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ENHANCING THE PERFORMANCE PHOTOVOLTAIC / THERMAL AIR FLAT PLATE USING LONGITUDINAL FINS INSIDE DUCT

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Concurrent approach of PV and PV/T devices are considered to observe the performance enhancement of Photovoltaic panel in real time environment. An array of PV panel that produces only electrical energy and an array of PV panel that produces both electrical and thermal energies using air for removing heat have been fabricated to facilitate the study parallelly. Duct that bottoms one array of panels have longitudinal fins , called metal plates fitted to effect the heat transfer rate results in simultaneous increase in thermal and electrical efficiency. Thermal and electrical parameters under different mass flow rates and climatic conditions are automatically logged in using Arduino micro controller along with necessary sensors.

1. INTRODUCTION

Solar energy is considered to be one of the green energies that plays an important role in reducing green house gases thereby reducing carbon footprint as it's main output is electrical energy from incidence of sun's light energy. To make it more greener thermal energy from Solar energy are being tapped. To make cost effective, combined production of electrical and thermal energy is possible by circulating air or water, as heat removing fluid around the panel. By doing so, the performance and lifetime of PV Panels can be undoubtedly increased. More and more theoretical,numerical,and experimental studies are undertaken in this area.. Othman et al.[1] observed 30% efficiency increase compared to other PV/T Collector by using V-groove shape placed underneath PV Panels.Jin et al.[2] attempted by fixing rectangle tunnel underneath the photovoltaic panel that results in combined PV/T efficiency of 64.72% and thermal efficiency of 54 %. Moshfegh.B et al [3]established that 30% of heat flux is transferred to the unheated wall of the duct from the PV Panel by radiation..

Mohamed Shedin at el [4] reported that including additional absorber section at top half of middle part of solar chimney results in improvement of PV Panel performance and induced natural draft. A.Q.Jakhrani et al [5] developed empirical models that gives more precise prediction of PV Module temperature during fluctuated operating conditions. Ghani et al.[6] discussed the effect of non-uniform flow distribution on thermal and electrical performance of solar system by considering PV/T Collector of various design, geometric shape and operating characteristics. Tiwari at el[7] established the glazed hybrid PV/T without tedlar gives the best performance compared to all configurations being evaluated. K.T.Patil at el[8] observed that maximum irradiance is possible by direct, tilt at 36 ^{o} C and optimum tilt angle radiation;

minimum module temperature is possible with diffuse and optimum tilt angle radiations and maximum heat extraction is possible with direct and optimum tilt angle radiations; finally stated maximum electrical efficiency is possible with diffuse, tilt at 90^o and optimum tilt angle radiations.

AA.Hegazy[9] observed performance of air- based PV/T systems using four different modes of air flow. Tonui et al.[10] used air channel and found optimum point for channel depth and mass flow rate afterwhich the PV/T behavior is reversed. Sarhaddi at el.[11] claimed that increase in inlet air temperature or wind speed or duct length decreases the overall energy efficiency and thermal efficiency of PV/T air collector. They also identified optimum value for solar insolation. Shahsarar et al[12] used a thin aluminium sheet suspended at middle of air channel for increasing heat transfer surface and optimized required no. of fans for maximum electrical efficiency. Sopian at el.[13] developed a modelfor comparing single pass and double pass PV/T collectors and confirmed that double pass model has higher efficiency that single pass one..R.Kumar.M.A. et al.[14] modified double pass PV/T system by adding fins and noted solar cell temperature drops from 82 ^{o} C to 66^o C.F.Hussain at el[15] developed PV/T system with honeycomb like structure located inside the channel and observed 60 % thermal efficiency increase and 0.1 % electrical efficiency increase.Amin ElSafi et al.[16] evaluate the steady- state performance of a double – pass flat plate hybrid PV/T Solar heater with vertical fins of different configurations and showed that rectangular fins are better that triangular and parabolic fins.

Mokalla. Srinivas at el.[17]used slats longitudinally at 100 mm interval fixed at the bottom side of absorber plate and proved that loss in electrical energy output is compensated by thermal gain of the system. Ahmad Rivai* et al [18]presented The hardware and software design of a low-cost photovoltaic (PV) monitoring system.

In this paper, three metallic longitudinal fins, called plates fitted to remove heat. This system is an innovative combination of producing thermal energy as well as electrical energy and cost effective data logging method. By using the longitudinal fins, the heat conglomerated in different layers below the panel and inside the duct is absorbed by the plate and removed by air thereby reducing PV panel temperature and hence both thermal and electrical performance is increased. Earlier, we used duct without longitudinal fins to assess both the thermal and electrical performance during summer. In order to increase both thermal and electrical performance, we reduced the duct size, monitored the readings, and then used longitudinal fins inside the duct.

2. COMBINED PV,PV/T AND PERFORMANCE MONITORING SYSTEM DESIGN

The module used in this experiment have 2 sets of flat PV solar panels (mono crystalline type)each consisting of 5 W p Panels(10 Nos.) totaling 50W p connected in parallel. One set of panel referred as Panel With Out Cooling while other set refers to With Cooling (ie .PV/T Air System).With cooling Panels Duct No.1 made of GI Sheet fitted underneath measuring 2000mm X 180mm X 180mm as shown in fig.1. After that the same has been replaced with Duct No.2 of size 2000mm X 156mm X 156mm.

In the next stage, inside the duct 3 nos. plates made of GI Sheet are fitted in longitudinal direction at 39 mm interval .Outside of the duct is fully insulated using 19mm thick thermocol. Also inside bottom of the duct is completely insulated with 38mmthick thermocol. To keep the longitudinal fins always perpendicular inside the duct, three studs with nuts fitted at equidistance along the fin’s length, that will snugly fit inside the vertical walls of the duct. A suction draught DC Fan driven by Potentiometer for getting various speeds fixed at top edge of the duct powered by separate solar Panel (50 W) produces different mass flow rates , thereby air is made to pass underneath the flat solar PV Panels.

Separate low cost performance monitoring and logging in system developed that automatically receives information from different sensors. The sensors that measures panel temperature of both PV and PVT Panels have them affixed underneath the solar flat panels at 270,645,1000,1560,1740 mm from lower end of the duct. There are two numbers Variable Rheostats(0-28Ω) connected to loads of both sets of panel. The sliders of the Rheostat are moved by 12V DC Heavy Duty Motor driven Screw Rod arrangement. The motor is controlled by Motor Driver circuit which is monitored by Microcontroller

Table 1 SPECIFICATIONS OF SOLAR AIR DUCT WITH LONGITUDINAL FINS

Description of component	Specification
Case I :Duct No.1 : GI Sheet Case II :Duct No.2 : GI Sheet	1980mm X 180mm X 180mm,Thickmness 1mm 1980mm X 156mm X 156mm,Thickmness 1mm
Case III :Duct No.2 with Longitudinal fins :GI Sheet	1980mm length,1mm thickness, mm height 102 mm
2 sets of 10 Nos. Solar Panels	Each panel 5Wp
Total Length of all PV Module	1850mm
Width of PV Module	180mm

Specifications of PVT Monitoring and Logging in System

Description of component	Details
Microcontroller	Arduino MEGA 2560
Motor Driver	Cytron MD 10 C
Current Sensor	ACS 712-05B
Voltage Sensor	Simple Voltage Divider Network
Temperature Sensor	LM 35
Variable Rheostat	0-28Ω

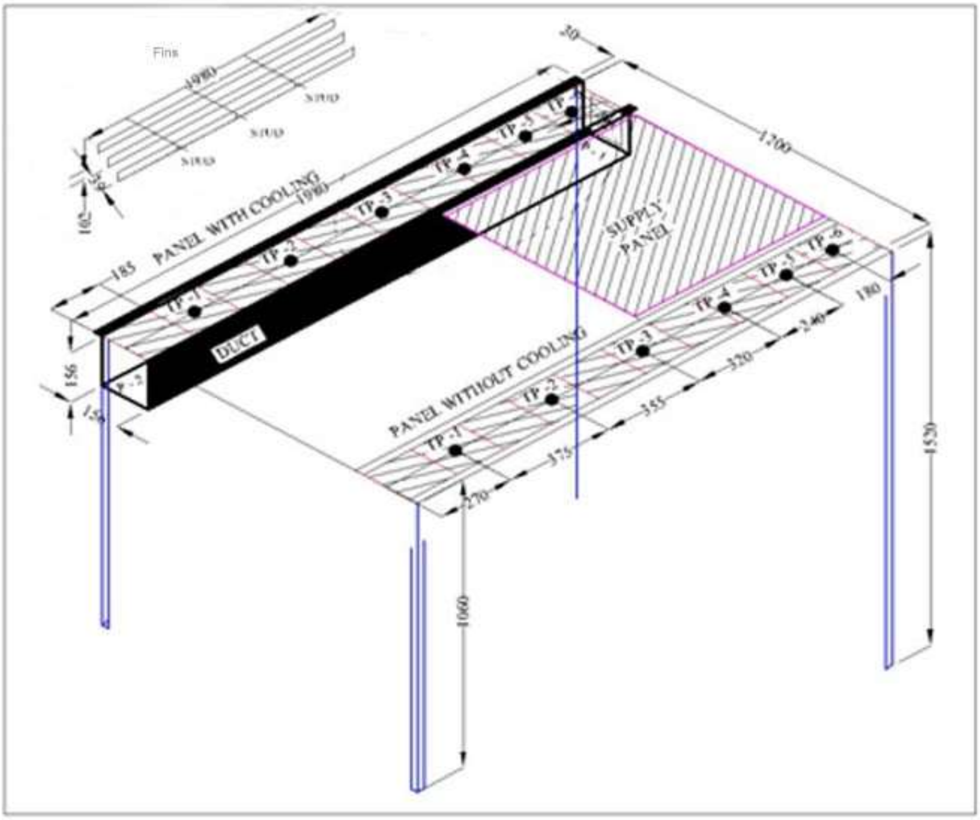
MEASUREMENTS

The following parameters were measured during experimentation.

1. Panel Temperature from six different points of both sets of panels
2. Inlet and outlet Temperature of air
3. Inlet and outlet velocity of air
4. Voltage and current from set of panels corresponds to without cooling
5. Voltage and current from set of panels corresponds to with cooling

3. EXPERIMENTAL SETUP

PV Panels of mono crystalline type silicon solar panels are kept in line over a frame at 23^o facing south and are connected in parallel to get more current output, referred as Without Cooling panel. A similar setup,



referred as With Cooling panel kept and bottomed by duct in first stage ,then with three nos. longitudinal fins inserted into it in second stages of experiment.

