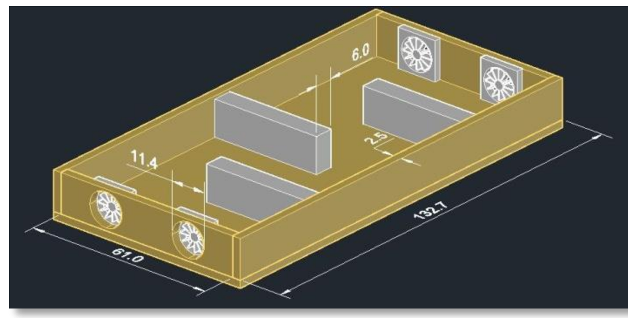

Fig. 1. Air duct equipped with the fins to enhance the overall heat transfer.

Fig. 2. Actual experimental setup.

Power extracted from the PV panel will be electrical in nature and can be calculate by using the information of current and voltage as given below.

$$Power = Voltage \times Current \tag{1}$$

Temperature of the solar cell is the strong function of ambient temperature and can be determined by [17]

$$T_{solar\ cell} = T_{amb} + \frac{NOCT-20}{0.8} G \tag{2}$$

Due to increase in cell temperature, the electrical power of the PV module will be derated and can be calculated by [17]

$$P_{T,dc} = P_{rated}\,[1 - C_T\,(T_{solar\ cell} - 25)] \quad (3)$$

Air duct is installed at the back side of the PV module to capture the heat from PVT. Amount of heat captured can be calculated by

$$Heat = mC(T_{outlet} - T_{amb}) \quad (4)$$

Electrical efficiency, thermal efficiency and the total efficiency of the PVT module can be determined as

$$\eta_{elec} = \frac{V_{max}I_{max}}{AG} \quad (5)$$

$$\eta_{ther} = \frac{Heat}{AG} \quad (6)$$

Since the total power obtained from the PVT is the sum of electricity and heat so the total efficiency of the PVT can be given as

$$\eta_t = \eta_{elec} + \eta_{th} \quad (7)$$

3. RESULTS AND DISCUSSIONS

To determine the performance of both PV and PVT, both types of panels have been tested experimentally on different days. The panels are placed at an angle of 25° approximately equal to the latitude of the location to capture the maximum solar energy. The electrical power from both the panels have been determined by measuring the current and voltage from both the panels and the results are precisely shown in table 3. The amount of electrical power obtained from PV and PVT on different days is presented from figure 3 to figure 11 which clearly represent that the IV curve of PVT covers more area than that of simple PV. The more area means that PVT is producing more power as compared to simple PV. This ultimately shows the electrical supremacy of PVT over PV. The comparison of electricity obtained from both the panels is presented in Figure 12, which clearly shows that PVT is able to produce more electricity than the simple PV. The additional power from PVT is due to the cooling effects. Since, air is cooling the panel which ultimately decreasing the solar cell temperature and results in increasing the electrical power. Thus, cooling of PV is good option to enhance the overall electrical energy gained by the panel.

Amount of heat captured from PVT air collector is summarized in table 4 and the total power obtained from PVT is presented in Figure 13. The total power obtained from PVT is the sum of both electricity and heat. From figure 13, it is evident that around 23% of the incoming solar radiation is converted into electricity while the rest of the incoming solar radiations are being converted into heat which can be utilized to fulfil the heating requirement of any building or space.

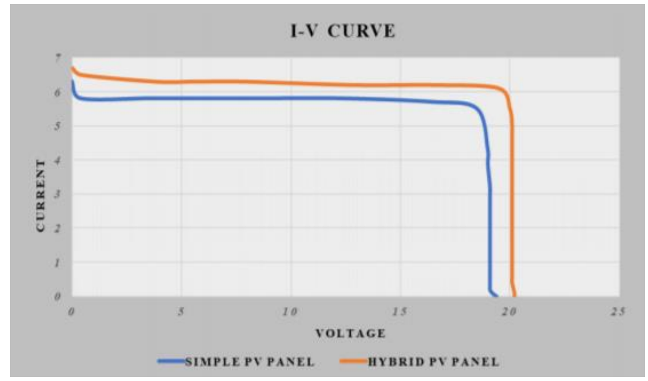

Fig. 3. Current versus voltage graph on February 21.

