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COMBINED PV, PV/T AND PERFORMANCE MONITORING SYSTEM DESIGN USING WAVY FINS

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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.AminElSafi 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]presentedThe hardware and software design of a low-cost photovoltaic (PV) monitoring system. In this paper, three metallic staves, 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 staves, the heat conglomerated in different layers below the panel and inside the duct is absorbed by the plate and removed by air thereby reducing PC panel temperature and hence both thermal and electrical performance is increased. Earlier, we used duct without staves 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 staves inside the duct.

To setup the experiment an arrangement has been erected whose dimensions are 2000mm X 1300mm. The longitudinal is kept sloped facing North – South with an angle of 23°. In the northern side it is kept at a height of 1520 mm and southern side it is kept at a height of 1060 mm. This is to accommodate the frames that support solar panel,easy access to the underside of solar panels used for experiment purpose, solar panel used for supplying power to DC fan and indigenously made PV Monitoring system.

For our experiment purpose,20 Nos. of 5 Wp flat solar panels(monocrystalline type) used. Out of these 20 solar panels, 10 Nos. solar panels are arranged in longitudinal direction in one set, and remaining 10 Nos. solar panels are arranged in another set parallel to the previous set. Therefore each set of solar panels is expected to give power output of 50 Wp .One set of solar panels referred as with cooling(ie.PV/T Air System) while another set referred as without cooling. The bottom of solar panels of PV/T Air system is closed with duct made of GI sheet whose measurement is 1980mm X 156mm X 156mm.

To make the air to pass underneath the solar panels of PV/T Air system, a suction draught DC fan is fitted at top edge of the duct. To obtain different air mass flow rates, the fan is driven by a potentiometer. A separate 50 Wp solar panel is used to provide for this fan. GI sheets are bent in the form of wave profile and are kept inside the duct in longitudinal direction in 3 nos. These wavy fins are spaced in such a manner that it will not hinder the air flow by having proper interval between duct and either side of wavy fins. The duct is fully insulated with 19 mm thermocol on its outside and its inside bottom is completely insulated with 38 mm thick thermocol. The overalllength of the wavy fins are slightly less than half of the total length of the duct. Due to rise in panel temperature, the heat accumulation is expected to be more at top half of the duct, these wavy fins are fitted from top edge of the duct.

Data from different sensors are sent to the indigenously developed solar panel performance monitoring and logging in system. There are six temperature sensors stuck at the back of both PV and PVT solar panels. They are affixed underneath the solar flat panels at a distance of 270,645,1000,1560,1740 mm from lowed and of the duct. It is worthy to note that more number of sensors are concentrated near top edge of the duct to give temperature indication of solar panels. This is because more temperature rise is expected near top edge of the duct

Two numbers Variable Rheostats(0-28Ω) are connected to both sets of panel to act as load. For varying the load, the sliders of the rheostat are linked to Screw Rod arrangement which is driven by 12 V DC Heavy Duty Motor. The motor is controlled by Motor Driver circuit which is monitored by Microcontroller

Table 1 SPECIFICATIONS OF SOLAR AIR DUCT WITH WAVY FINS

Description of component	Specification
Duct : GI Sheet	1980mm X 156mm X 156mm,Thickmness 1mm
2 sets of 10 Nos. Solar Panels	Each panel 5Wp
Length of PV Module	185mm
Width of PV Module	180mm

Specifications of PVT Monitoring and Logging in System

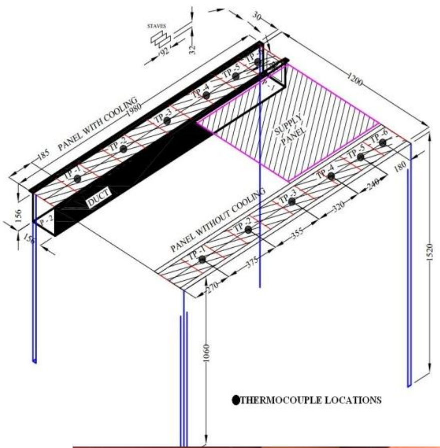
Description of component	Details
Microcontroller	Arduino MEGA 2560
Motor Driver	Cytron MD 10 C
Current Sensor	ACS 712-05B
Voltage Sensor	Simple Voltage Divider Network
Temperature Sensor	LM 35
Variable Rheostat	0-28Ω

MEASUREMENTS

The parameters that are measured during experiment are Panel Temperature from six different points of both sets of panels, Outlet and inlet air temperature, Outlet and inlet air velocity Current and Voltage from both sets of flat solar panels that corresponds to with and without cooling

EXPERIMENTAL SETUP

Flat plate solar panels of mono crystalline type are kept in line over a frame and all are connected in parallel to get more current output referred as without cooling as shown in figure 1.One more similar setup panels referred as with cooling is fixed with a duct underneath PV Panels and 3 nos. wavy fins fitted inside the duct with 1.5” equal gap in between the wavy fins. After that, in the next set up, these equal gap has been changed and unequal gap has been maintained.