Figure 1. Experimental Lay out

Figure 2. Experimental Set up

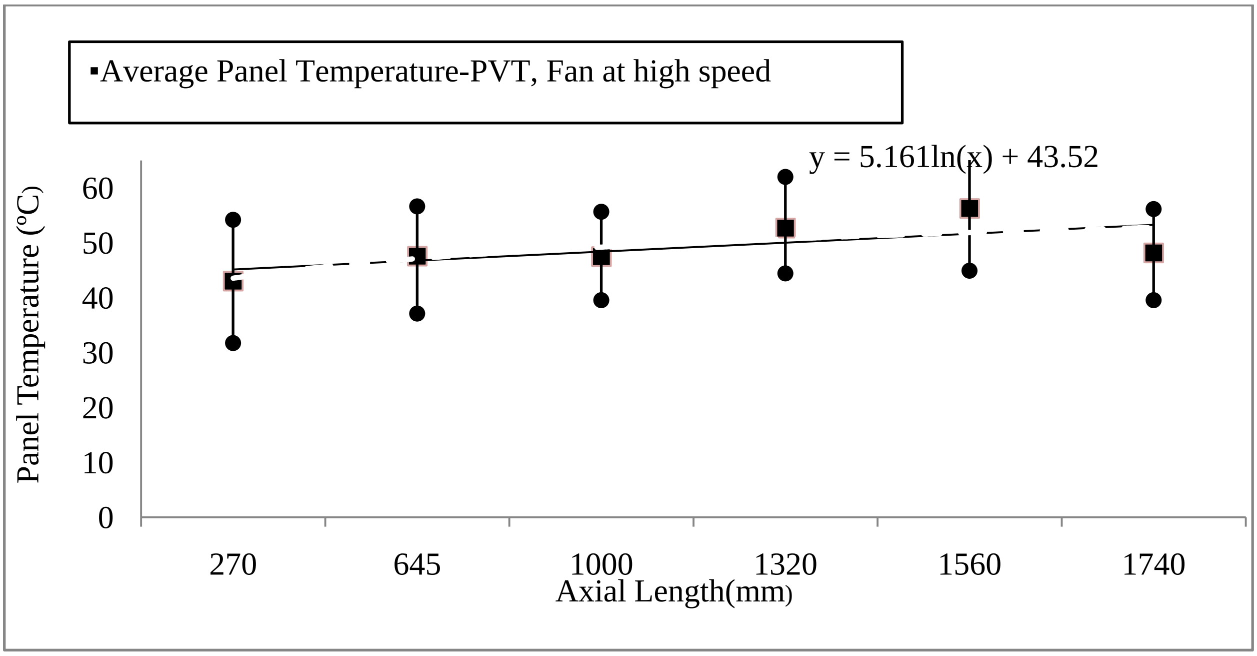
A variable speed DC fan fitted at the top end of duct used to vary mass flow rate. In between both sets of panels another 50Wp solar panel referred as Power Supply Panel that caters power requirement of variable speed DC fan. Air is made to pass below the panels through the longitudinal fins fitted inside the duct takes away the heat from the solar panels created by insolation, thereby reducing panel temperature. The longitudinal fins attached to the duct that create the turbulence, taking the heat from the solar panel by convection and conduction and transfer the same to the working fluid. Thus the very purpose having the longitudinal fins inside the duct is achieved. The whole setup is open to sky without any obstruction to avoid any shading effect which will reduce solar insolation as shown in fig.2

4. EXPERIMENTAL PROCEDURE

To assess the thermal and electrical characteristics, both PV and PVT system tested concurrently at real time environment conditions. The readings are recorded automatically by performance monitoring system at every half an hour interval for different load settings starting from two hours before and ending two hours after solar noon. The Screw Rod connected to the sliders of both the Rheostats that acts as load for both sets of panels provides different load settings namely 10%,35%,60%,85% of full load. At various load settings sufficient time is given to obtain stable readings for error free measurements. The panel temperatures of both sets of panels, air inlet and outlet temperatures current and volt are recorded automatically while mass flow rates is measured by anemometer. During different climatic conditions at different mass flow rates at 0.232 m/s(high speed),0.215m/s(medium speed),0.181m/s(low speed) and throughout the year, system's performance monitored. In this paper from May 2016 to December 2017 with two different sizes of duct fitted , the data collected and subsequently logged in the system.

5. RESULTS AND DISCUSSION

The temperature at different points on the panel along the axial length collected for both panels and assessed as given below in the figure3.It is observed that with fan rotating at high speed sucking air through duct No.1, during some days of May and June 2016, it is possible to obtain axial temperature distribution $y = 5.161\ln(x) + 43.52$ for PVT system and $y = 5.160\ln(x) + 48.91$ for PV system as shown in Fig 3. With Duct No.2. Readings taken during January 2017 to June 2017 with same testing conditions as stated above. Figure 4 shows axial temperature distribution of $y = 0.089x + 47.45$ for PVT System and $y = 0.136x + 52.53$ for PV system.



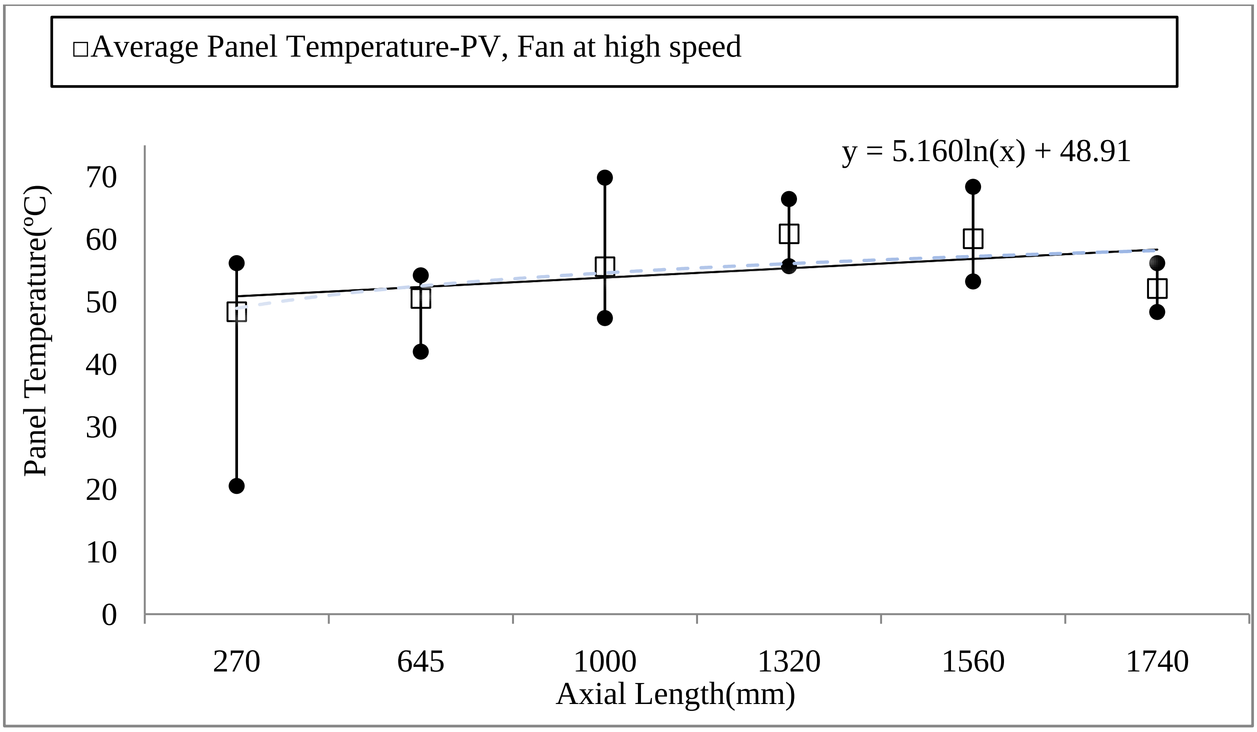
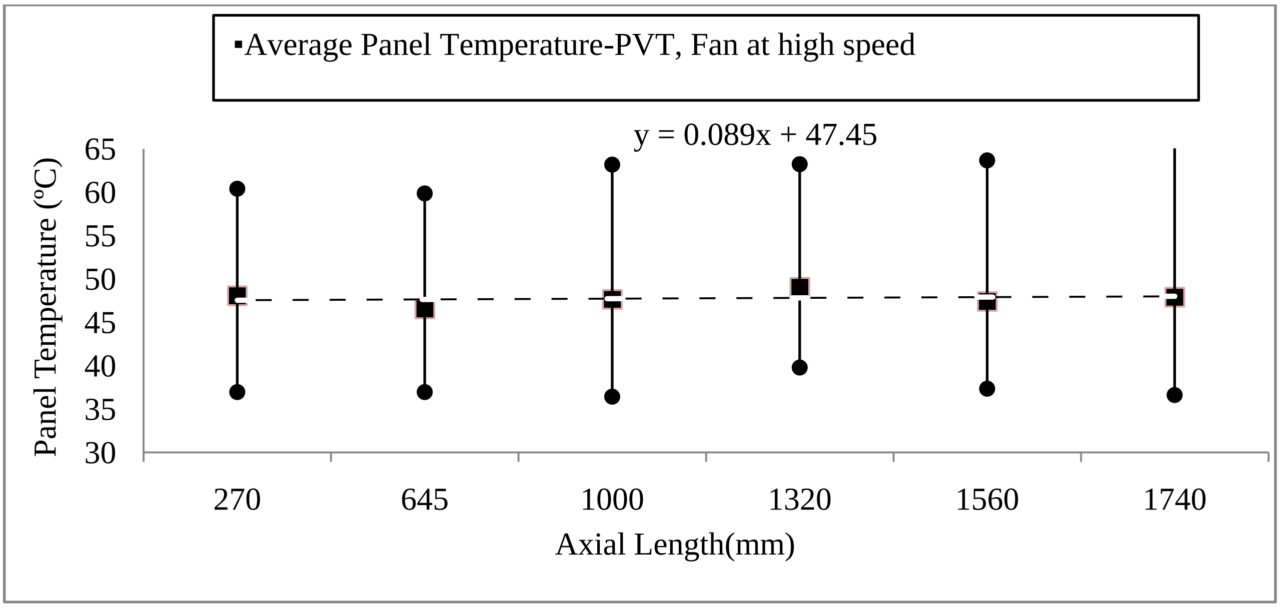


Figure 3. Measurement of Temperature of photovoltaic panels of PV and PVT air systems along the axial length when Fan rotates at high speed with Duct No.1



