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# Performance Study of Solar Photovoltaic Thermal Collector Integrated with Cooling System

**Rahul.S R[1], Hariharan R[2]**

[1]Department of Mechanical Engineering, LBS, Kasaragod, Kerala, India.
[2]Department of Mechanical Engineering, LBS, Kasaragod, Kerala, India.

**Abstract:** *Photovoltaic power generation is a method of producing electricity using solar cells. A solar cell converts solar optical energy directly in to electrical energy. The major problem related to the solar cell is their lower efficiency. Photovoltaic cells have low efficiency of 15% only about 1/6 th of the sunlight striking the cell generates electricity. Photovoltaic cells suffer from a drop in cell efficiency with rise in temperature due to increased resistance .So there by cooling the solar cell we can improve their efficiency by lowering the resistance. The present work concentrates upon mainly two things, The first one is to improve the cell efficiency by decreasing the temperature and the other is using the extra heat energy at the rear side of the solar panel for different purposes. The cell efficiency can be increased by lowering the temperature of the panel; this can be achieved by passing continuously air with the help of a blower on the rear side of the panel. So the temperature can be lowered and the air can be heated also, so that we can use it as solar air heater. Another method of lowering the temperature of the panel is done by cooling the panel by the supply of water at the rear side. This is also an effective method. In the present work water is passing through the aluminum channel and the newly fabricated plate is fixed at the rear side also. Then comparing with the results obtained for the newly modified panel with the normal solar panel.*

**Keywords:** *Photovoltaic effect, Solar panel, Cell efficiency, Modified panel.*

## 1. INTRODUCTION

Solar energy in the form of solar radiation has been identified as one of the promising source of energy to replace the dependency on other energy resources. About 86 % of the world's energy supply comes from the fossil fuels. Moreover, the pollution hazard arising out of fossil fuel burning has become quite significant in recent years. The world is becoming acutely aware of the urgent need to resolve the many issues associated with energy consumption and climate change. Limited availability of fossil fuels and the need to reduce greenhouse gas emissions call for fundamental innovations in the global energy landscape. Sustainable energy plays a key role in tackling these issues. The global need for energy savings requires the usage of renewable sources in many applications. One of the renewable sources of energy is the photovoltaic solar energy The nozzles are of converging or diverging or converging-diverging type as per the design. An efficient nozzle is designed to have higher velocity, greater mass flow and minimum inlet losses. Chamber is a portion of nozzle and facilities the tangential entry of high velocity air-stream into hot side. Generally the chambers are not of circular form, but they are gradually converted into spiral form. Hot side is cylindrical in cross section and is of different lengths as per design. Valve obstructs the flow of air through hot side and it also controls the quantity of hot air through vortex tube. When the PV modules are operated in an outdoor environment, there will be fluctuations in the environmental temperature and irradiation intensity, it causes a drop in electrical output and hence a drop in electrical efficiency of the panel. This also gives rise to critical thermal-related factors that may affect their performance and reliability of PV modules For example, the effects of the variation of temperature and irradiation intensity inherently lead to the deterioration in the output power of PV modules In addition, the thermal effect also influences the estimation of the maximum power point.

### 1.1. Working of Photovoltaic Cell

The working principle of all today solar cells is essentially the same. It is based on the photovoltaic effect. Solar cell is an electrical device that converts the energy of light directly in to electricity by the photovoltaic effect. In general the photovoltaic effect means the generation of a potential difference at the junction of the two different materials in response to visible or other radiation. The basic processes behind the photovoltaic effect are

1. Photons in the sunlight hit the solar panel and are absorbed by semi conducting materials such as silicon
2. Electrons (negatively charged) are knocked loose from their atoms causing an electrical potential difference.

   Current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of the solar cells the electrons are only allowed to move in single direction.
3. An array of solar cell converts solar energy in to a usable amount of direct current electricity.

In general a solar cell structure consists of an absorber layer in which the photons of incident radiation are efficiently absorbed resulting in the creation of electron-hole pairs. In order to separate the photo generated electrons and holes from each other, the so-called ’semi-permeable membranes’ are attached to the both sides of the absorber. The important requirement for the semi-permeable membranes is that they selectively allow only one type of charge carriers to pass through.

Silicon is the material of prime importance in any technology that is used in solar panels. The outer most part of the solar panels is the glass frame in which the solar cells are enclosed in an array. The glass used in the solar panels must be highly transparent allowing an easy penetration of photons in to the embedded frame. Also at the same time the glass must not be of too brittle in nature because of the safety and maintenance uses.

### 1.2. Objective of Present Thesis

The major objectives of the present work are

1. To fabricate a channel type PV/T working on the thermosyphon effect with water and air as fluid.
2. To study the variation in performance of the following parameters of solar PV/T made with the normal solar panel.
   a. Electrical Efficiency
   b. Power Output
   c. Thermal Efficiency
3. Study of variation of efficiencies obtained for water based PVT system and air based system with the normal solar panel.