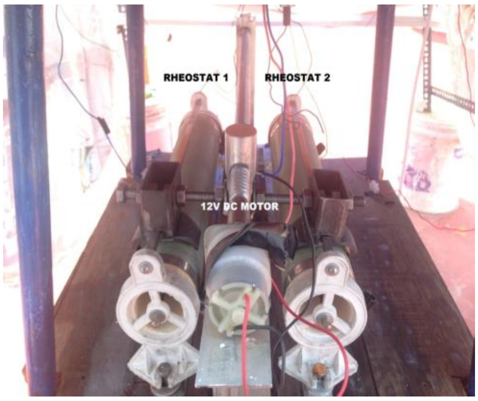


FIG.1 EXPERIMENTAL SETUP

To obtain different mass flow rate, a variable speed DC fan is fitted at the top end of duct. To meet the power requirements of this variable speed DC fan, a separate 50 Wp flat solar panel is fixed in between both sets of PV Solar panels. Due to insolation on solar PV Panels, the heat produced underneath solar panels is carried away by the air turbulence created by the wavy nature of fins, that leads to reduction n panel temperature..Due to wavy nature of fins, no other arrangement is required to maintain its even gap in between fins, when they are inside the duct. Due to its wavy nature, good turbulence is expected which will further enhance heat transfer form flat plate PV Solar panels. Thus the very purpose of having the wavy nature of fins inside the duct achieved. The complete experimental setup is fixed open to sky without any obstruction to avoid any shading effect that will reduce solar insolation.

EXPERIMENTAL PROCEDURE

The experiment is conducted at real time environment conditions. Both PV and PVT System are tested simultaneously for assessing thermal and electrical characteristics.The measurements are taken at every half an hour interval beginning from two hours from solar noon(12:00 noon) and stopping two hours after solar noon. And at every half an hour interval for different load settings the datas are collected and stored automatically by performance monitoring system. Different load settings, namely 10%, 30%, 60%,90% of full load of rheostatsare possible by moving the sliders of the rheostat with screw rod arrangement. To obtain stable readings for error free data collection, sufficient time is given at different load settings. Whatever may be the climatic conditions throughout the year, system's performance can be monitored. While mass flow rates are monitored by anemometer, the other parameters like panel temperatures of both sets of panels,air inlet and outlet temperatures, current and volt are recorded automatically.

RESULTS AND DISCUSSION

The panel temperatures at different points along the axial length are measured for both sets of panels for both cases of wavy fins while maintaining the fan speed at its full. When Suction Draught Fan sucks air at high speed through the duct, the maximum panel temperature as in figure 2, for PV and PVT System are 62ºC and 52ºC respectively, while average panel temperature stays around 49ºC for PV System and 43ºC for PVT System. In addition to this, it can be noticed that axial temperature distribution has a negative coefficient of axial distance (T_p= 43.85-1.118x)for PV system, whereas the same is negative coefficient of axial distance(T_p = 49.26-0.050x) for PVT air system.

When we consider the case of wavy fins with unequal gap and with the suction draught fan maintained at high speed,the maximum panel temperature for PV and PVT System are 65ºC and 41ºC respectively, while average panel temperature stays around 45ºC for PV System and 41ºC for PVT System. It can also be noticed that axial temperature distribution has a negative coefficient of axial distance (T_p=45.89-0.237x) for PV system, whereas the same is negative coefficient of axial distance(T_p= 41.18-0.641x) for PVT air system.