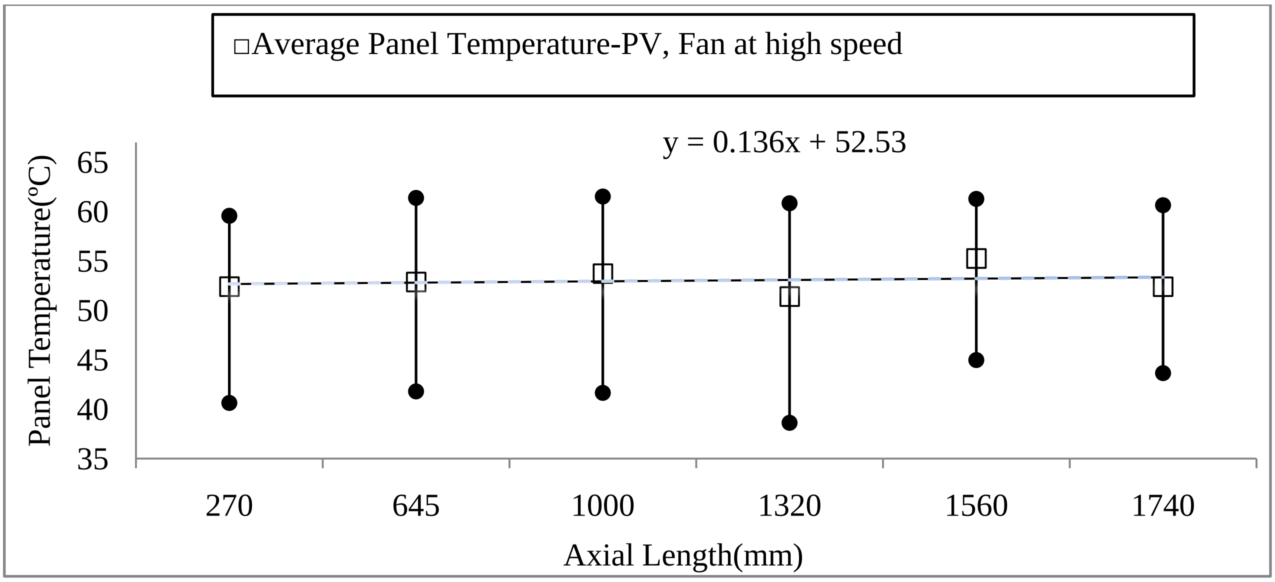
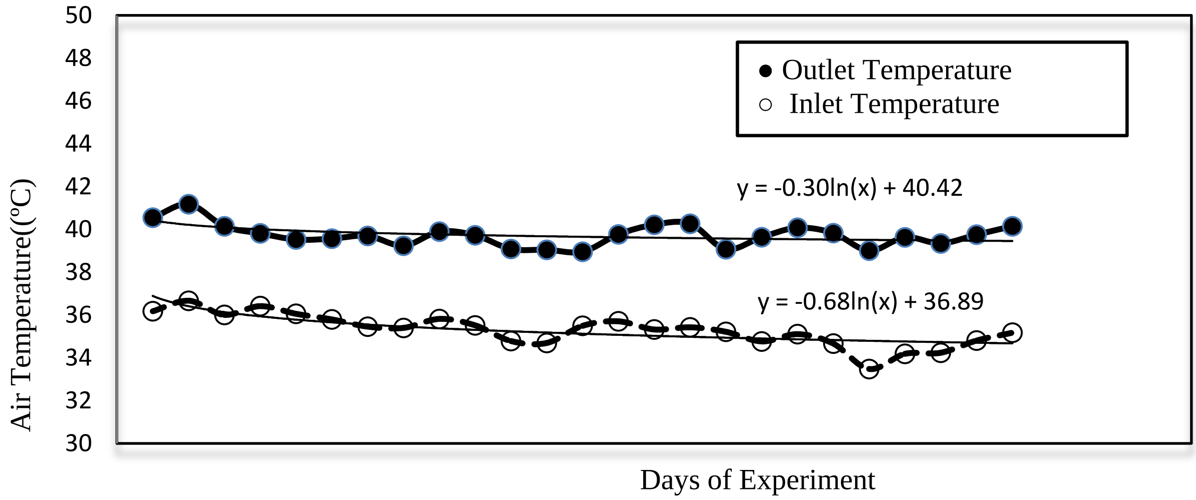


Figure 4. Measurement of Temperature of photovoltaic panels of PV and PVT air systems along the axial length when Fan rotates at high speed with Duct No.2.

Figure 5 shows the difference between inlet and outlet temperature of air through the duct No.1 stays around 3°C ,whereas for Duct No.2 it is around 2.5 °C.



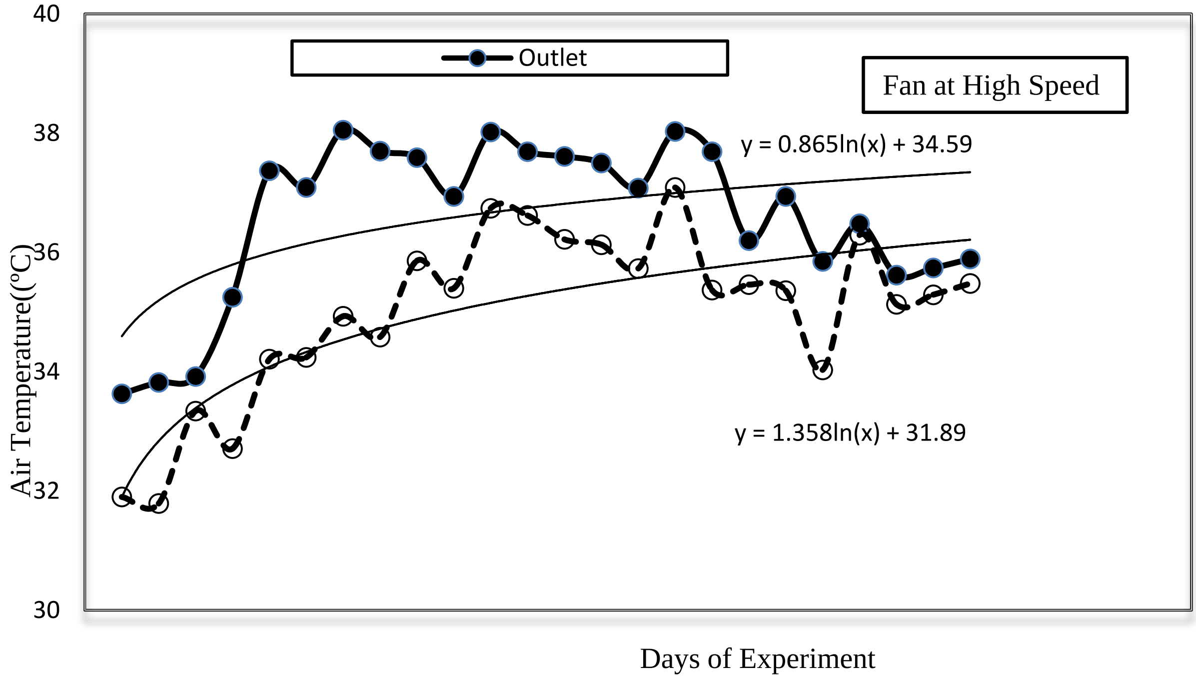


Figure 5 Difference in inlet and outlet temperature of air through Duct No. 1 and Duct No. 2

In order to obtain better heat transfer, wider temperature difference between inlet and outlet of the duct and better I-V Characteristics, we inserted Longitudinal fins inside the duct and results are discussed.

As shown in figure 6-8, the panel temperatures at different points along the axial length are measured for both sets of panels at different mass flow rates. When Suction Draught Fan sucks air at high speed through the duct as given in figure 6, the maximum panel temperature as in figure, for PV and PVT System are 59ºC and 48ºC respectively, while average panel temperature stays around 42ºC for PV System and 33ºC for PVT System. In addition to this, it can be noticed that axial temperature distribution has a positive coefficient

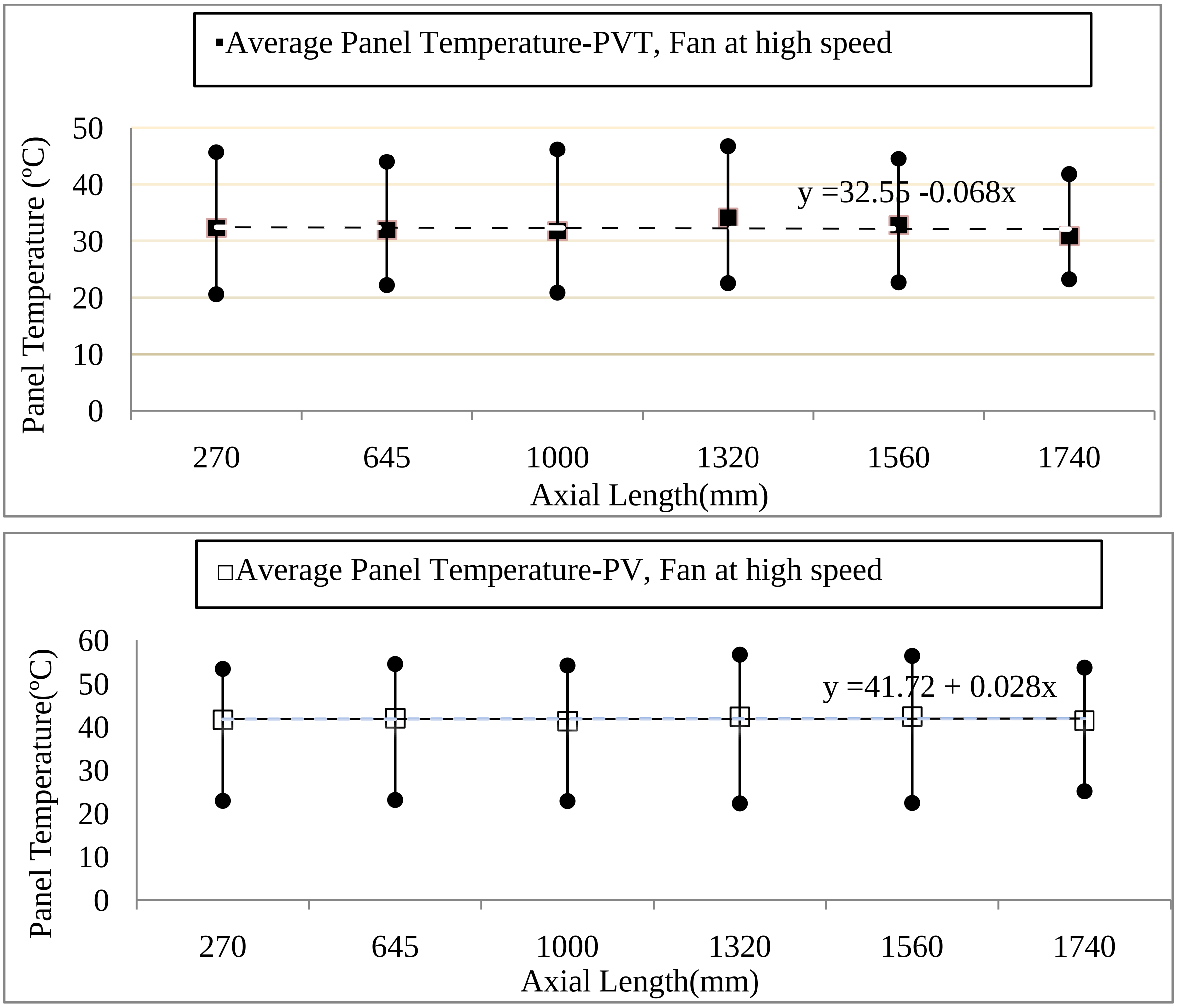


Figure 6.Measurement of Temperature of photovoltaic panels of PV and PVT air systems with monitoring system along the axial length when Fan rotates at high speed

Of axial distance (T_p = 41.72 +.028 x) for PV system, whereas the same is negative coefficient of axial distance(T_p = 32.55 -0.068 x) for PVT air system.