## 2. LITERATURE REVIEW

M.S.Sodha et al[1].developed a thermal model of an integrated photovoltaic and thermal solar (IPVTS) water/air heating system. They gave an analytical expression for the temperature of solar cell and water and an overall thermal efficiency of IPVTS system have been derived as a function of climatic and design parameters. In this paper numerical computations have been carried out for composite climate of New Delhi for parametric studied. Comparison of the IPVTS system with water and air heater has also been carried out. It is found that the characteristic daily efficiency of IPVTS system with water is higher than with air.An analytical expression for the water temperature of an integrated photovoltaic thermal solar water heater under constant flow rate hot water withdrawal has been obtained and investigated by Arvind Tiwari et al.[2].In this work, the analysis based upon basic energy balance for hybrid flat plate collector and storage tank, respectively, in the terms of design and climatic parameters. And also the further analysis has been extended for hot water withdrawal at constant collection temperature. In this paper numerical computations have been carried out for the design and climatic parameters of the system used by Huang et al. It is observed that the daily overall thermal efficiency of the present system increases with increase constant flow rate and decrease with increase of constant collection temperature. The exergy analysis of IPVTS system has also been carried out. It is further to be noted that the overall exergy and thermal efficiency of an integrated photovoltaic thermal solar system (IPVTS) is maximum at the hot water withdrawal flow rate of 0.006 kg/s. Wei He et al.[3] found out using experiments that the electricity conversion-efficiency of a solar cell for commercial application is about 6–15% and 85% of the incoming solar energy is either reflected or absorbed as heat energy. Thus the working temperature of the solar cells increases considerably after prolonged operations and the cells efficiency drops significantly. They concluded that for improving the efficiency of solar cell, hybrid photovoltaic and thermal (PVT) collector technology using water as the coolant has been seen as a solution for improving the energy performance. Through good thermal-contact between the thermal absorber and the PV module, both the electrical efficiency and the thermal efficiency can be raised. Fin performance of the heat exchanger is one crucial factor in achieving a high overall energy yield. In this paper, the design developments of the PVT collectors are briefly reviewed. Their observation is that very few studies have been done on the PVT system adopting a flat-box absorber design. Accordingly, an aluminum-alloy flat-box type hybrid solar collector functioned as a thermosyphon system was constructed. While the system efficiencies did vary with the operating conditions, the test results indicated that the daily thermal efficiency could reach around 40% when the initial water-temperature in the system is the same as the daily mean ambient temperature. Anand.S.Joshi [4] has been made an attempt in this paper to evaluate exergy analysis of a hybrid photovoltaic–thermal (PV/T) parallel plate air collector for cold climatic condition of India (Srinagar). The climatic data of Srinagar for the period of four years (1998–2001) has been obtained from Indian Metrological Department (IMD), Pune, India. Based on the data four climatic conditions have been defined. The performance of a hybrid PV/T parallel plate air collector has been studied for four climatic conditions and then exergy efficiencies have been carried out. It is observed that an instantaneous energy and exergy efficiency of PV/T air heater varies between 55–65 and12–15%, respectively. These results are very close to the results predicted by Bosanac et al.This paper presents a review of the available literature on PV/T collectors by P.G.Charalambous[5] The review is presented in order to enable an easier comparison of the findings obtained by various researchers, especially on parameters affecting PV/T performance (electrical and thermal). The review covers the description of flat plate and concentrating, water and air PV/T collector types, analytical and numerical models, simulation and experimental work and qualitative evaluation of thermal/electrical output. The parameters affecting PV/T performance, such as covered versus uncovered PV/T collectors, optimum mass flow rate, absorber plate parameters (i.e. tube spacing, tube diameter, fin thickness), and absorber to fluid thermal conductance and configuration design types are extensively discussed. Based on an exergy analysis, it was reported that the coverless PV/T collector produces the largest available total (electrical + thermal) exergy. From the literature review, it is clear that PV/T collectors are very promising devices and further work should be carried out aiming at improving their efficiency and reducing their cost, making them more competitive and thus aid towards global expansion and utilization of this environmentally friendly renewable energy device. Experimental and numerical simulations were implemented by Tiwari *et al*.[6] to evaluate the overall performance of PV/T air collector. In this study, different kind of configurations of PV/T air collector (like unglazed, glazed, with and without tedlar were used to investigate the electrical and thermal performance. It was shown that the glazed PV/T air collector without tedlar provides the best performance. Saurabh Mehrotra et al [7].also studied and done experimental analysis related to solar cell immersed in water. They also studied the performance of solar cell with temperature. With the increase in surface temperature of solar cells or panels their efficiency decreases quite dramatically. To overcome the heating of solar cell surface, water immersion cooling technique can be used i.e. it can be submerged in water so as to maintain its surface temperature and provide better efficiency at extreme temperatures. In this study, electrical parameters of solar cell were calculated which showed that the cooling factor plays an important role in the electrical efficiency enhancement. Solar cell immersed in water was monitored under real climatic conditions; cell surface temperature can be controlled from 31-39 .C. Electrical performance of cell increases up to great extent. Results are discussed; panel efficiency has increased about 17.8% at water depth 1cm. The study can give support to the concentrated photovoltaic's System by submerging the solar cells in different mediums.