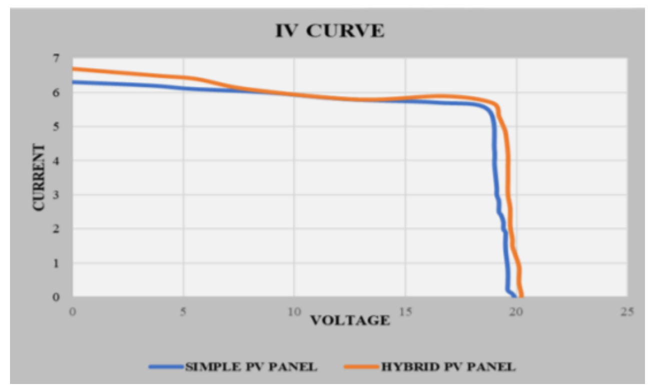

Fig. 4. Current versus voltage graph on March 04.

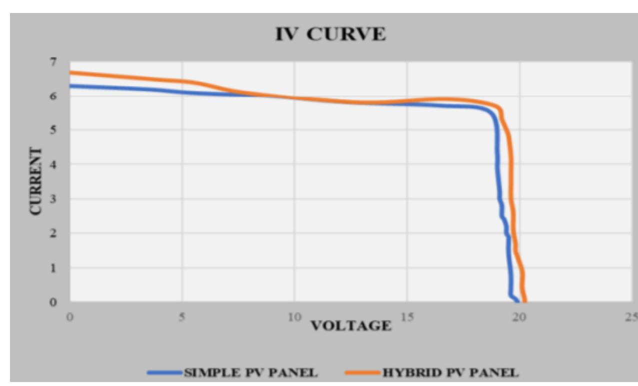

Fig. 5. Current versus voltage graph on March 09.

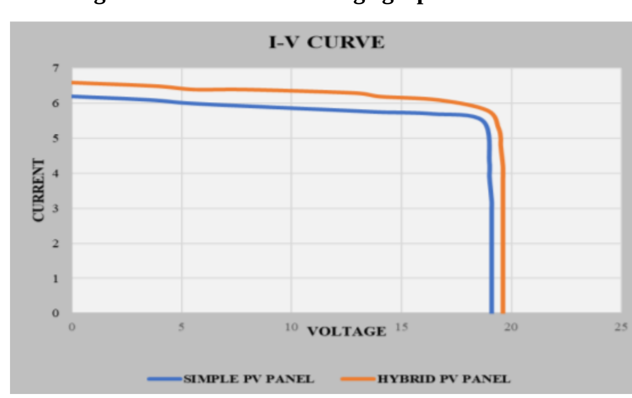

Fig. 6. Current versus voltage graph on June 09.

Table 3. Comparison of electrical power obtained from both PV and PVT

	PVT	PV	PVT	PV	PVT	PV	VT	PV	PVT	PV	PVT	PV	PVT	PV	PVT	PV	PVT	PV
Date	February 21		March 04		March 9		June 9		June 15		July 12		July 16		July 26		Aug, 16	
Irradiance W/m^2	841.00		781.00		967.00		1011.00		883.00		822.00		781.00		923.00		897.00	
Environment temperature	26.9 °C		26.1 °C		28.1 °C		37.2 °C		35.1 °C		34.2 °C		32.3 °C		35.9 °C		33.8 °C	
Cell Temperature	62.00 °C		61.00 °C		63.00 °C		72.00 °C		70.00 °C		69.00 °C		67.00 °C		71.00 °C		69.00 °C	
Maximum current	6.10	5.50	5.78	5.18	5.70	5.40	5.81	5.59	5.76	5.33	6.03	6.02	6.02	5.98	6.44	5.81	6.05	5.86
Maximum Voltage	19.03	18.50	19.41	18.23	19.20	18.90	19.18	18.76	19.01	18.01	18.89	18.79	19.20	18.83	17.56	18.31	18.37	17.41
Maximum power	116.08	101.75	112.19	94.43	109.44	102.06	111.44	104.87	109.50	95.99	113.91	113.12	115.58	112.60	113.09	106.38	111.14	102.02
Temperature adjusted power	123.36	123.36	124.08	124.08	122.64	122.64	116.16	116.16	117.60	117.60	118.32	118.32	119.76	119.76	116.88	116.88	118.32	118.32
Electrical Efficiency	13.8 %	12.1 %	14.4 %	12.1 %	11.3 %	10.6 %	11.0 %	10.4 %	12.4 %	10.9 %	13.9 %	13.2 %	14.8 %	14.4 %	12.3 %	11.5 %	12.4 %	11.4 %

