INTEGRATED SOLAR PHOTOVOLTAIC AND THERMAL COLLECTOR SYSTEM FOR INCREASING ENERGY EFFICIENCY

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Abstract: One of the challenges facing the world currently is how to minimize energy consumption using fossil fuels due to the negative socio-environmental impacts and price volatility. One of few approaches is to increase renewable energy sources such as solar as an alternative clean source to protect the environment, adhere to global and national policies towards the clean energy development as well as increase energy access, to urban and rural areas.

India has raised concerns regarding the development of renewable energy sources such as wind, hydro and solar energy. Integration of a combined photovoltaic and thermal system was considered to transform simultaneous energy into electricity and heat.

This was done to challenge the low energy efficiency observed when the two solar energy conversion technologies are employed separately, in order to gain higher overall energy efficiency and ensure better utilization of the solar energy. Therefore, the notion of using a combined photovoltaic and thermal system was to optimize and to improve the overall PV panel efficiency by adding conversion to thermal energy for residential and commercial needs of hot water or space heating or space cooling using appropriate technology.

The PV/T model constructed using water as fluid like the one used for the experimental work, presented a marginal increase in electrical efficiency but a considerable yield on the overall PV/T efficiency, because of the simultaneous operation by coupling a PV module with a thermal collectors.

Keywords: Solar Energy, Photovoltaic PV, solar Combined Photovoltaic and Thermal collector PV/T.

I. INTRODUCTION

This Paper is based on two aspects, namely **Analytical** or **Numerical model** works, which will entail **experimental work**. The principal objective of this research is to enhance low energy efficiency using a combine PV/T collector type system under local climate, and weather conditions of the North INDIA.

The second objective is to perform analytical or experimental work on the constructed PV/T model.

The purpose of using PV/T liquid system is to minimize energy consumption of fossil fuels and reduce the negative environmental impacts. It is known that renewable energy sources such as solar energy are an alternative clean source to protect the environment, decrease dependence on fuel energy and will never end. It contributes to customers saving on their bills and develops a new business area for the industry to create jobs.

1. PHOTOVOLTAIC (PV) SYSTEMS.

1.1 PV system components:

A Photovoltaic (PV) system also recognized as “Solar cell” can be described as a semi-conductor device designed to perform the direct conversion of electromagnetic radiation from the sun into electricity. In the middle of 1970s, PV cells became to be used for power in places where it was too expensive to use grid power, and in remote areas as well as islands. Today some countries like INDIA, many people are using electricity from PV systems than electricity from the main power grid, since PV technology is now more efficient and cost less than ever at generating electricity from sunlight.

The most basic system can use the following components:

- A “PV Module” which is the power source.
- A “Charge Controller” to avoid overcharging of the battery if using one.
- A“Battery” to simply store energy and use when there is no sunlight. It also supplies an extra power to the load that can exceed the power rating of the PV module or array.
- A “DC distributor panel” for fuses, switches, or circuit breakers for any protection.

2. COMBINED SOLAR PHOTOVOLTAIC AND THERMAL(PV/T).

The combination of a PV cells and a thermal collector is called a Combined Photovoltaic and Thermal system (PV/T). These two solar technologies are assembled together because photovoltaic cells performance decreases while the temperature of the units increases. Therefore, the addition of a thermal collector at the panel back allows the extraction of the heat from the PV cell with a circulating fluid through the pipe to increase the cell's performance. In the case that heating is required for a boiler,the extracted PV heat will also assist to increase performance. In a PV/T collector or system a PV cell does not only generate electricity, but it can also serve as a thermal absorber. This justifies the fact that PV/T systems simultaneously produce heat and power. There are four types of solar collector developed in the field of Solar PVT which are:

- PV/T Liquid collectors.
- PV/T Air collectors.
- Ventilated PV with heat recovery.
- PV/T Concentrators.

Therefore, in this paper only water type systems were considered because hybrid water PV/T systems can be used effectively on the actual season, especially in regions where ambient temperature is usually below 20 degrees like in North India.

3. PV/T Liquid Collectors.

They are designed to heat up the water and instantaneously produce electricity, liquid PV/T collectors (PV/TLC) are similar to flat plate collector water heating system. In a PV/TLC, the PV cells absorb a huge amount of solar radiation that helps to generate undesirable heat, which can be reused in water pre-heating uses and there are mostly used for different domestic and industrial applications.

PV/TLC can either be glazed or unglazed. Unglazed liquid type PV/T collectors ensure a higher electrical performance and a lower thermal performance. A glazed liquid collector can generate a greater heat loss and resultantly lower operating temperatures. Furthermore water, air or refrigerant can be used as the heat removal support to cool the solar cells. The most convenient liquid to use is actually water, not only because of its high thermal capacity, but due to its optical properties.