## 3. EXPERIMENTAL INVESTIGATIONS

Figure 2 shows the layout of in-house fabricated experimental setup. Solar PV/T sytem for water based and air based systems are shown.

### 3.1. Experimental Set Up for PV/T Water Based System

The layout of the experiment setup is given below,

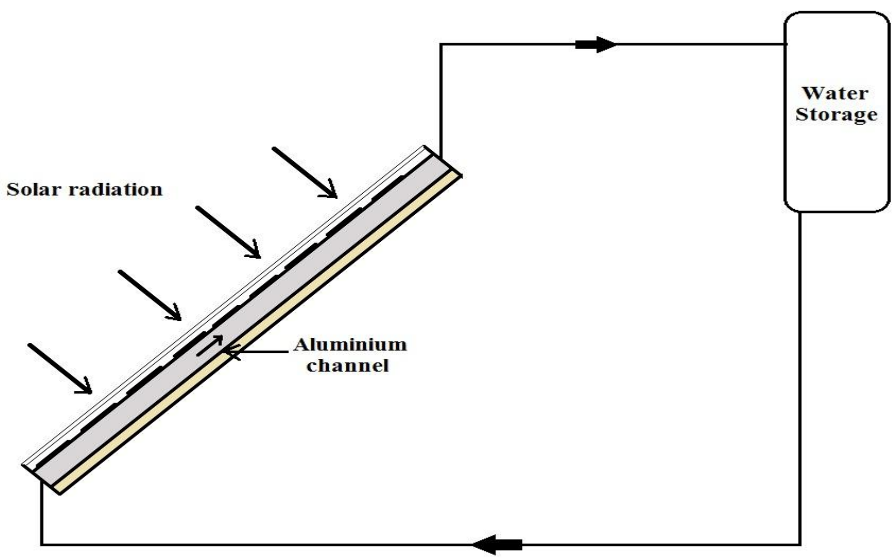


**Fig1**. *Experimental layout of solar PV/T water based system*

For the purpose of doing the experiment three solar panels of 10W are used. One panel is observed at normal test conditions and the other two panels are modified for the given conditions. All the materials needed for the experimental set up are available in the market. The solar panel was manufactured by the company named Frontech. The area of the solar panel is 250×370 mm, the cell technology is based upon polycrystalline silicon. The complete experiment set-up for solar PV/T water based system is given below.

**Fig2**. *Complete experimental set up for water based PV/T system*

In the figure given above it can be seen that the new modified solar panel is situated near the normal solar panel and the results obtained are compared with the normal panel. At the rear side of the panel is completely covered with insulation for the purpose of preventing heat loss.

**Fig3**. *Newly modified aluminum channel*

The newly modified system is fabricated by using aluminum channel fixed at the rear side of the normal solar panel. For this purpose the area of the solar panel was measured and the fabricated channel is fixed at the back side very effectively. Through that aluminum channels water is passed for cooling purpose. The passage of water at the rear side of the solar panel will results in decreasing the panel temperature. The inlet and outlet temperatures of water are measured using a J type thermocouple.

*Experimental Set Up for PV/T Water Based system*

Air can be used for cooling purpose of solar panel and thus improving the efficiency of the solar panel. In the case of water based PV/T system the experimental procedure is little bit difficult. But in air based PV/T system it is easier to fabricate and do the experiment. For the purpose of conducting the experiment blower is needed. At the rear side of the panel wood is placed for the purpose of thermal insulation. Two holes are created for air inlet and air out let respectively and the holes are perfectly insulated as well.

**Fig4**. *Complete experimental set up for air based PV/T system*

### 3.2. Experimental Procedure

*3.2.1. Water Based System*

The water will flow through these channels (fig3) and this water will absorb heat on the rear side of the panel and ultimately the water gets heated up. The flow of water is based on Thermosyphan effect. That is heated water particles will have low density and this will rises up and that will leads to the continuous flow. The panel temperature was measured by using a J type thermo couple.

The thermocouple is fixed at the top of the panel and the readings are measured using a Digital Multi meter. We cannot measure the temperature directly from the thermocouple. While fixing the thermo couple we can get only the values of different voltages. Corresponding voltage-temperature graphs are plotted and the corresponding temperature is also found out. A thermocouple can be defined as a junction between two different metals. According to the changes in the temperature each metal produces different electrical potential. Thermocouple can be calibrated by plotting the voltage-temperature graph.

For the purpose of measuring the temperature we use J-type thermocouple and the temperature range for J-type thermocouple is in between 0 to $750^0$c.The inlet and outlet water temperatures can be measured by thermometers. At the top surface of the solar panel we are fixing the thermo couple. Solar intensity can be measured by Pyranometer.Data's are available on internet for solar intensity.