When we keep Fan at Medium Speed as given in figure 7, as Suction Draught Fan removes air at medium speed through the duct, the maximum panel temperature as in figure, for PV and PVT System are 55ºC and 45ºC respectively, while average panel temperature stays around 41ºC for PV System and 33ºC for PVT System. It can also be noticed that axial temperature distribution has a positive coefficient Of axial distance (T_p = 40.98 +0.046 x) for PV system, whereas the same is negative coefficient of axial distance(T_p = 32.88 -0.087 x) for PVT air system.

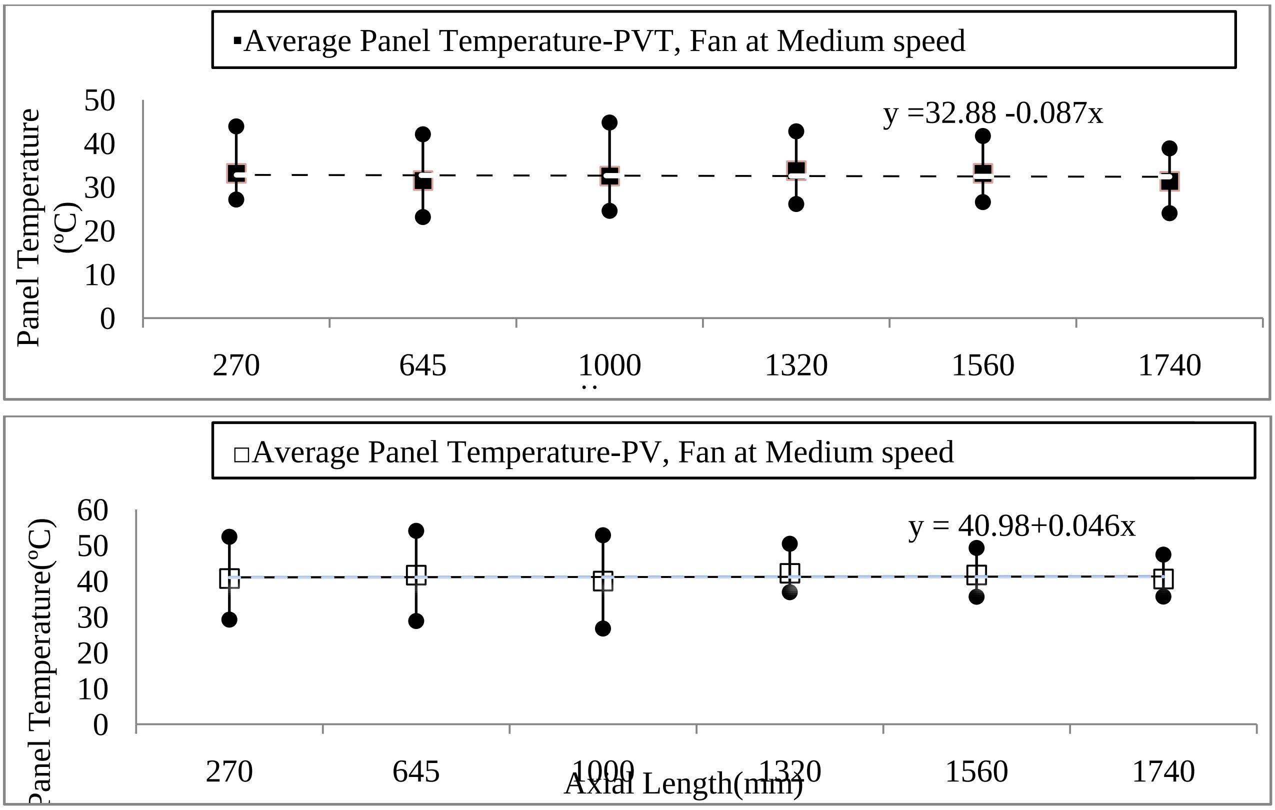
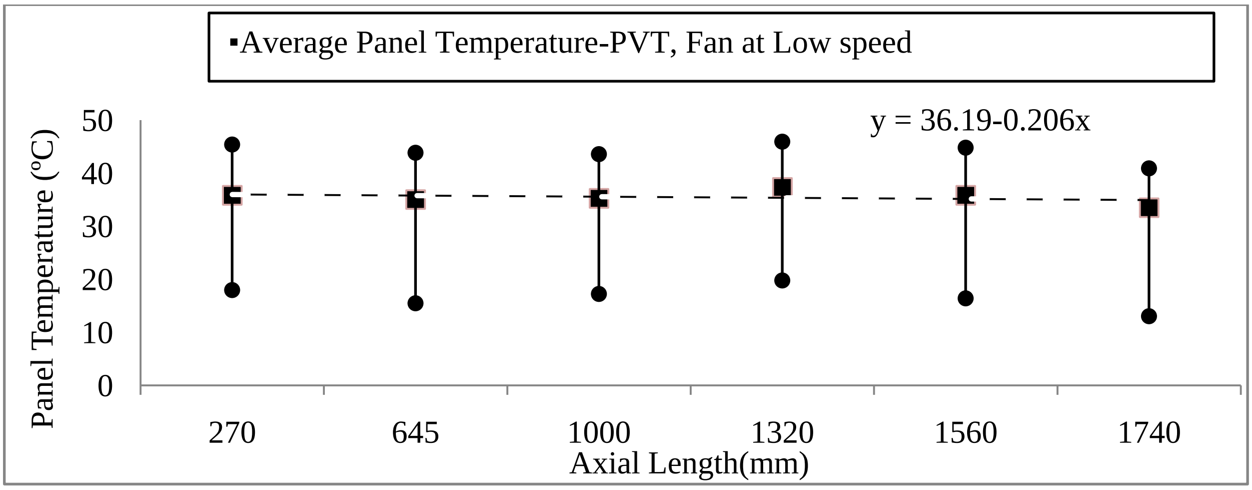


Figure 7. Measurement of Temperature of photovoltaic panels of PV and PVT air systems with monitoring system along the axial length when Fan rotates at medium speed

When we consider fan at Low Speed as given in figure 8, as Suction Draught Fan takes air at low speed through the duct, the maximum panel temperature as in figure, for PV and PVT System are 68ºC and 48ºC respectively, while average panel temperature hovers around 46ºC for PV System and 36 ºC for PVT System. Added to this, it can be noticed that axial temperature distribution has a positive coefficient Of axial distance (T_p = 45.73 +0.012 x) for PV system, whereas the same is negative coefficient of axial distance(T_p = 36.19 -0.206 x) for PVT air system.



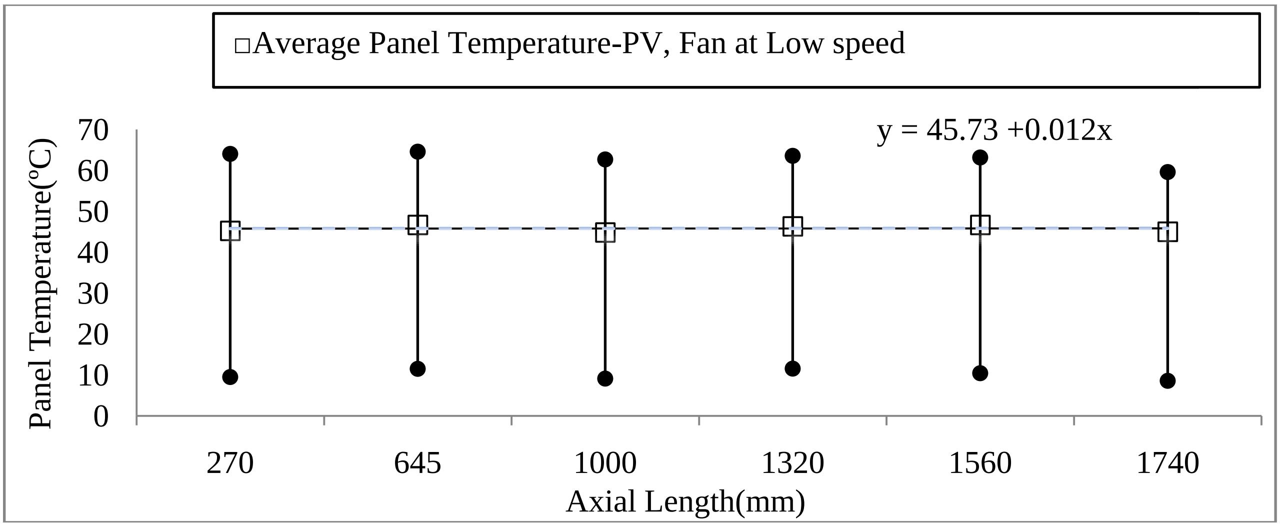


Fig 8. Measurement of Temperature of photovoltaic panels of PV and PVT air systems with monitoring system along the axial length when Fan rotates at low speed

Figure 9 shows good temperature difference between inlet and outlet of the duct exists in the order of 7°C when fan speed is maintained medium compared to other speeds . This may be due to the fact that the resident heat in the Plates, cannot be removed when air speed is high.