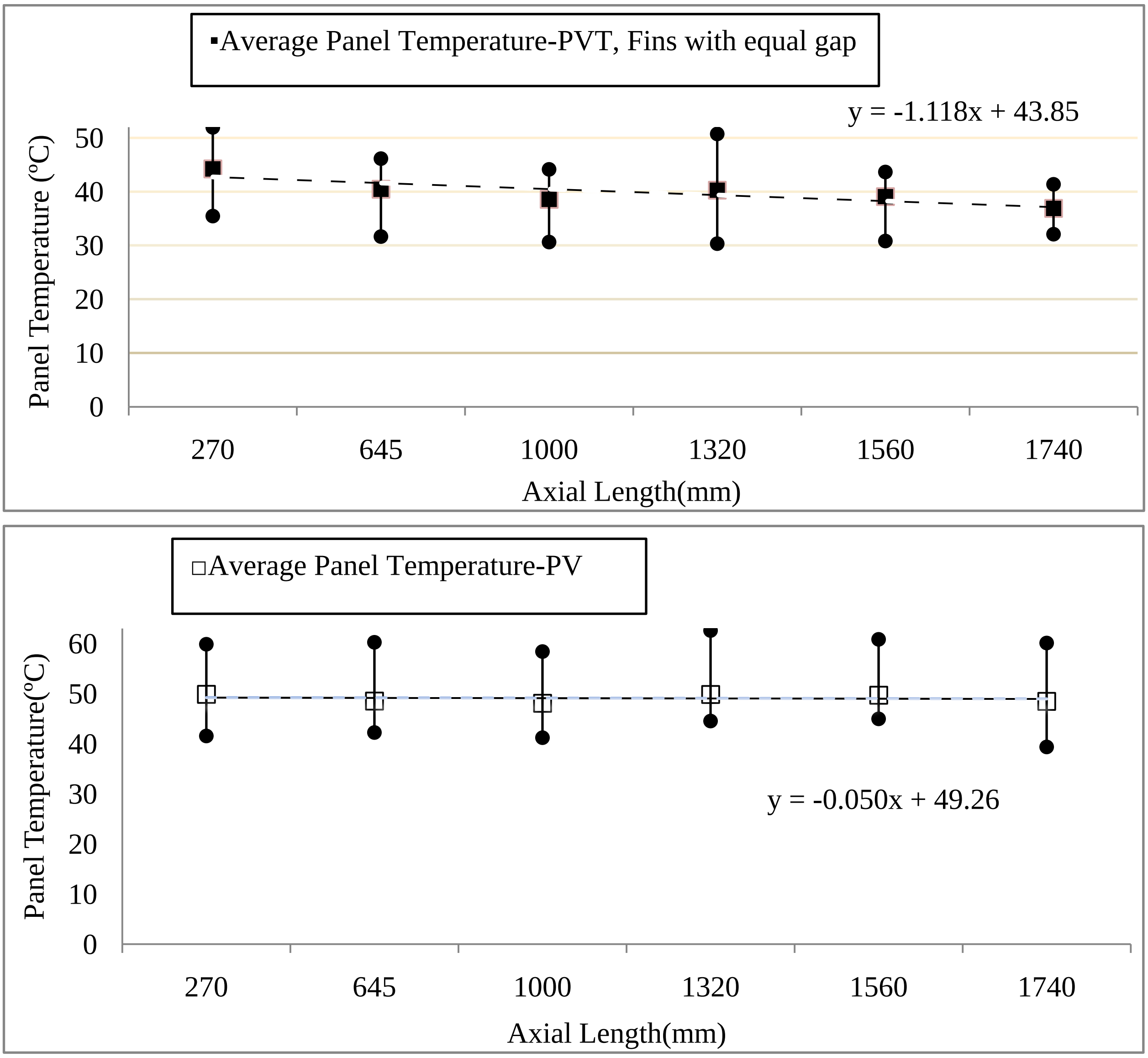
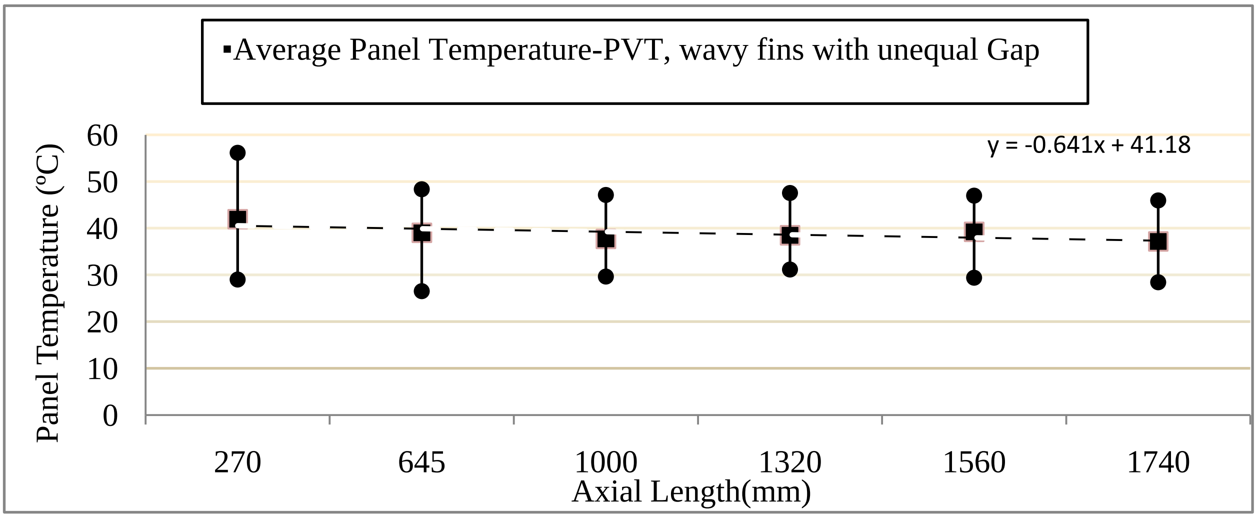


Fig. 2 Measurement of Temperature of PV panels of PV and PVT air systems along the axial length with wavy fins maintained at equal gap