*3.2.2. Air Based System*

In the figure given above (fig4), it can be seen that two openings are created on the wood at the bottom and top side. Two PVC pipes are also placed for the entering and outgoing of air and it is well insulated. While switch on the supply, the blower will starts to run and the air flow rate is noted down. The flow rate of air should be calculated at the inlet where the blower is connected we are measuring the mass flow rate of air by using a digital anemometer. Blower is fitted at the bottom side opening and the air will blow down to the panel. The heated air will rise up due to density variation and will come out through the other opening provided at the top side. When the air gets heated its density varies. Heated air will become less dense. Less density air will move up due to less weight.

**Fig5.** *Rear side of the solar panel-Air based PV/T system*

### 3.3. Mathematical Relations

The thermal efficiency of the PV module can be calculated by using the equation given below.

$$\eta_{thermal} = \frac{mC_p(T_0 - T_i)}{HA} \tag{1}$$

Here m is mass flow rate in kg/s and Cp is specific heat in J/Kg K. $T_o$ is the outlet temperature in K, $T_i$ is inlet temperature in K and A is area of the panel in $m^2$and H is the solar radiation in $W/m^2$.

The variation of thermal efficiency is a function of mass flow rate, temperature difference and incident solar radiation. The temperature difference depends on the ambient temperature of air.

The electrical efficiency of PV module is found out using the formula,

$$\eta_{electrical} = \frac{FF\, V_{oc} I_{sc}}{HA} = \frac{V_m I_m}{HA} \tag{2}$$

Fill factor of solar cells can be calculated by using the following relation,

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \tag{3}$$

The fill factor is defined as the ratio of the actual maximum obtainable power to the product of the open circuit voltage and short circuit current. This is a key parameter in evaluating the performance of solar cells. Here $V_{oc}$ is open circuit voltage of PV module in Volts and $I_{sc}$ is short circuit current of PV module in ampere.FF is fill factor of the PV module.

The result obtained was analyzed and compared and graph is plotted.

## 4. RESULTS AND DISCUSSION

The results obtained from the experimental investigation is drawn below, various graphs are drawn, The experimental analysis for the PV/T system is carried out for different panel temperatures; especially four different panel temperatures $27^0$c, $31^0$c, $35^0$c, $39^0$c respectively and electrical efficiency, thermal efficiency and power output are calculated for these different panel temperatures and the graphs are plotted.

From the graph shown below for two different day's temperature Vs time graph is plotted. When the time is increases the temperature also increases. For the day May 21 st the temperature is maximum when the time reaches 12.30 AM, for the next day the readings are approximately same.

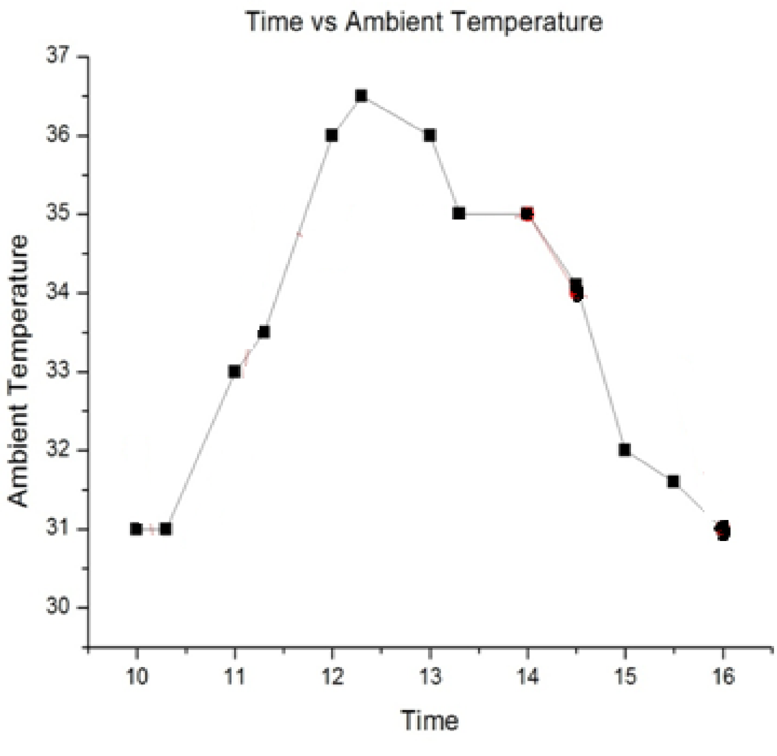


**Fig6.** *Ambient temperature Vs Time*

By analyzing the above graph by increasing the cold mass fraction at certain valve,the temperature is decreasing, after a certain value it is going on increasing, that is temperature decreases upto .7 mass fraction then temperature increases, also we noted that by increasing nozzle from one to four here the temperature decreases. Temperature is lesser than the vortex tube with four nozzle, then two nozzle, then one nozzle