4. PV Efficiency.

The PV efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun, efficiency is the most used parameter to compare the performance of different solar devices. It depends on the range and intensity of the incident sunlight and the temperature of the PV module. Therefore, the PV efficiency of the module can be determined as the fraction of incident power which is converted to electricity and is defined as follow:

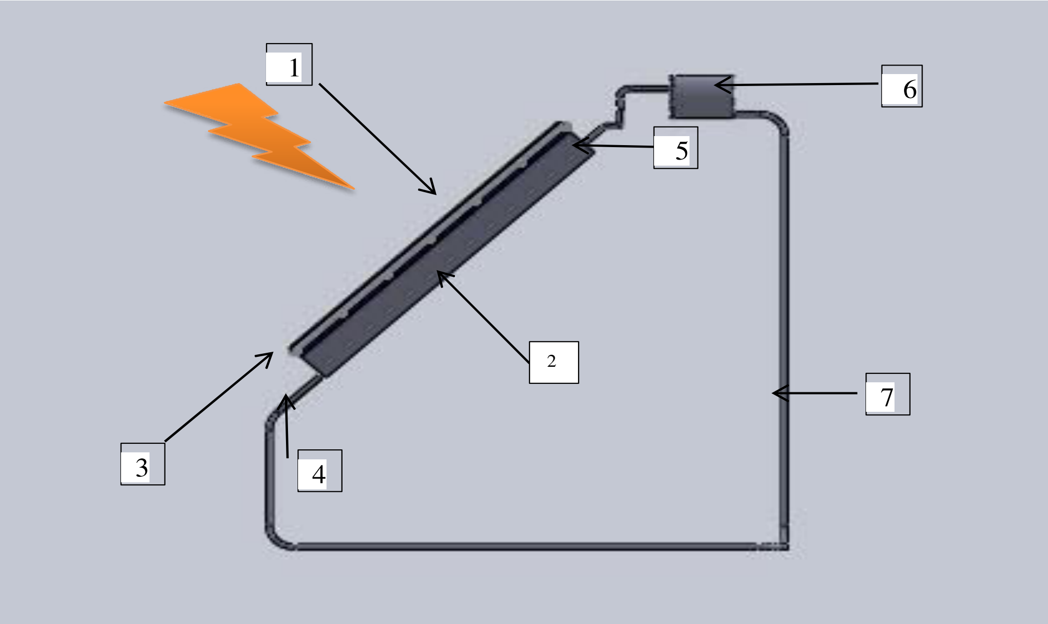


Figure1: Assembly of the PV/T Collector System side view drawing. (1) Cover plate; (2) Thermal collector (water flow); (3) Photovoltaic cell (PV module); (4) Inlet water flow; (5) Outlet water flow; (6) Tank; (7) Flexible pipe or water conduct.

Since,

$$P_{\max} = FF * I_{sc} * V_{oc}$$

$$\eta_{ee} = (FF)\frac{I_{sc} * V_{oc}}{P_{in}}$$

Were,

- I_{sc} is the current [A].
- V_{oc} is the cell voltage [V].
- FF is the fill factor.
- P_{in} is the Input power , which is equal to $P_{in} = A_{pv} * E$.
- E is the irradiance on the collector surface [W/ m^2].
- A_{pv} is the PV module area [m^2].

Knowing the efficiency of a panel is important in order to choose the correct panels for the appropriate photovoltaic system.

4.1. PV/T Energy Efficiency Determination.

PV/T modules are more productive with the ability of generating more energy per unit surface area than side by side PV panels and solar thermal collector. The results regarding the PV/T efficiency can be obtained by addition since it depends on the thermal and electrical efficiency of the device or the hybrid system.

$$\eta_{PV/T} = \eta_{ee} + \eta_{th} = \frac{W + Q}{H}$$

Where:

- W is the mechanical work, or the electricity produced.
- Q is the thermal energy delivered.
- H is the input energy.
- $\eta_{ee} = W / H$ and $\eta_{th} = Q / H$ are respectively representing the electric efficiency and heat efficiency.

5. EXPERIMENTAL PROCESS.

The experiment of a scale model constructed, and tested PV/T water system was done in the North India. The experiments parameters were collected for seven (7) days during the period of April 2020 from 8:00am to 18:00pm each day. The solar radiation and atmospheric temperature data were collected from the Weather Forecast station of Metrological department of India.

The following measurements were collected from the weather station of the department which has been connected whit a data log monitor located on top of the building roof .

- Solar irradiation or insolation.
- Ambient temperature of the location.
- Wind speed.

The rest of the data were measured manually:

- Current and Voltage
- Top and the back temperature of the PV/T device.
- Temperature inlet and outlet of the fluid.