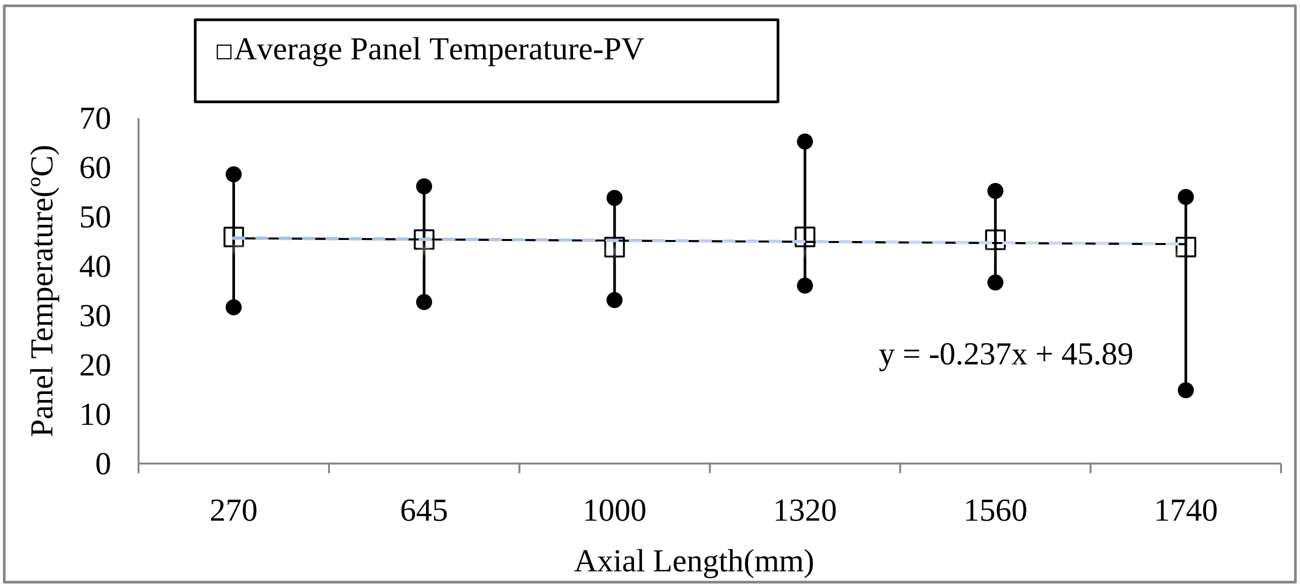


Fig 3 Measurement of Temperature of PVpanels of PV and PVT air systems along the axial length with wavy fins maintained at unequal gap

Figure 4 shows outlet and inlet air temperature of air, with the wavy fins maintained at equal gap. It is clear that only 5-6º C temperature increase is observed.