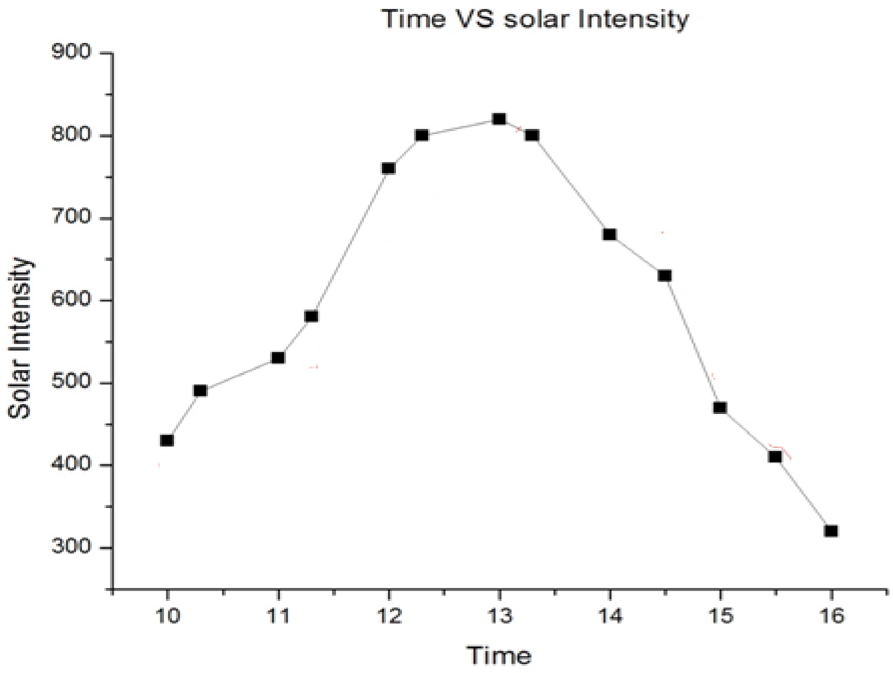


**Fig7.** *Solar Intensity Vs Time*

For water based photovoltaic thermal collector system, different graphs are plotted for analyzing the performance compared to the normal solar panel. Electrical efficiency Vs Time, Thermal efficiency Vs Time, Power output Vs Time graphs is plotted and the results are discussed.