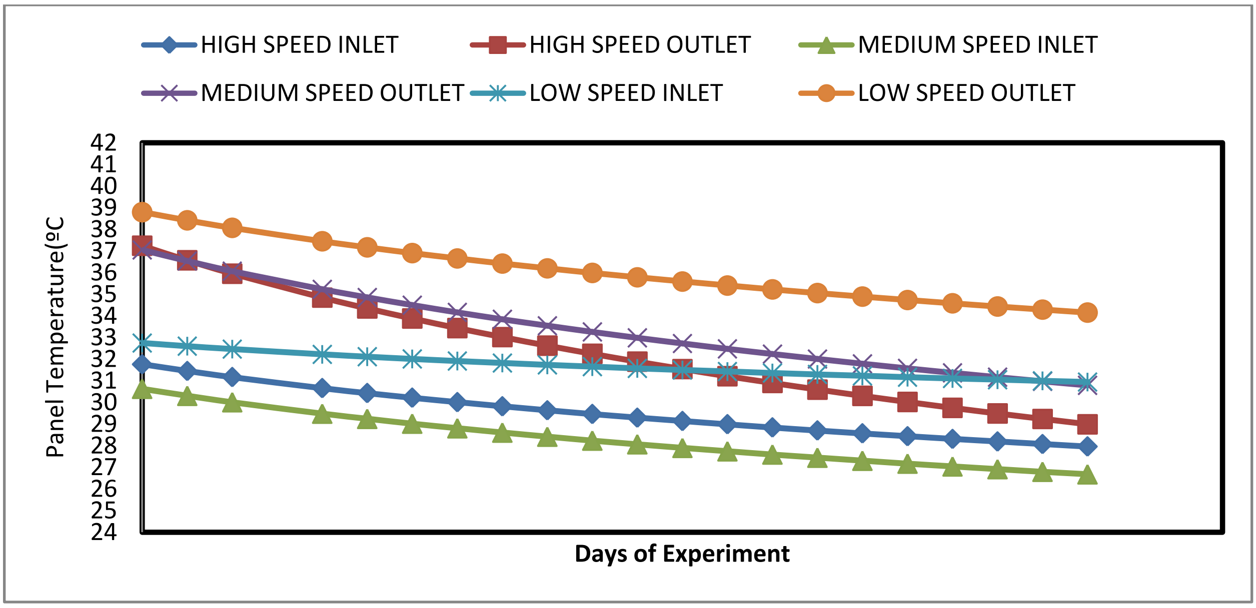


Figure 9. Inlet and Outlet Temperature of air in PVT system at different mass flow rates

The heat absorbed by air in PVT air system is calculated using $Q = m\ c_p\ (T_{out} - T_{in})$, where $m=\rho AV$ denotes mass flow rate, c_p is the specific heat capacity of air at constant pressure, T_{out} is the outlet air temperature and T_{in} is the inlet air temperature.

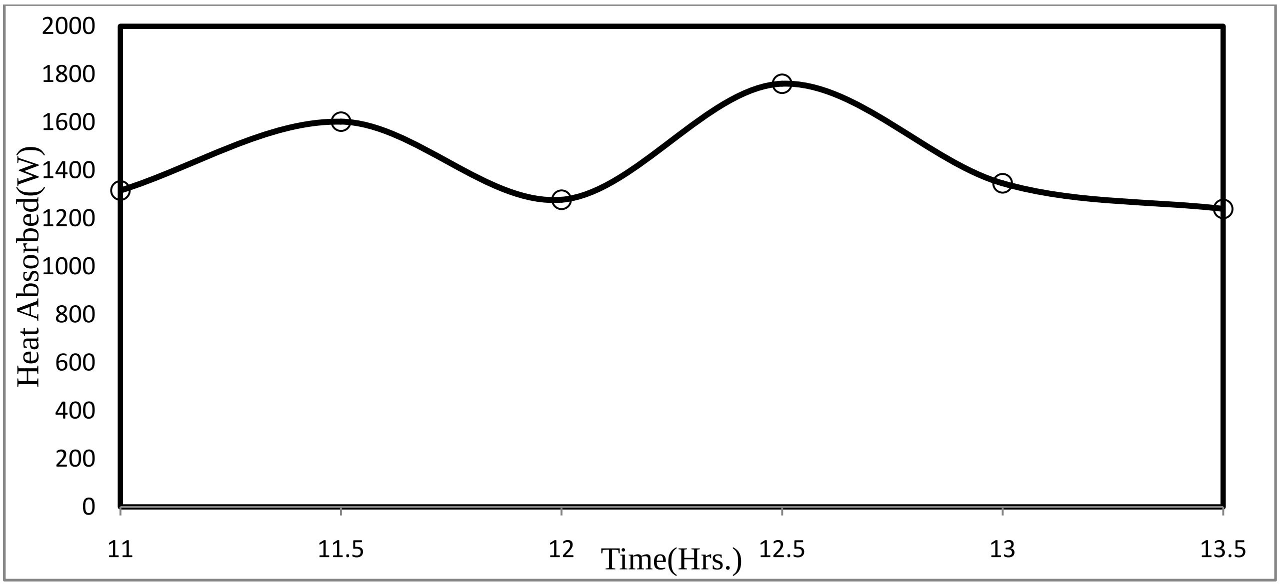


Figure 10. Heat Absorbed through Duct No.1

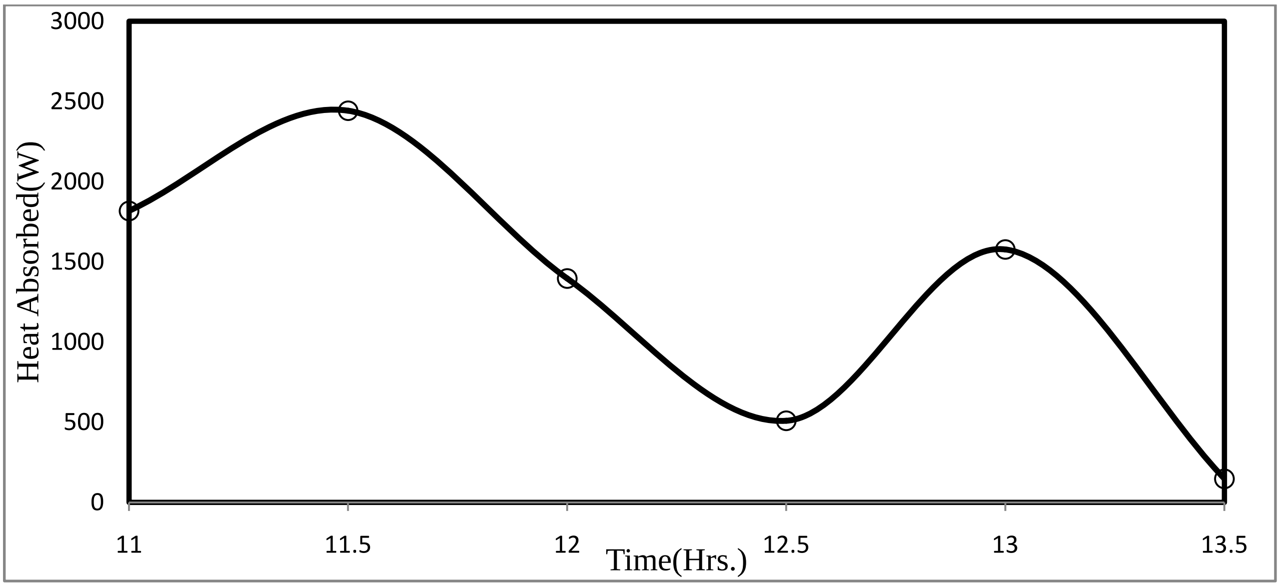


Figure 11. Heat Absorbed through Duct No.2

The figure 12-14 shows heat absorbed at different mass flow rates.

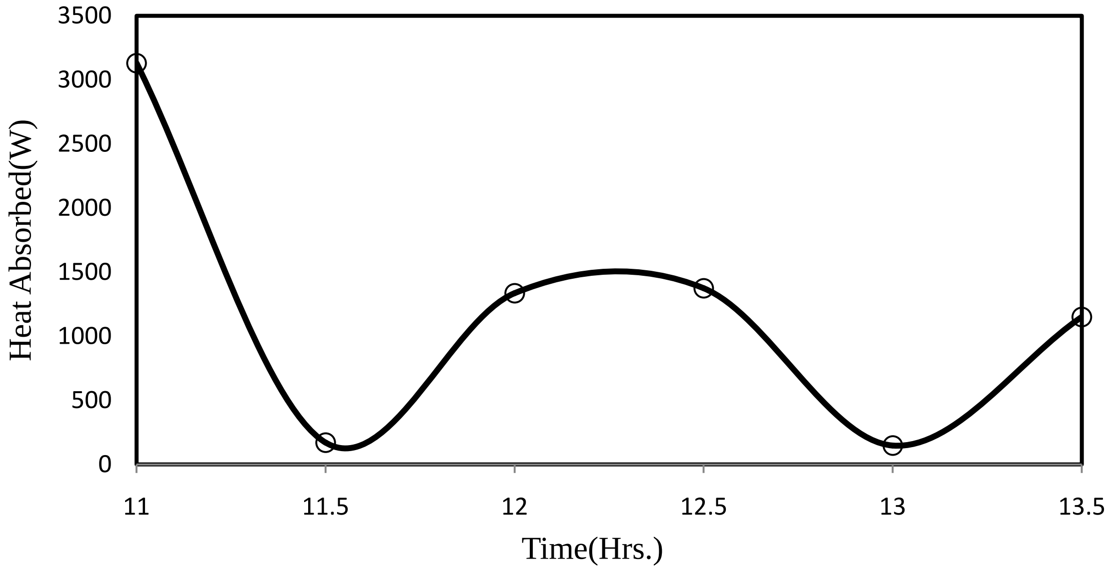


Figure 12. Heat absorbed by air in PVT Air system when fan rotates at High Speed

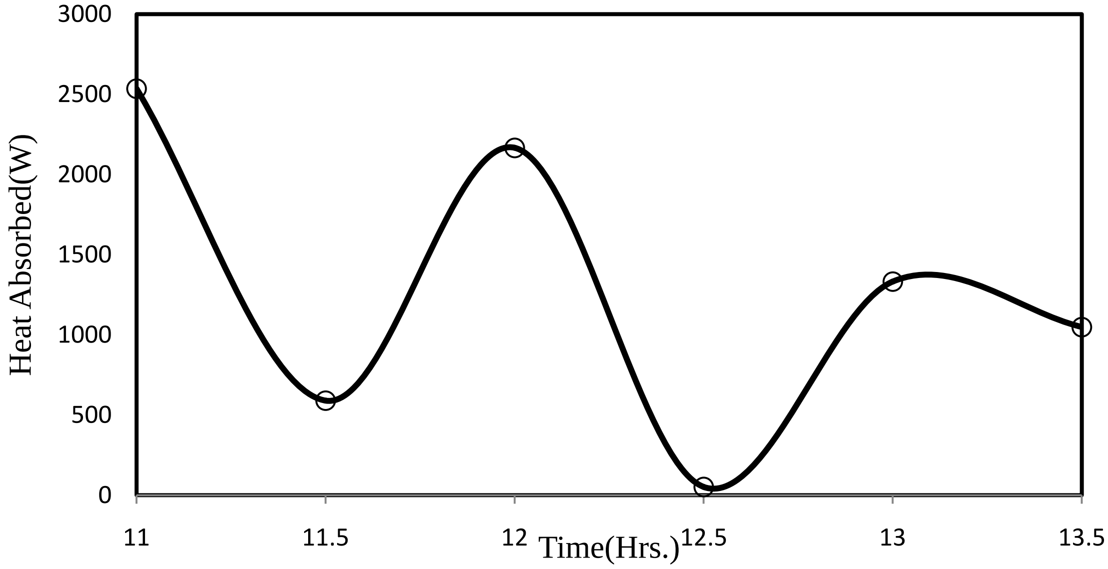


Figure 13. Heat absorbed by air in PVT Air system when fan rotates at Medium Speed