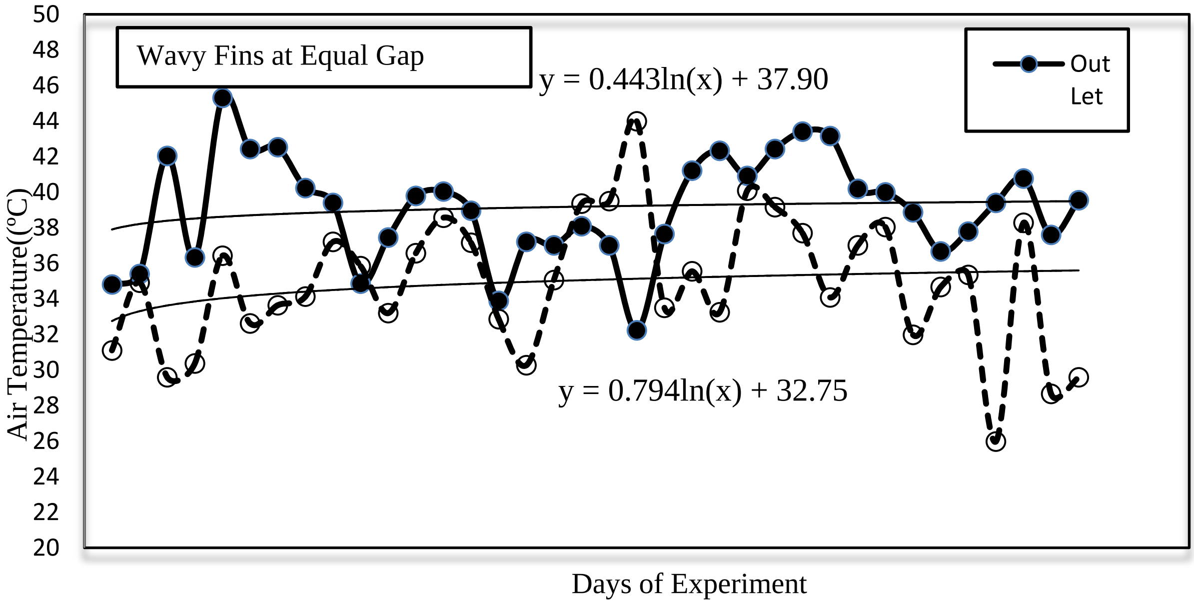


Fig. 4 Inlet and Outlet Temperature of air with wavy fins at equal gap

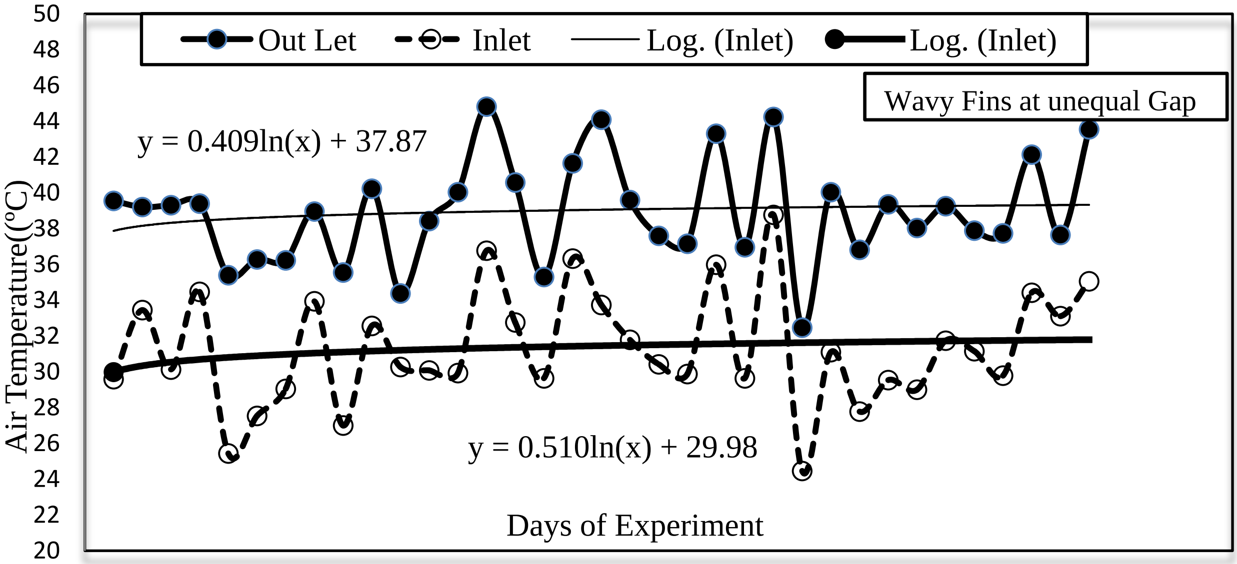


Fig. 5 Inlet and Outlet Temperature of air with wavy fins at unequal gap

While considering the wavy fins at unequal gap, about 8-9º C temperature increase is observed. This temperature difference is much higher compared to the wavy fins with equal gap. This is due to the fact that sufficient gap is not available in between either side of the fins and the duct when we consider the wavy fins with equal gap. But it is not so, in case of wavy fins with unequal gap.

The heat absorbed by air in PVT air system is calculated using $Q = m\ c_p\ (T_{out} - T_{in})$, where m=ρAV 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. The figure 6-7 shows heat absorbed in both cases of wavy fins one with equal gap and with unequal gap.

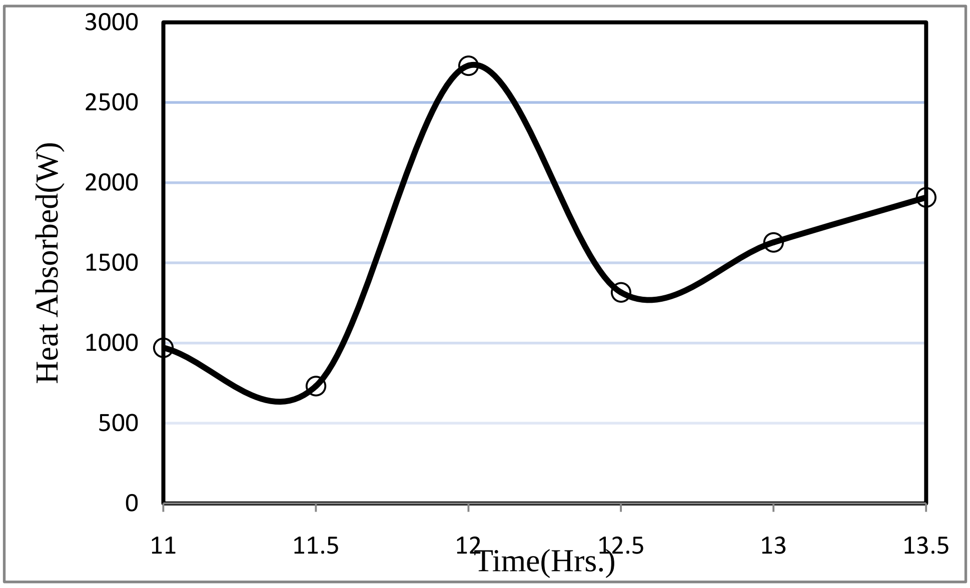


Fig. 6 Heat absorbed with wavy fins at equal gap.