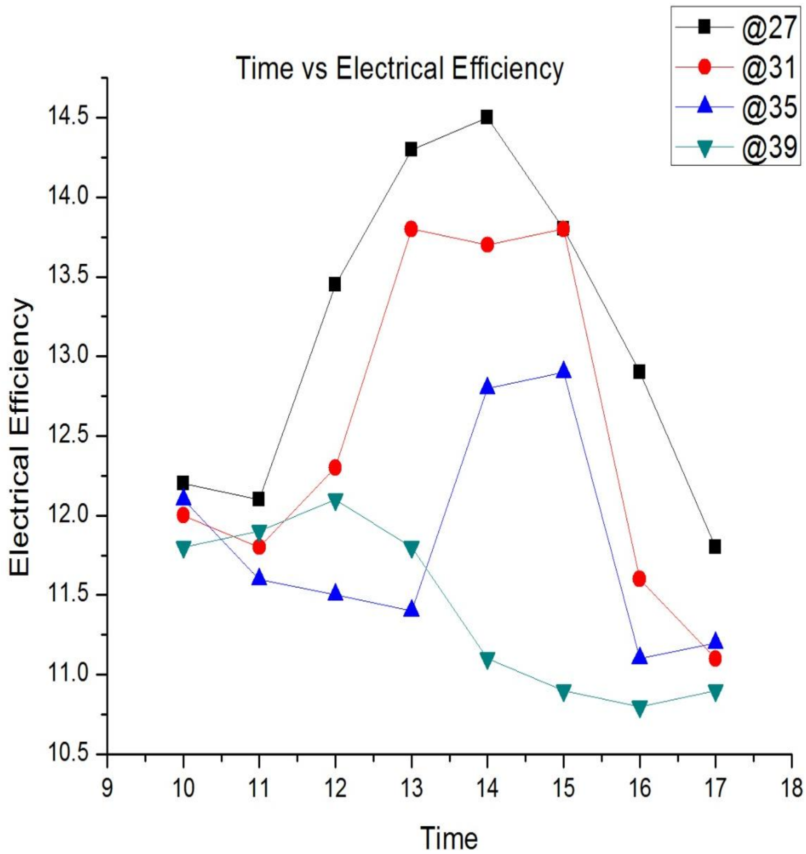


***Figure.8*** *Time Vs Electrical efficiency for water based pv/t system.*

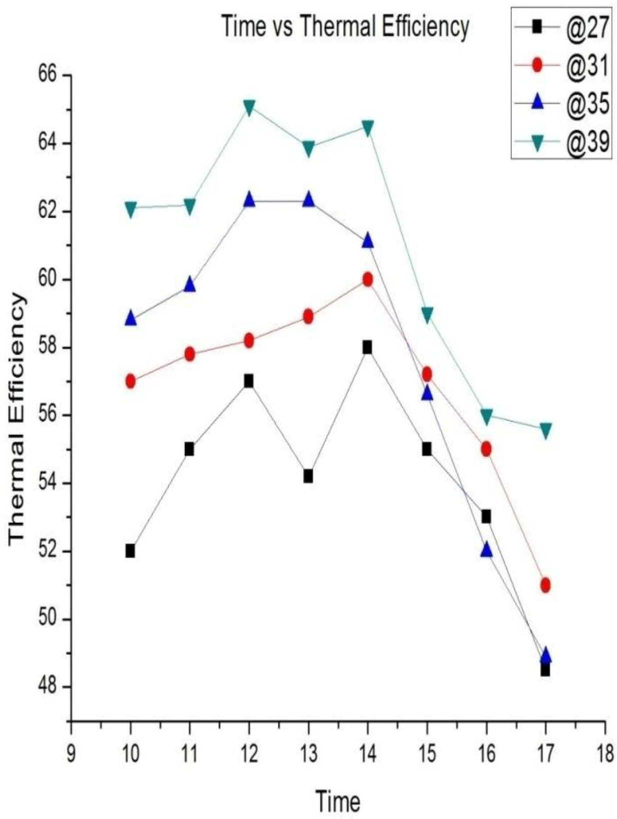


**Fig9.** *Time Vs Thermal efficiency for water based pv/t system.*

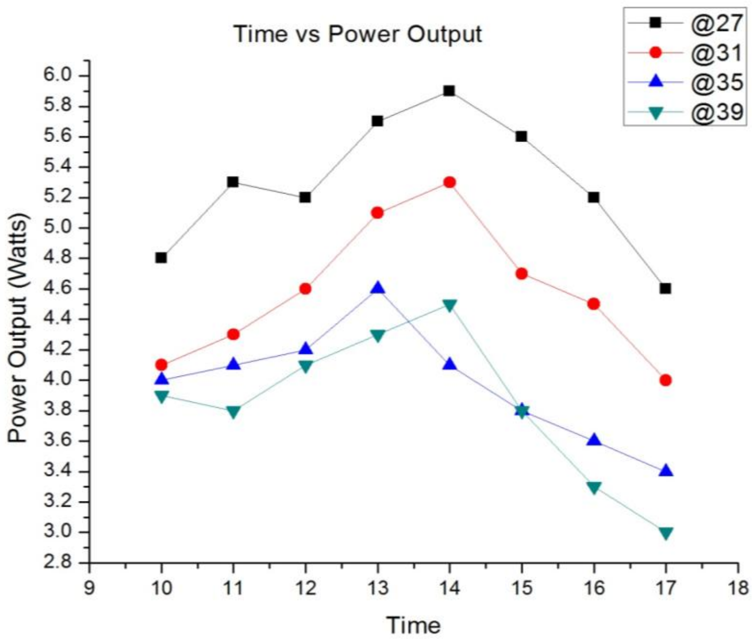


**Fig10.** *Time Vs Power output for water based pv/t system*

This graph gives a good idea about the variation in power output with the variation in different timings. The power output is also calculated for different panel temperatures and the values are noted down. Power output is given in Watts and the owe output is maximum for the value of temperature was at $27^0$c.Inthis case also when the temperature value is decreasing the power output value increases. Four different panel temperatures are recorded for the analysis purpose and the values obtained were noted down and using the values the graph Time Vs Power output was plotted.

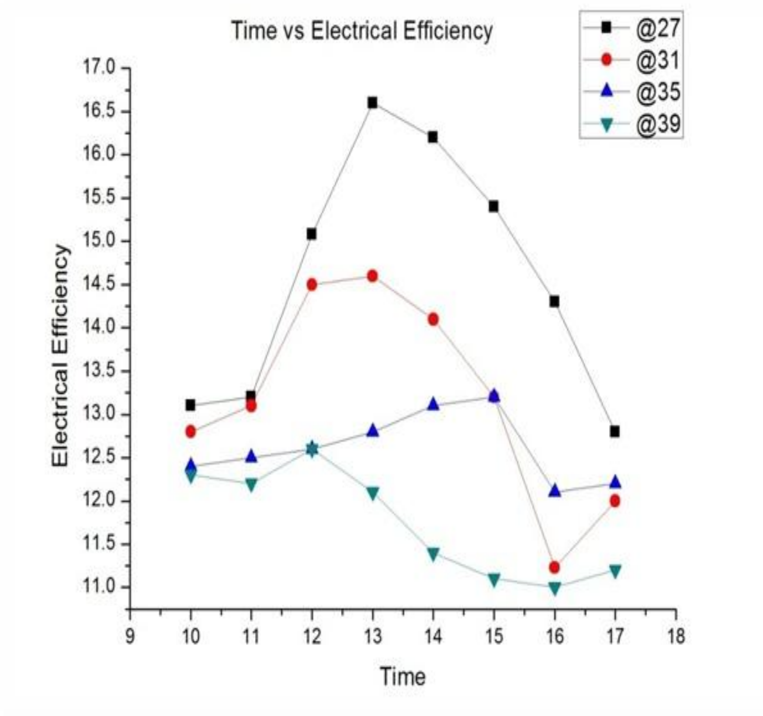


**Fig11.** *Time Vs Electrical efficiency for air based pv/t system*

In the air based photovoltaic /thermal system the results obtained are basically similar to that of water based system since there was a slight variations in the efficiency of the system. That is in the case of air based photovoltaic/thermal system more effective cooling was done by looking through the results obtained from the graph. The variations of different temperatures are also shown and when the temperature was increasing the electrical efficiency decreases.