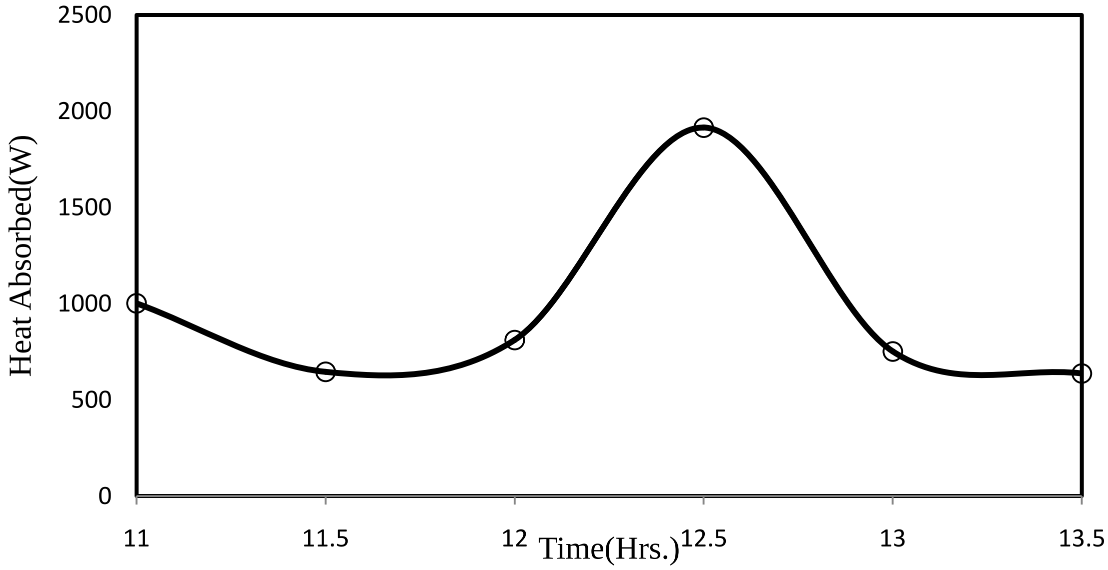
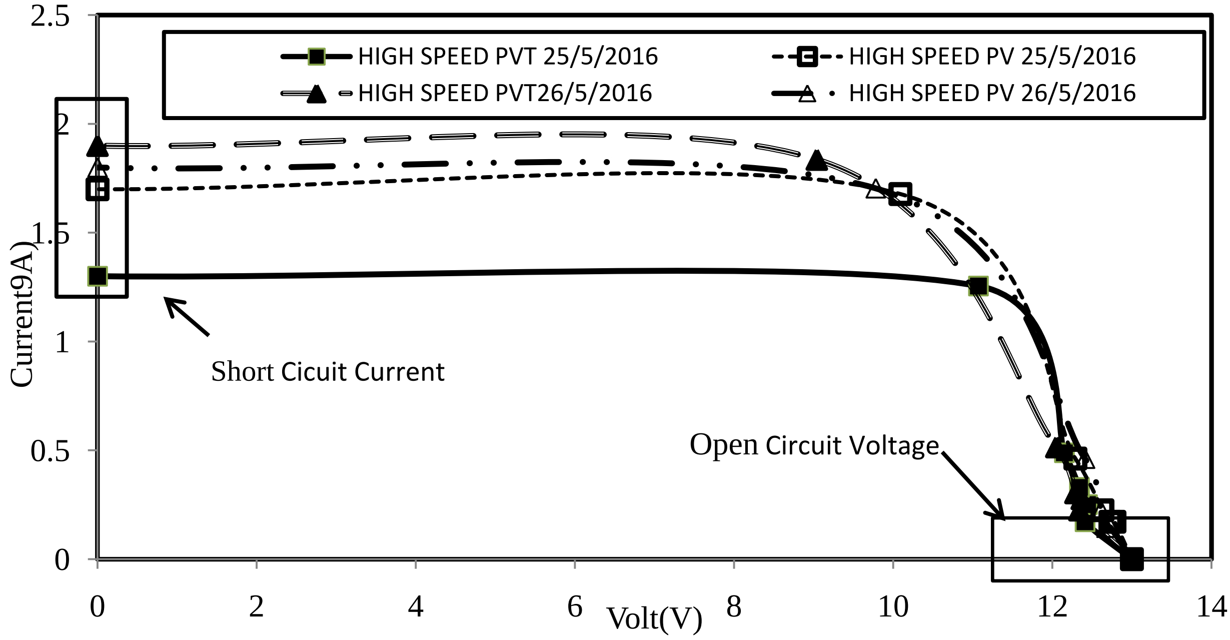


Figure 14. Heat absorbed by air in PVT Air system when fan rotates at Low Speed

The heat absorbed by air in PVT air system during a solar noon on 28/11/2017 when fan rotates at high speed, on 01/12/2017 with fan rotating at medium speed and on 05/12/2017 with fan rotating at low speed have been shown in Figure12,13,14 respectively. At the maximum 3100 W can be extracted while fan rotated at high speed, and 2500 W was possible when fan rotated at medium speed, whereas 2000 W when fan rotated at low speed. This is because good reduction in panel temperature at high mass flow rates causes increase in heat transfer. In all the cases, the sudden change in environment conditions, heat absorbed by air in PVT air system changes significantly. And it is clear that this heat can be used for residential, agricultural drying purposes.

ELECTRICAL CHARACTERISTICS



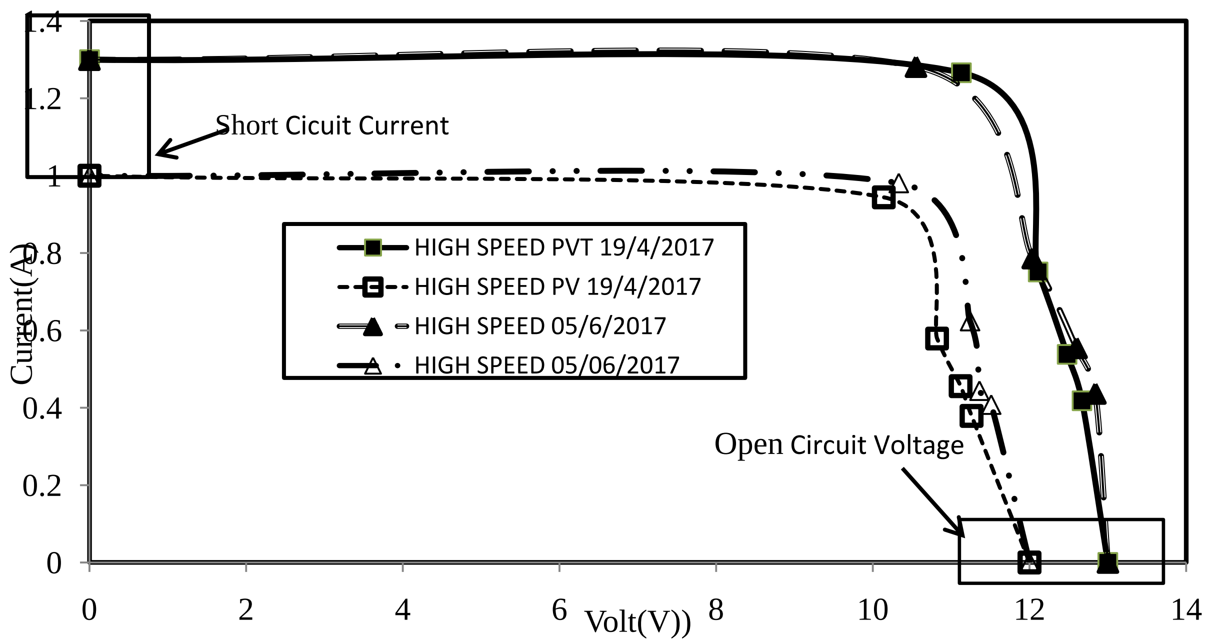
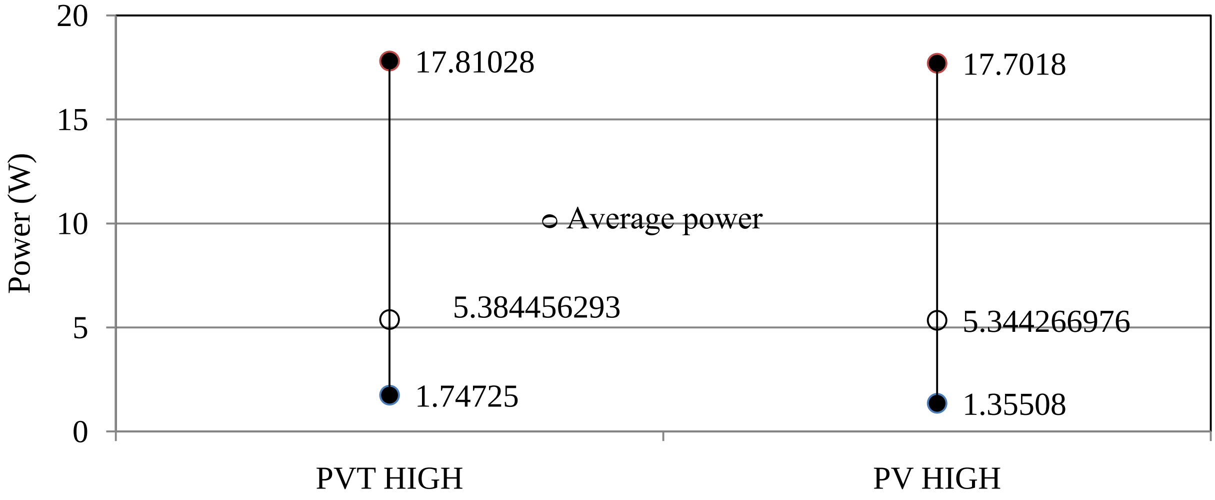


Figure 15. I-V Characteristics for Duct No.1 and Duct No.2



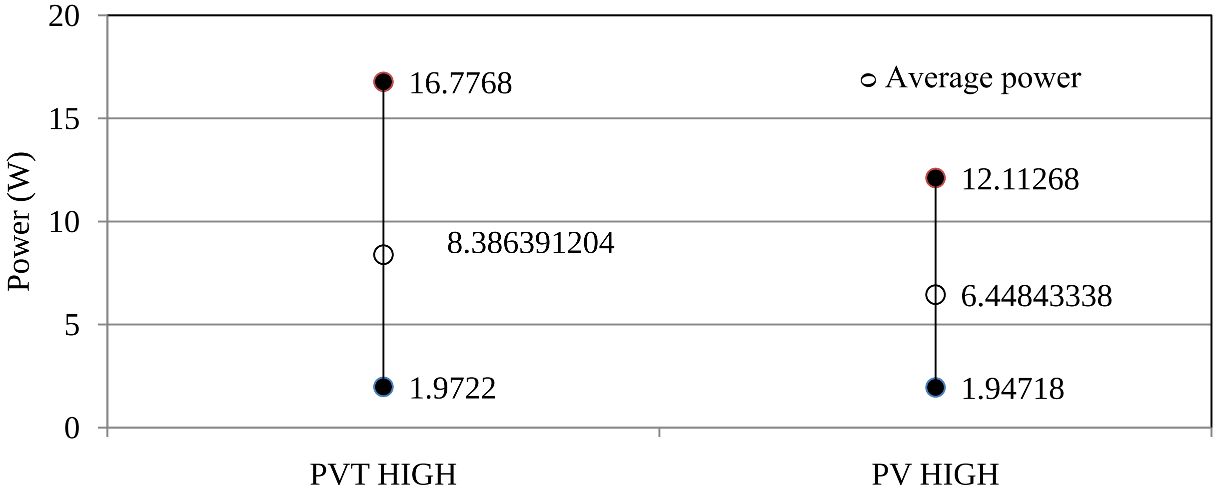


Figure 16. Power obtained with duct No.1(May and June 2016) and Duct No.2(March to June 2017)

In terms of power output, Duct No.1 does not provide any marginal increase in power produced by PVT Panel compared to PV Panel, while Duct No.2 gives 30% to 38% increase in power.