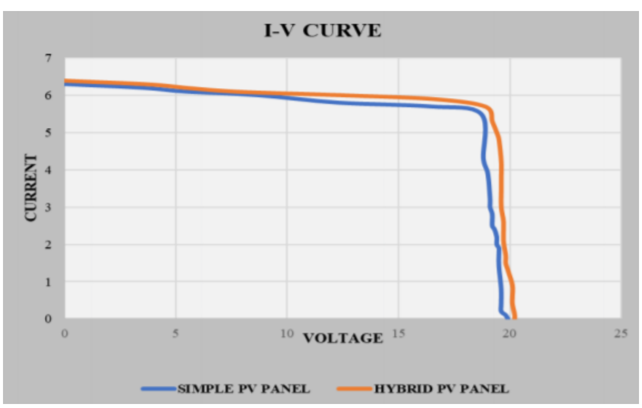

Fig. 7. Current versus voltage graph on June 15.

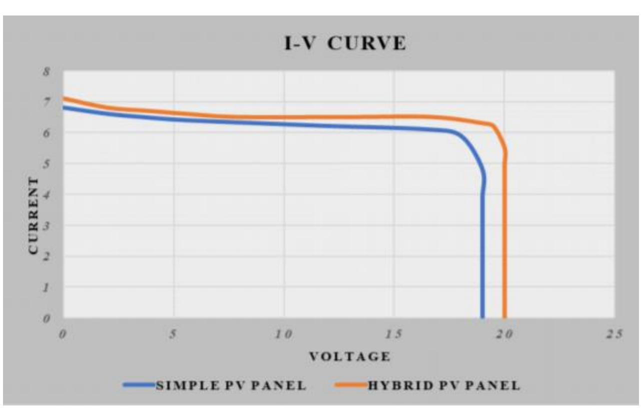

Fig. 8. Current versus voltage graph on July 15.

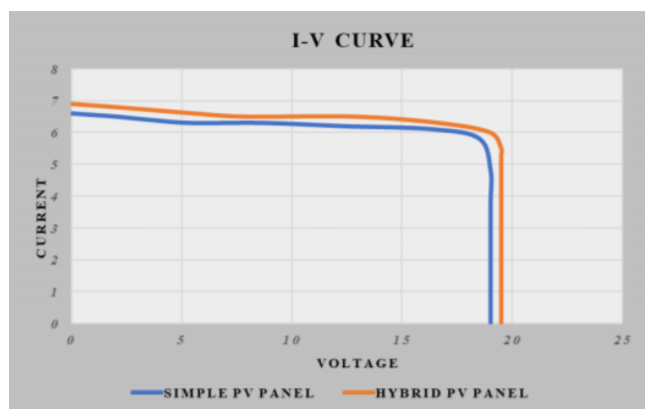

Fig. 9. Current versus voltage graph on July 16.

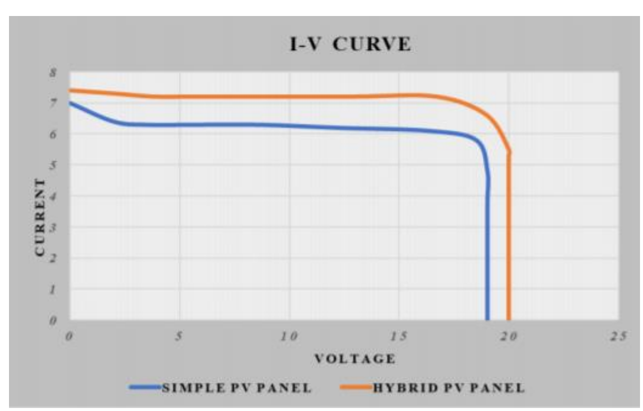

Fig. 10. Current versus voltage graph on July 26.