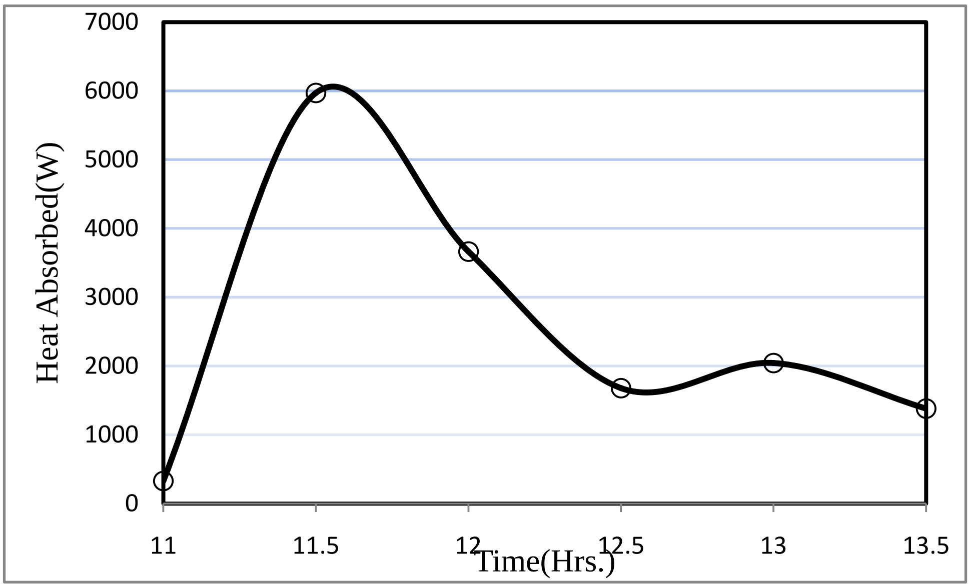


Fig. 7 Heat absorbed with wavy fins at unequal gap.

On 01/06/2018, heat absorbed by air in PVT air system as shown in figure 6, during a solar noon with wavy fins fitted inside the duct by maintaining equal gap in between the fins. The figure 7 shows the heat absorbed by air in PVT air system during a solar noon with wavy fins fitted inside the duct by maintaining unequal gap in between the fins. From the graph, Fins with unequal gap provides maximum heat absorption of around 6000 W, while it is 2800 W in case of wavy fins with unequal gap. In all the cases, the sudden change in environment conditions, heat absorbed by air in PVT air system changes significantly. And this heat can be used for residential, agricultural drying purposes.

ELECTRICAL CHARACTERISTICS

The experiments have been conducted and readings were taken on different days starting from May 2018 to October 2018 under various climatic conditions with fan rotating at high speed. The electrical power developed at 11.00 am in a 4 minute interval at different dates are shown in figure 8. Measurements that have been shown were for four different load settings, say 10%, 30%, 60%,90% of full load. 78 seconds are the duration maintained between load settings.