The PV/T water system was tested to determine its electrical and thermal performances at steady conditions for various operating temperature. The inlet temperature of water was not constant due to the type of system implemented “Close loop system", it changes as the outlet temperature changes too. For measuring the load current and load voltage multi-meters were used separately, besides an error of ± 0.3% was considered for all the measurements. The PV/T collector was operated at a variable mass flow rate during the experimentation. Digital infrared temperature gun was used to record the top and the back temperature of the panel. For the determination of system thermal efficiency, the PV/T device was connected with a load to avoid PV module overheating and to simulate real system operation using the solar radiation that is converted into heat instead of electricity.

All the data related to the electrical and thermal performances of the PV/T were taken with thirty (30) minutes of interval between the values. This data was used to evaluate the overall efficiency of the PV/T solar collector water based.

Figure 2 shows illustration of the different parameters measured to analyse the performance of the collector.

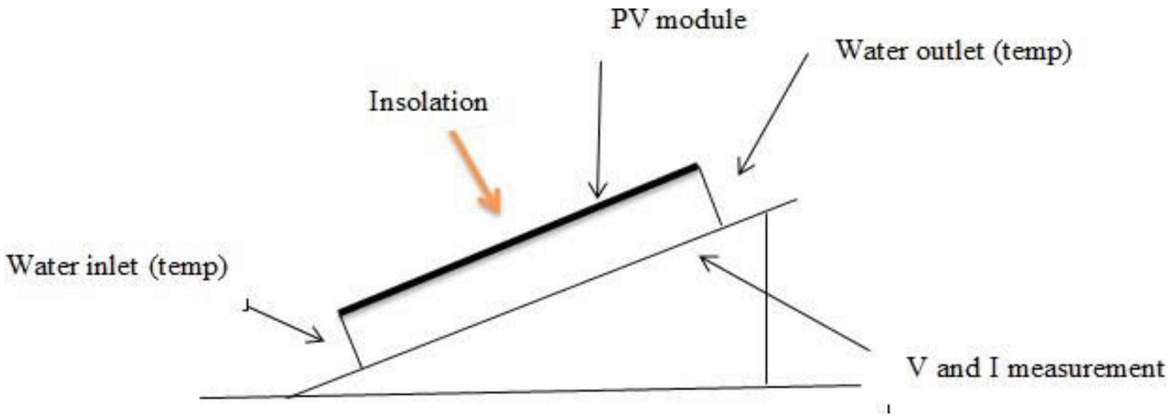


Figure 2: Schema to indicate different parameters measured during experimentation.

II. RESULTS AND DISCUSSION

PV cells are suffering from low electrical energy efficiency due to the warming of the cells and the unavailability of low ambient temperature for cooling warm PV cells. Thus, by placing a solar thermal collector behind a solar photovoltaic PV module, the PV cells can be cooled up while at the same moment recovering the heat. In fact, the solar collector can return most of the energy that passed through the module that would probably be lost, then recovering it for useful and productive applications.

In this situation, the PV cells were cooled by solar thermal collector with inlet and outlet fluid flow inside the absorber as shown in Figure 3.

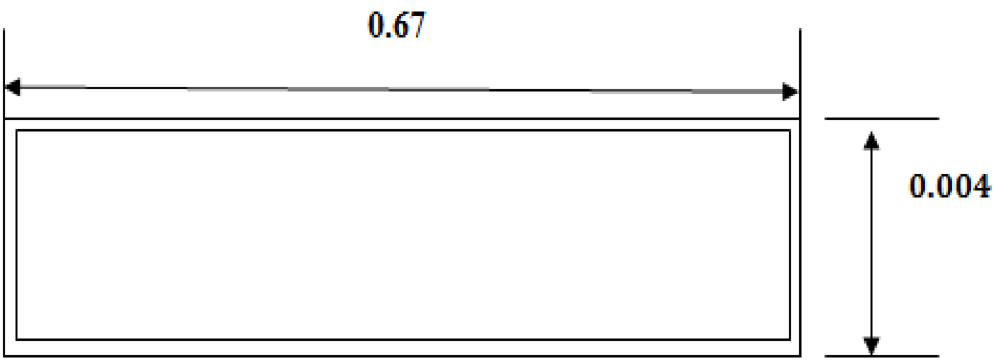


Figure 3: Schema of the PV/T collector side.

The heat produced by the solar cells was utilized to warm the water under the module in order to control the temperature of the PV by the flow of the cooling fluid. The hourly variation of the ambient temperature, water inlet and outlet temperature, solar radiation for the seven days. During the test, the maximum hot water temperature 44°C of the system was obtained while the ambient temperature was at 38.8°C. The efficiencies results plotted on the graphs below were based on performance analysis for seven days data obtained. All the value were recording with an interval of 30 minutes on the days of experiments (from 14th to the 20th of April 2020). Figures below show the efficiencies results of the collector versus time from the first day to the last day of experiment. The results on the graphs represent the values of thermal and electrical efficiency at a specific time of the day.