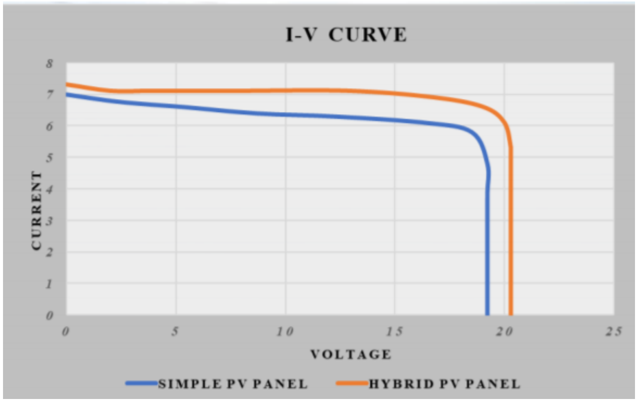

Fig. 11. Current versus voltage graph on August 16.

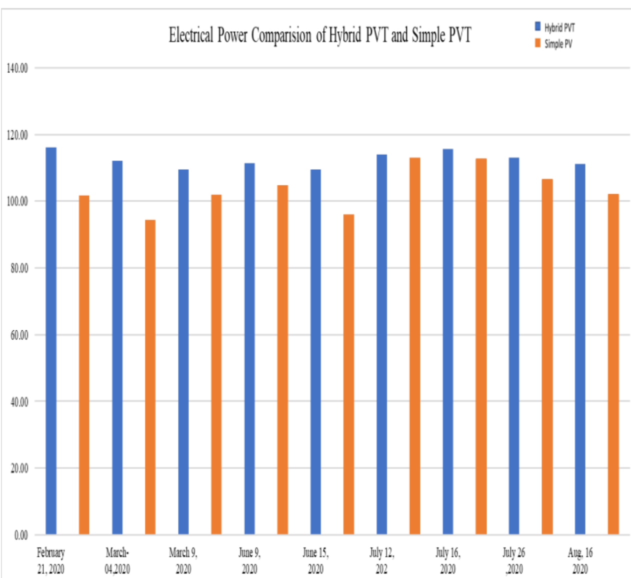

Fig. 12. Comparison of electricity obtained from PV and PVT panel.

The ratio of heat collected from the PVT to the electricity obtained from PVT is termed as heat coefficient (COH) and can be determined from equation 8. This parameter can help in determining the thermal energy obtained from PVT throughout year by using the knowledge of electrical energy. Table 5 shows the values of heat coefficient obtained on the experimental days.

$$COH = \frac{Thermal\ energy}{Electrical\ Energy} \tag{8}$$

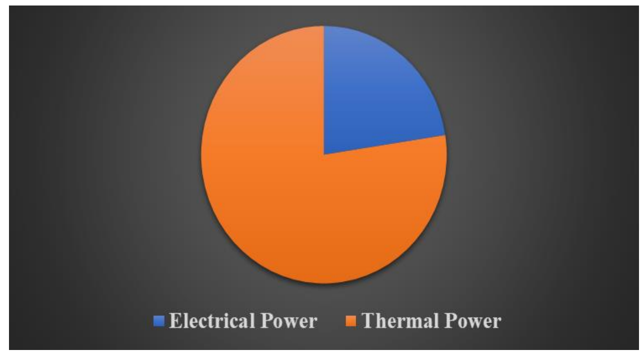

Fig. 13. Overall power gained from PVT air collector.

4. ECONOMIC ANALYSIS

Economic viability of PVT has been checked by taking a case study in consideration in which there is a low-grade heat requirement for crop drying around $40^o\ C$ which can be fulfilled either by electrical heater of 5 kW or by hybrid PVT air collector. They both are compared to check the economic advantages of PVT over electrical heater.

The cost required to run the heater with electricity is summarized in table 6. The cost of electricity considered for study is PKR. 19/kWh.

Table 4: PVT panel thermal data

Date	Feb 21	Mar 04	Mar 09	Jun 09	Jun 15	Jul 12	Jul 16	Jul 26	Aug 16
Irradiance W/m^2	841.00	781.00	967.00	1011.00	883.00	822.00	781.00	923.00	897.00
Environment Temperature	26.9 °C	26.1 °C	28.1 °C	37.2 °C	35.1 °C	34.2 °C	32.3 °C	35.9 °C	33.8 °C
Air Outlet temperature	39.9 °C	39.3 °C	40.5 °C	47.3 °C	46.2 °C	45.4 °C	43.6 °C	46.2 °C	45.3 °C
Air flow rate kg/s	0.0377	0.0378	0.0388	0.0373	0.0361	0.0375	0.0365	0.0370	0.0387
Heat Obtained	483 Watts	504 Watts	485 Watts	382 Watts	404 Watts	425 Watts	431 Watts	378 Watts	431 Watts
Thermal efficiency	57.3%	64.6%	50.2%	37.8%	45.8%	51.7%	55.1%	40.9%	48.1%