The experiments have been conducted and readings were taken on different days starting from June 2017 to December 2017 under various climatic conditions and under different mass flow rates. The electrical power developed at 11.00 am in a 4 minute interval at different dates and at various mass flow rates are shown in figure. Measurements that have been shown were for four different load settings, say 10%,35%,60%,85% of full load. 85 seconds are the duration maintained between load settings. It is observed that when fan at high speed maximum power output was 15.3 W for PVT air system while for PV system it was 12.5W and average power developed for PVT air system it was 6.2 W and for PV system it was 4.6 W as given in Figure 18. While fan rotates at medium speed(figure 19), power for PVT air system stood at 14.17 W maximum and for PV system 11.74W, whereas average power for PVT air system 6.78 W and PV system 5 W. While fan rotates at low speed, maximum power produced were 15.69 W and 14.63 W for PVT air system and PV system respectively and average power developed were 7 W and 5.2 W for PVT air system and PV system respectively. This is due to the fact that with high mass flow rates of air, optimum kinetic energy of electrons are maintained, consequent to reduction in panel temperature. This results in good power production with high mass flow rates of air. When mass flow rates are reduced, the total volume of air that can carry away heat is also reduced, leading to increase in panel temperature and reduction in electrical power yield and heat absorption,

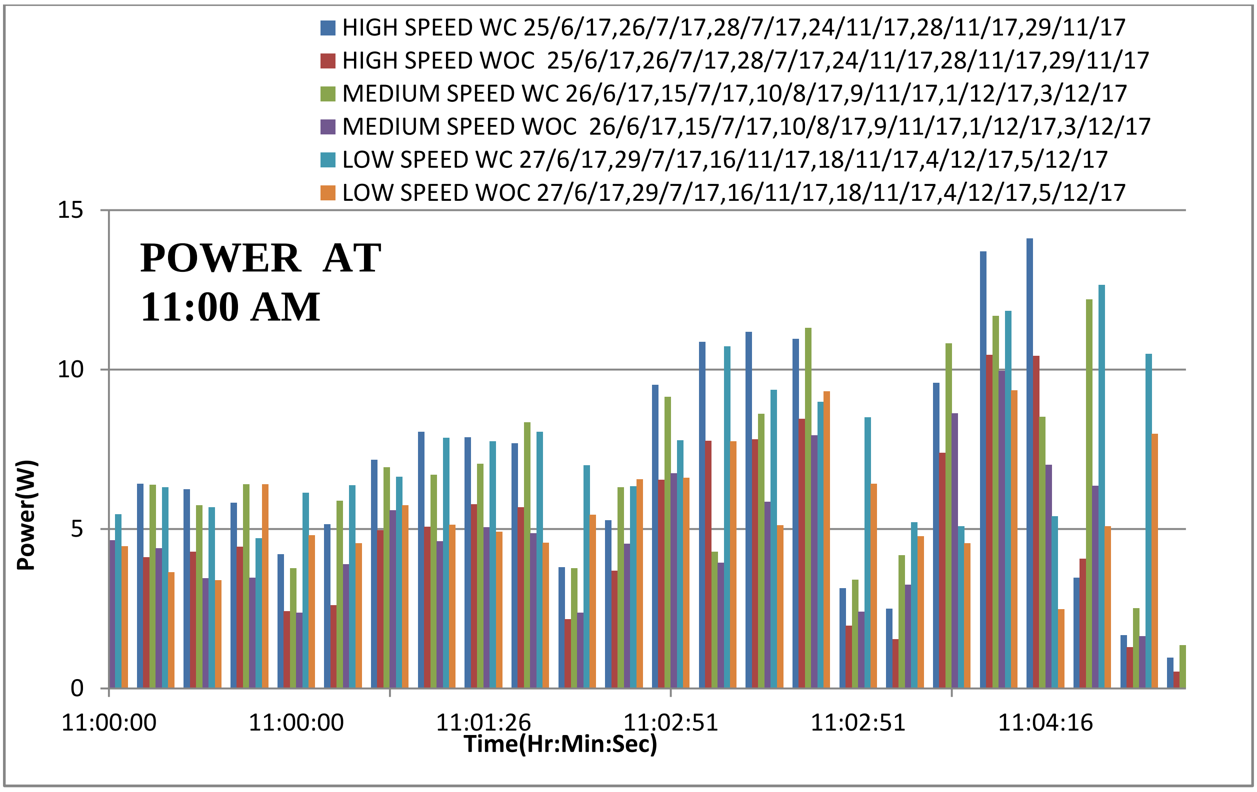


Figure 17. Electrical power output obtained with PV and PVT air system at different mass flow rates