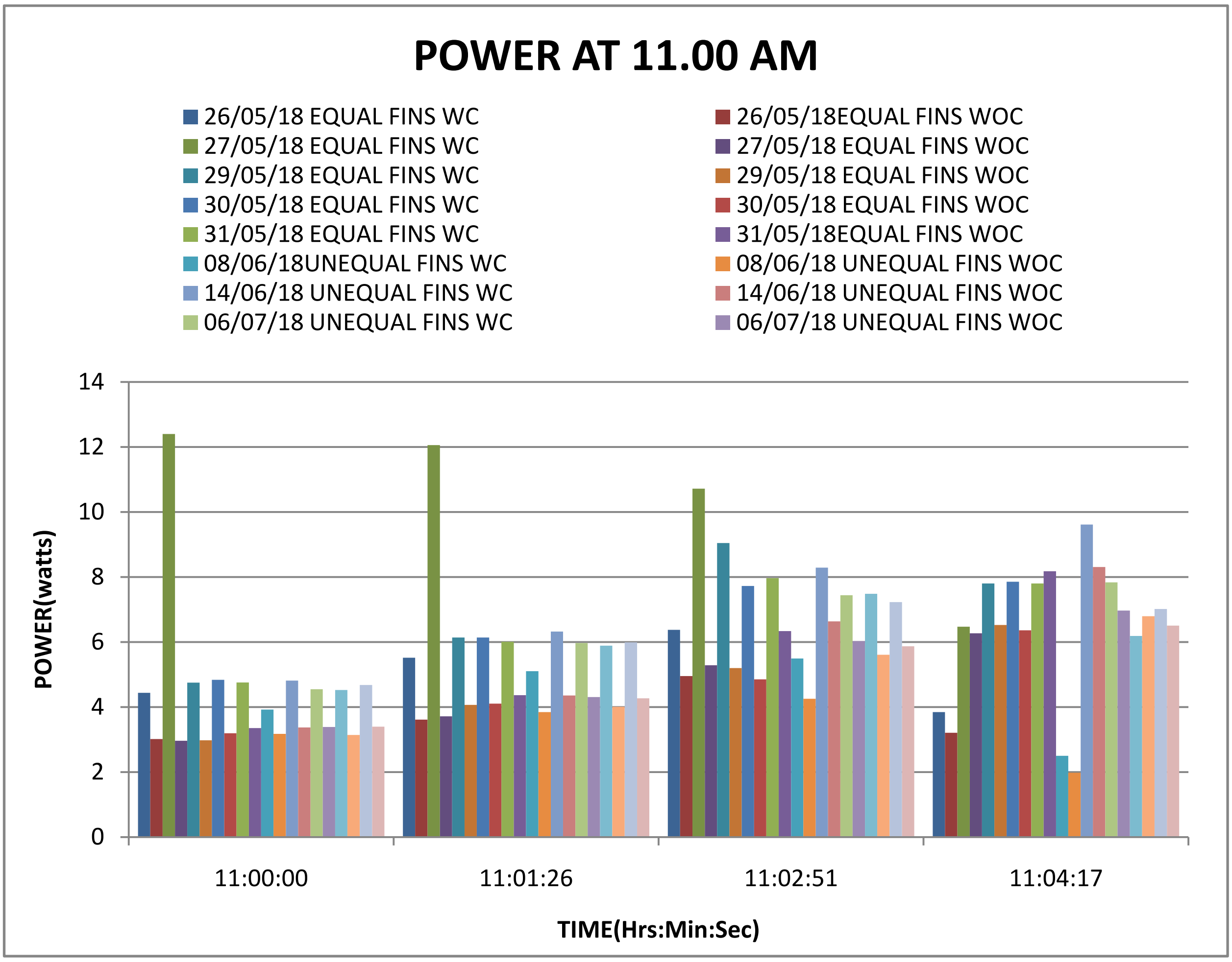


Figure 8 Electrical power output obtained with PV and PVT air system

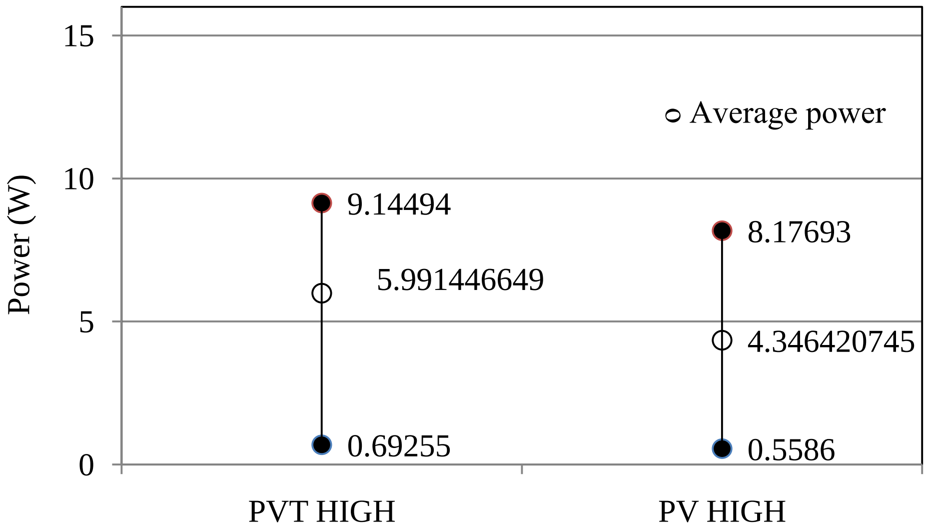


Figure 9 Comparison of electrical power yield when fins are at equal gap with fan at high speed

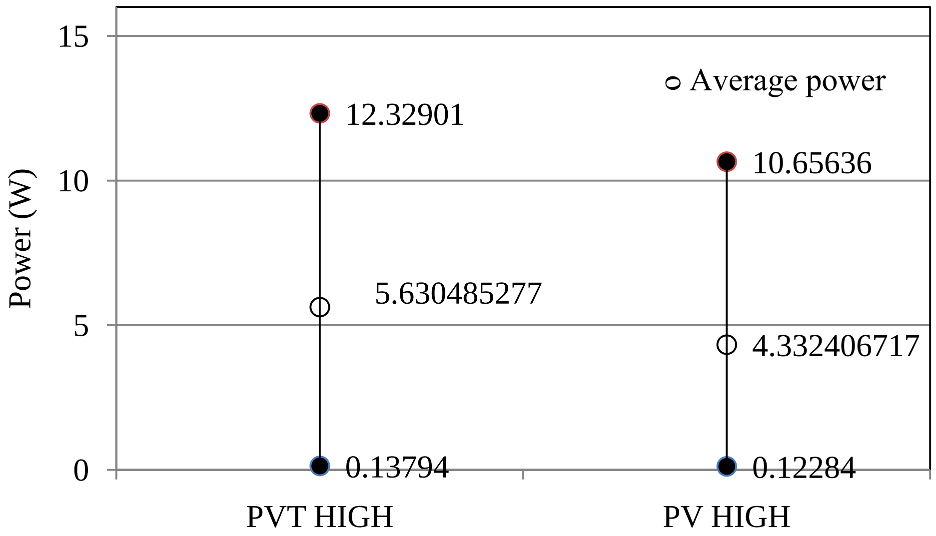


Figure 10 Comparison of electrical power yield when fins are at unequal gap with fan at high speed

Figure 9 shows the case of fins with equal gap, where power for PVT air system stood at 9.14 W maximum and for PV system 8.17W, whereas average power for PVT air system 5.99 W and PV system 4.34 W.