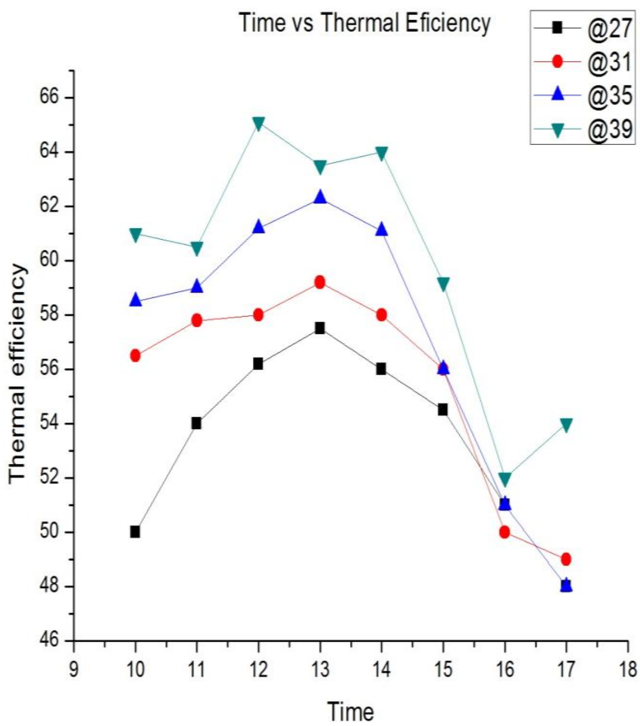


**Fig12.** *Time Vs Thermal efficiency for air based pv/t system*

This graph represents the Time Vs Thermal efficiency of the air based photovoltaic thermal system. It is different in the case of electrical efficiency. That is when the temperature increases the thermal efficiency of the solar panel also increase but not in the case of electrical efficiency. When the temperature increase from 27 to 39 the thermal efficiency of the solar panel also increases. Power output for different panel temperatures are shown in the graph below. For a temperature $27^0$c the maximum power output is obtained. When increasing the panel temperature from $27^0$c to $39^0$c there is a reduction in the power output. Only thermal efficiency increases when the panel temperature increases.