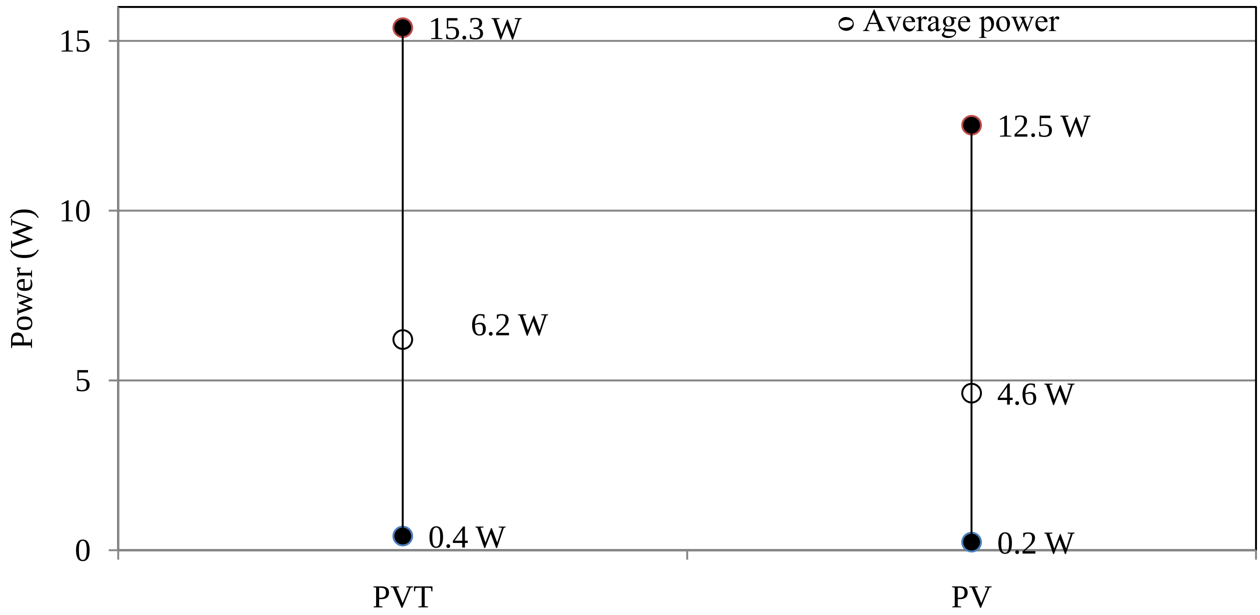


Figure 18. Comparison of electrical power yield when fan at high speed

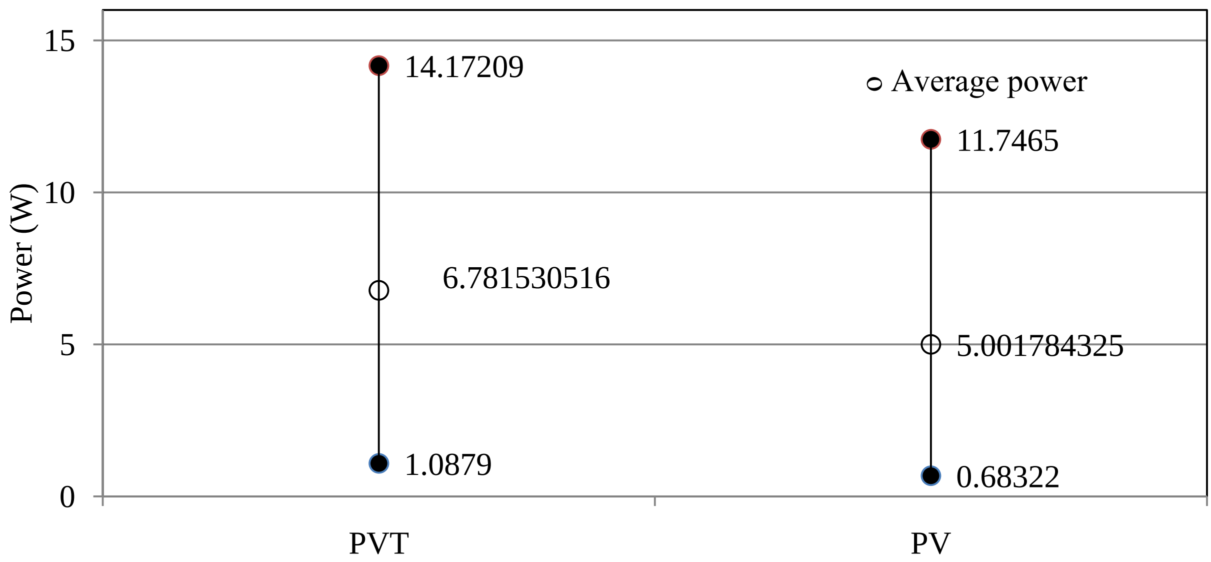
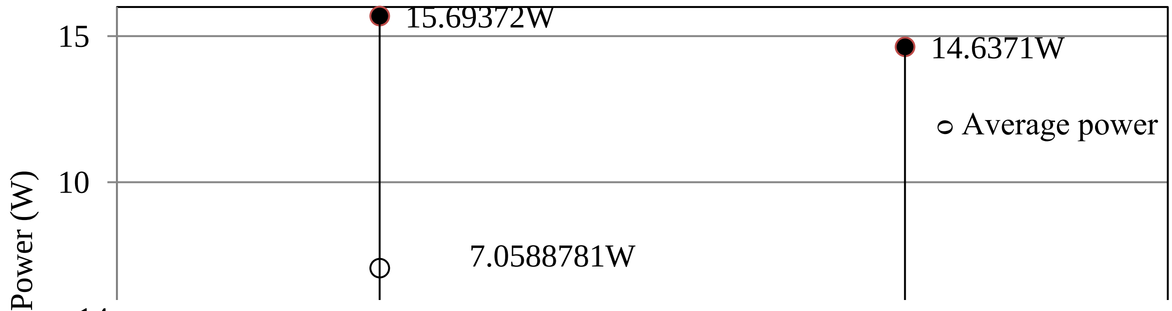
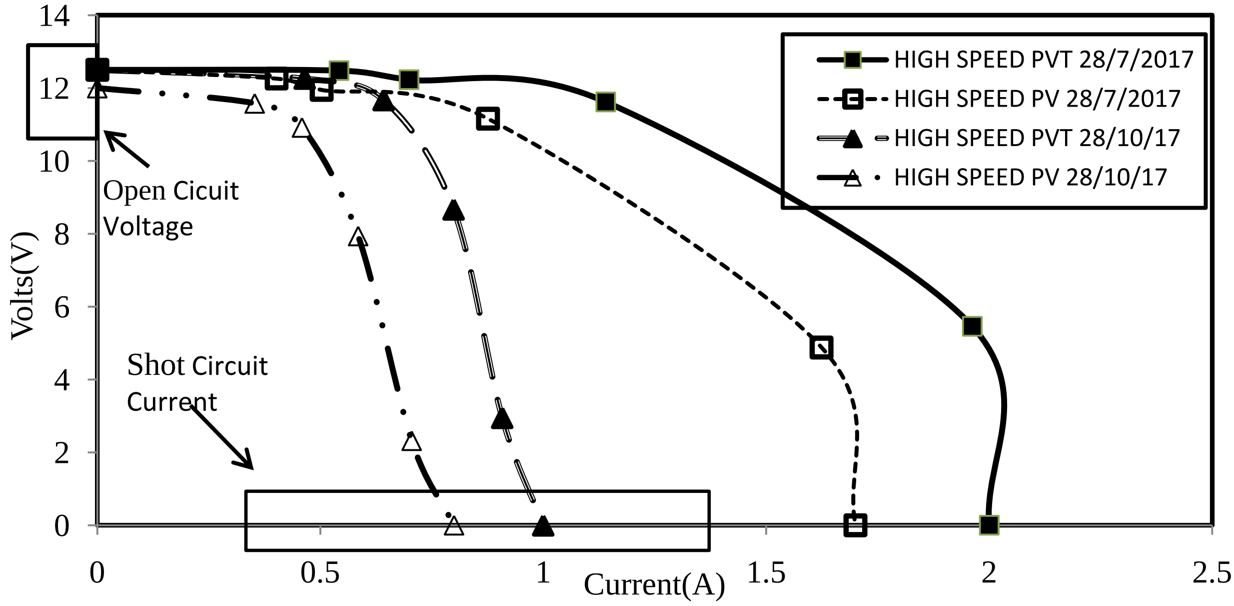


Figure 19. Comparison of electrical power yield when fan at medium speed

Figure 20. Comparison of electrical power yield when fan at low speed

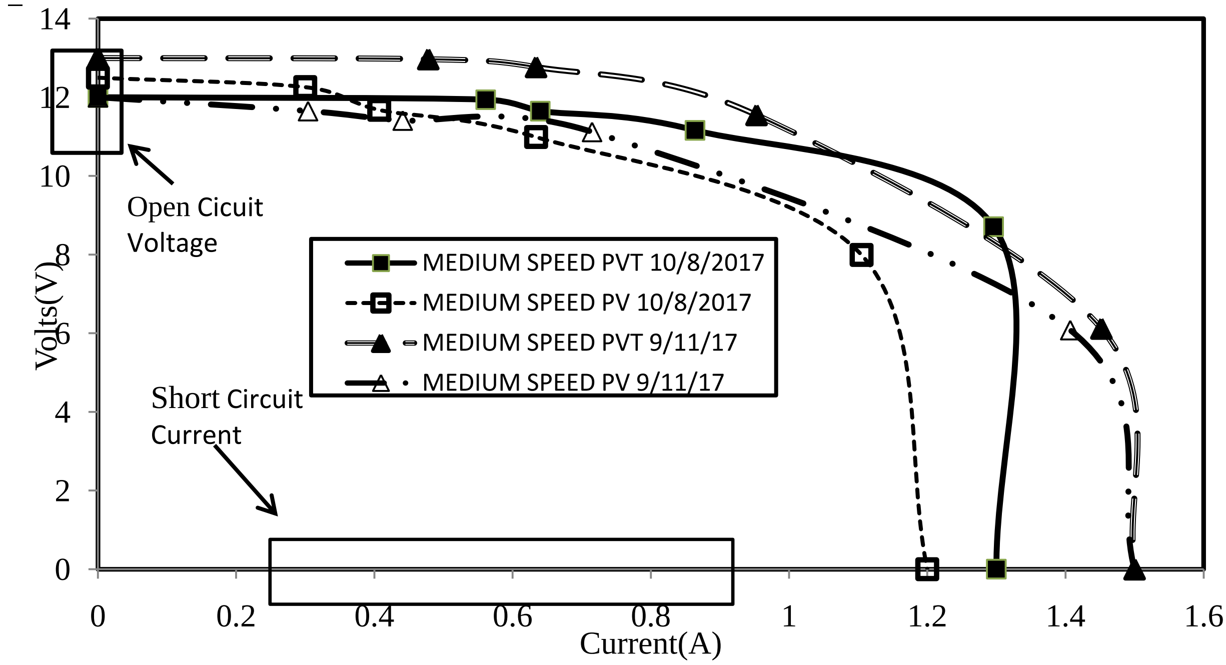




When electrical power yield is considered for comparison, the maximum power produced by PVT Panel is 22%higher than PV Panel with high mass flow rates, and medium mass flow rates it is 20%,and7% for low mass flow rates. While the same is compared for average power, they are 34%,,35%,33% for high, medium, low mass flow rates. The marginal difference of average power between different mass flow rates are due to variation in climatic conditions on different days.

Figure 21 I-V Characteristics when fan at high speed

Figure 22 I-V Characteristics when fan at medium speed



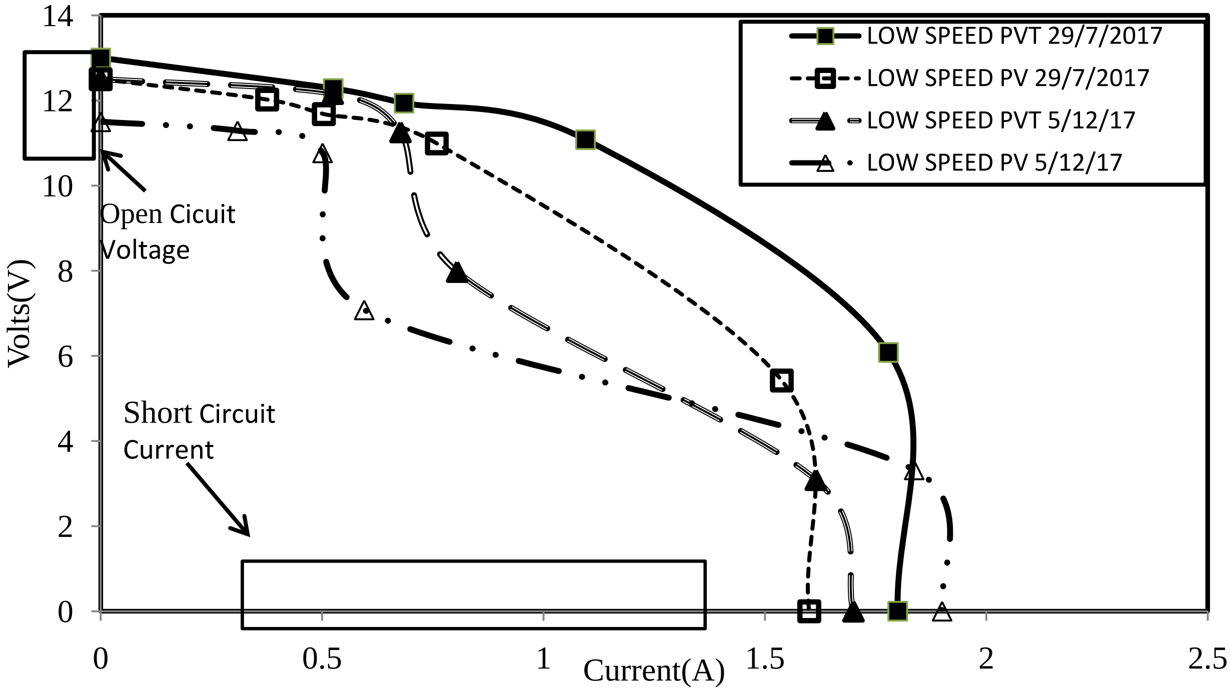


Figure 23 I-V Characteristics when fan at Low speed

I-V characteristics were also monitored for different mass flow rates and sample of I-V assessed for Higher mass flow rate, medium mass flow rate, low mass flow rates at different dates is given in figures 21,22,23 respectively. In all cases we observed increase in both short circuit current and open circuit voltage of PVT air panels compared to PV panels, the reason increase in power output from PVT air system.

6. CONCLUSION

We observed better heat absorption in case of duct no.2 is maximum of 2500 watts which is due to smaller size of the duct and better temperature difference between inlet and outlet. This helps in increasing the power production due to reduction in panel temperature as well, comparatively with Duct No.1. In addition to this we observed by using Duct No.2, more power is produced in comparison with duct

No.1. After inserting the longitudinal fins, when we compare the Heat absorbed between different mass flow rates, best heat absorption is possible, when mass flow rate is high and the panel temperature is very much reduced in case of higher mass flow rates. This is due to that fact that the absorbed heat from the panel is passed to longitudinal fins by convection in the gap between panel and fins ,and is able to be taken away by high mass flow rates. Whereas in the case of Medium mass flow rates, better reduction in panel temperature and better heat transfer rate is observed .

In case of lower mass flow rates neither reduction in panel temperature nor better heat transfer is absorbed. Hence if we use duct no.2 with longitudinal fins at high mass flow rates, we can get good reduction in panel temperature and better heat transfer. Also Electrical power output with Duct No.2 inserted with longitudinal fins, forced with high mass flow rates, is observed to be better on almost all days which is due to the fact that better heat absorption with high mass flow rates. I-V Characteristics are also quite smooth in case of high mass flow rates. Hence it is suggested to use the duct No.2 with longitudinal fins fitted into it to obtain better thermal and electrical output.

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