In the case of fins maintained at unequal gap as shown in Figure 10,the maximum power produced were12.32 W for PVT air system and 10.65 W for PV system respectively and average power developed were 5.6 W and 4.3 W for PVT air system and PV system respectively.

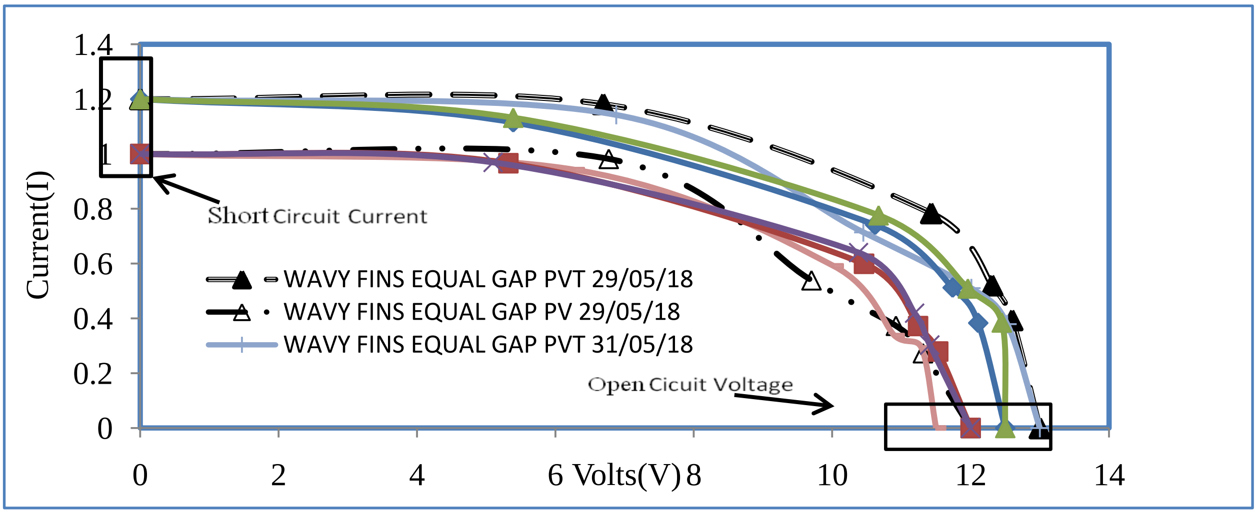


Figure 11 I-V Characteristics of PVT air system with fins maintained equal gap

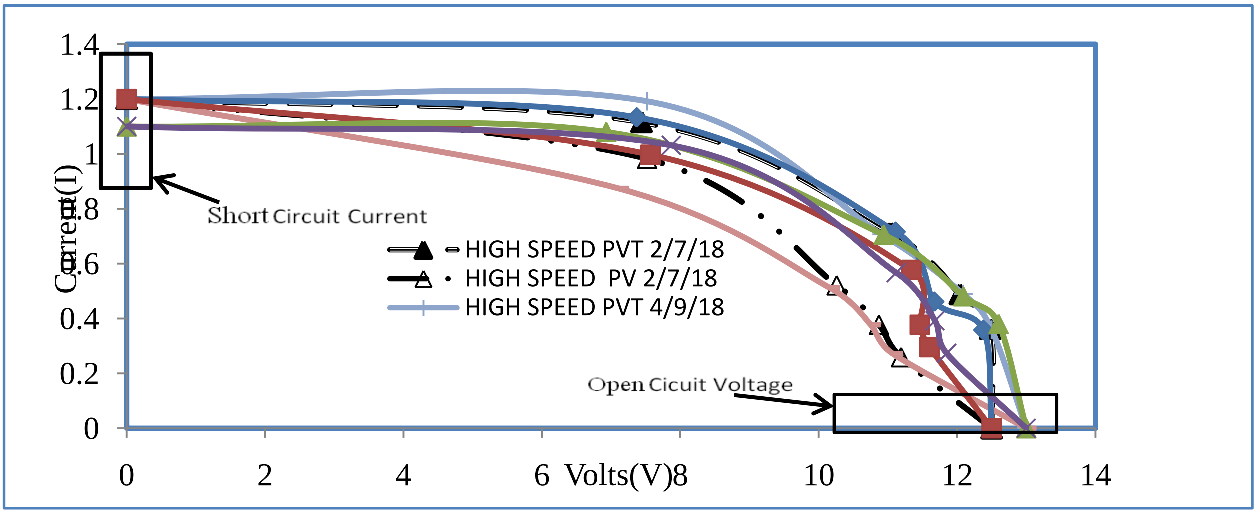


Figure 12 I-V Characteristics of PVT air system with fins maintained unequal gap

I-V characteristics were also monitored for different gap in between wavy fins and sample of I-V assessed for two cases of wavy fins at different dates are given in figures11,12. 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.

CONCLUSION

It is imperative that The wavy fins performed better compared to Straight fins in terms of decrease in Panel Temperature, Heat Transfer, Power generation. For comparison purpose between Straight fins and wavy fins the experiments conducted in similar environment . The experiments were conducted in real time environment. Hence it is clear that Wavy fins have better performance.

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