Table 5. Heat coefficient on experimental days

Dates	Heat (W)	Electricity (W)	COH
Feb 21	483	116.1	4.17
March 04	504	112.2	4.50
March 09	485	109.5	4.44
June 09	382	111.5	3.43
June 15	404	109.6	3.70
July 12	425	113.90	3.73
July 16	431	115.58	3.72
July 26	378	113.08	3.34
Aug 16	431	111.13	3.87

Table 6: Cost required running an electric heater

Rated power (kW)	5.0
Peak sun hours	5.40
Daily electricity consumption (kWh)	27.0
Yearly electricity consumption (kWh/year)	9,855
Running cost per annum (PKR)	177,390

Total number of PVT panels require to fulfill the heating demand can be determined by

$$Number\ of\ PVT\ panels\ = \frac{Heat\ required}{Heat\ available} \quad (9)$$

Since hybrid PVT is able to produce both electricity and heat from a single system so the total saving from PVT air collector includes the saving by not running an electric heater and also the cost generation due to electricity production.

$$Cost\ saved = Saving\ of\ cost\ by\ heating + Generation\ of\ cost\ by\ electricity\ production$$

So, to fulfil the required amount of heat, total 12 PVT modules will be required each having the rated electrical capacity of 150 watts. The maximum electrical energy obtained per year can be determined by

$$E_{elec} = P_{rated} \times \eta_{conversion} \times no. of\ hours\ in\ an\ year \quad (10)$$

It is evident from previous studies [17] that the conversion is around 75% which includes mismatch losses, dirt losses and inverter efficiency.

One will invest to install the PVT air collector, so the investor is more interested in determining the payback period of the investment. The payback time can be determined

$$Pay\ back = \frac{Capital\ required}{Cost\ saved\ per\ annum} \quad (11)$$

5. CONCLUSION

To determine the electrical efficiency of both PV and PVT panel, experiments have been performed on different days and then comparison is made. Two panels were considered for study. One is transformed into PVT air collector by installing the air duct at the back side of the panel. Air is forced into the duct which ultimately decreases the panel temperature and results in increase in electrical efficiency. The experiments were conducted on different days. It was found that PVT panel is more electrically efficient than the simple PV. The maximum electrical efficiency of the PVT was found to be 14.8% while on that day the electrical efficiency of PV was 14.4% making the PVT more electrically efficient while the maximum thermal efficiency was found to be 64.6%. The economic aspects of the PVT are tested by considering a case study in which PVT is compared with electric heater to fulfill the heating requirement of crop drying. It was found that the saving from PVT is more than the electric heater as it is not only fulfilling the heating demand but is also capable to produce electricity. The investment to install PVT is very little and the investment will return in just 8 months making the system to be technically as well as economically sound. The PVT collector can be made more efficient by doing exergy analysis of the equipment by including the water as cooling fluid equipped with nano particles.

NOMENCLATURE

η_{elec}	Electrical Efficiency
P_{rated}	Maximum Rated Power (W)
η_t	Total Efficiency
T_{amb}	Ambient Temperature $(.^{O}C)$
η_{therm}	Thermal Efficiency
$T_{solar\ cell}$	Cell Temperature $(.^{O}C)$
A	Area of the Collector (m^2)
T_{inlet}	Air Inlet Temperature $(.^{O}C)$
COH	$Heat\ Coefficient$
T_{outlet}	Air Outlet tempertaure $(.^{O}C)$
C	Specific Heat at Constant Pressure (KJ/kgK)
V	Voltage (V)
C_T	Temperature Coefficient $(\%/^{o}C)$
V_m	Voltage at Maximum Powere point (V)
E_{elec}	Electical Energy (KWh)
V_{oc}	Open Circuit Voltage (V)
E_{th}	Thermal Energy (KWh)
G	Incoming Solar Flux (W/m^2)
I	Current (A)
I_m	Current at Maximum Powere point (A)
I_{SC}	Short Circuit Current (A)
m	Mass Flow Rate of air (kg/s)

$NOCT$ Nominal Operating Cell Temperature ($.^{O}\,C$)

P Instantenous Power (W)

$P_{T,dc}$ Temperature Adjusted Power (W)

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