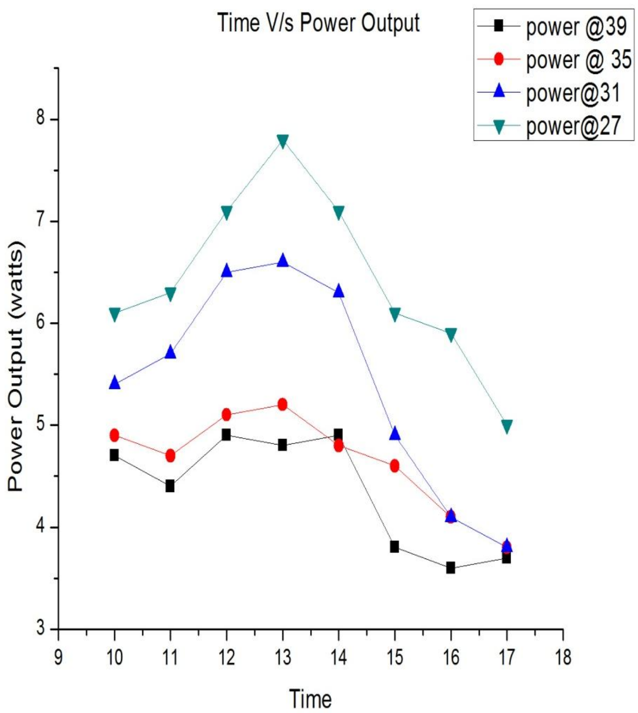


**Fig13.** *Time Vs Power output for air based pv/t system*

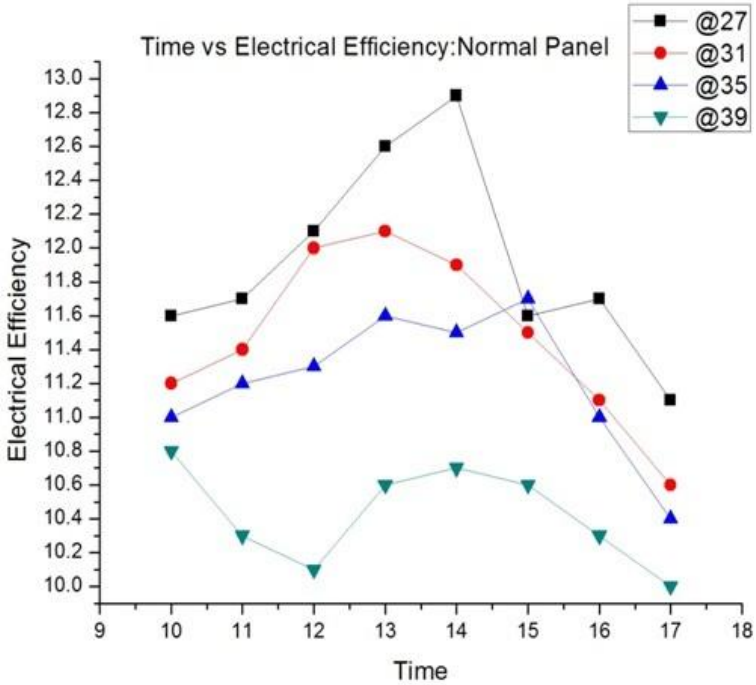


**Fig14.** *Time Vs Electrical efficiency for Normal solar panel system*

This graph represents the electrical efficiency values of normal solar panel with respect to time. In the case of normal solar panel the values are also noted down and compared with the modified panels results. As in the case of the other two systems, the electrical efficiency of the normal solar panel also decreases with increase in the temperature. The thermal efficiency of the normal solar panel system also increases with increase in the panel temperature. Time Vs different values of thermal efficiencies are plotted in the graph shown below and the thermal efficiency is maximum when the temperature is having the higher value.

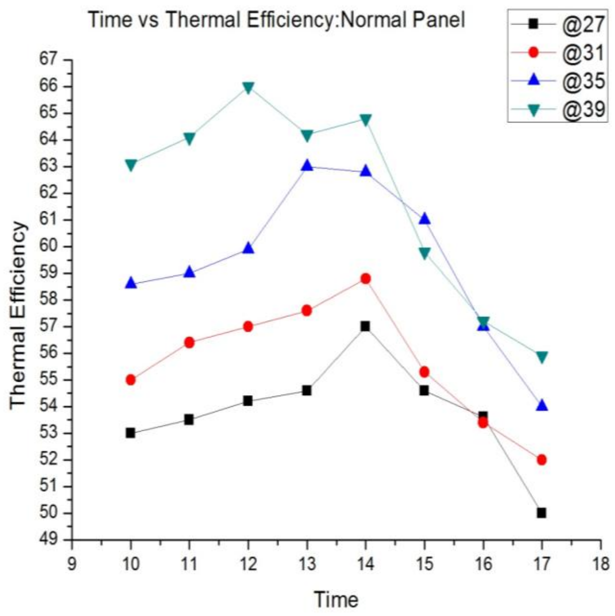


***Figure.15.*** *Time Vs thermal efficiency for Normal solar panel system*

The Power output Vs Time graph is also plotted for normal solar panel for the comparison purpose with the other two systems. Power output value is also decreases when the value of temperature increases. Power output values are also noted down for the four different panel temperature readings that are from 27 to 39$^0$c.

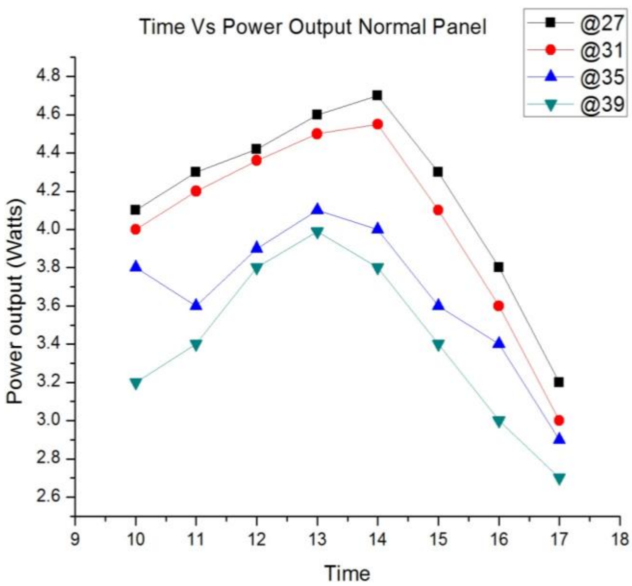


**Fig16.** *Time Vs Power output for Normal solar panel system*

## 5. CONCLUSION

After the detailed reference and performance study of various factors like Electrical efficiency, Thermal efficiency and Power outputs, it can be concluded that cooling of the solar panel increases the electrical efficiency and also power output values. Using two systems namely Water based PV/T system and Air based PV/T system both systems used for the cooling of the panel and thus improvement in the efficiencies and power output values are obtained. In this analysis water cooling method and air cooling method are used and the efficiencies are increased by considerable amount. When the temperature of the panel decreases the performance factors varies very effectively, by lowering the value of the temperature ultimate efficiency of the solar panel can be increased.This cooling method is also an effective method of improving the cell efficiency and the other important factor in this analysis is we can use the heated water or heated air for other useful purposes. That is the main advantage of the system, separate installation of water heater or air heater can be avoided, this can be used for both purposes, for increasing the cell efficiency and usage of heated water or heated air for other useful purposes.

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### AUTHORS' BIOGRAPHY

**Rahul SR** doing M-Tech in Thermal and Fluids Engineering at lbs College of Engineering kasaragod, kerala.

**Hariharn R** Currently working as Assistant Professor in Mechanical Engineering Department at lbs College of engineering kasaragod, kerala.