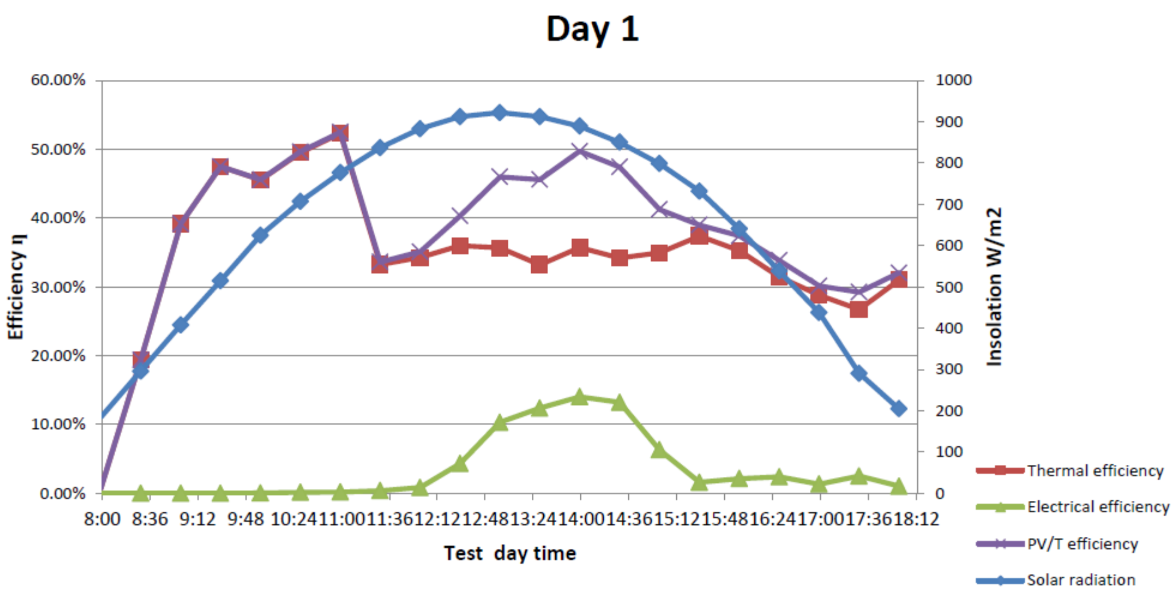


Figure 4: Graphical plot of test result of efficiencies (thermal, electrical and PV/T) as function of time during day 1.

Figure 4 represents efficiencies of four distinctive parameters (Thermal efficiency, electrical efficiency, PV/T efficiency, solar radiation) with time assessed in Day 1. The results show that from 08:00 to 11:00 am, Thermal and PV/T efficiencies exhibit increase fluctuation that reached a maximum of 53% that later decreased to 33% between 11:00 and 11:30 am. Conversely, from 12:00 to 18:00 pm the aforementioned efficiencies repetitively increased and progressively decreased with PV/T dominating over thermal efficiency. On the other hand, the solar radiation efficiency shows a parabolic tendency with a progressive increase up to 55 % from 08:00 to 12:30 pm that continuously dropped to 11% between 12:30 to 18:00 pm. Finally, from 08:00 to about 11: 36 Am, the electrical efficiency was 0% and steadily rose to 13% from 11:50 am to 14:00 pm and drastically dropped to 2% from 14: 30 to 15:30 pm and became constant till 18:00 pm.

Here, the first peak observed at 11am was due the connexion of the load on the circuit to be able to read the current generated by the PV module. The curves related to electricity and thermal efficiency shown the performance during the preparation of the experiment before the normal operating system. We also noticed when the thermal efficiency drops the inlet temperature started to rise from 18° to 20° . The designed PV/T was responding as expected to the solar radiation, the results on the second day of the experiment were expressive compared to the starting day.

Figure 5: Graphical plot of test result of efficiencies (thermal, electrical and PV/T) as function of time during day 2.

The results plotted in Figure 5 show that from 08:00 to 10:30 am, Thermal and PV/T efficiencies exhibit increase until a value of 44% that later decreased a bit between 11:00 and 12:30 am. On the other hand, from 12:12 to 18: 12 pm the above-mentioned efficiencies repetitively increased and progressively decreased with PV/T dominating over thermal efficiency. The solar radiation efficiency shows a parabolic tendency again with a progressive increase from 08:00 to 12:48 pm that continuously decrease to 11% between 12: 48 to 18: 12 pm. Finally, from 08:00 to about 9: 30 am, the electrical efficiency was 0% and steadily rose continuously from 11:50 am to 14:00 pm and drastically dropped from 14: 00 to 15:30 pm. The highest value on the electrical efficiency was obtained 18.89%. From the recorded data calculated, Figure 30 presents values of four characteristic parameters (Thermal efficiency, electrical efficiency,

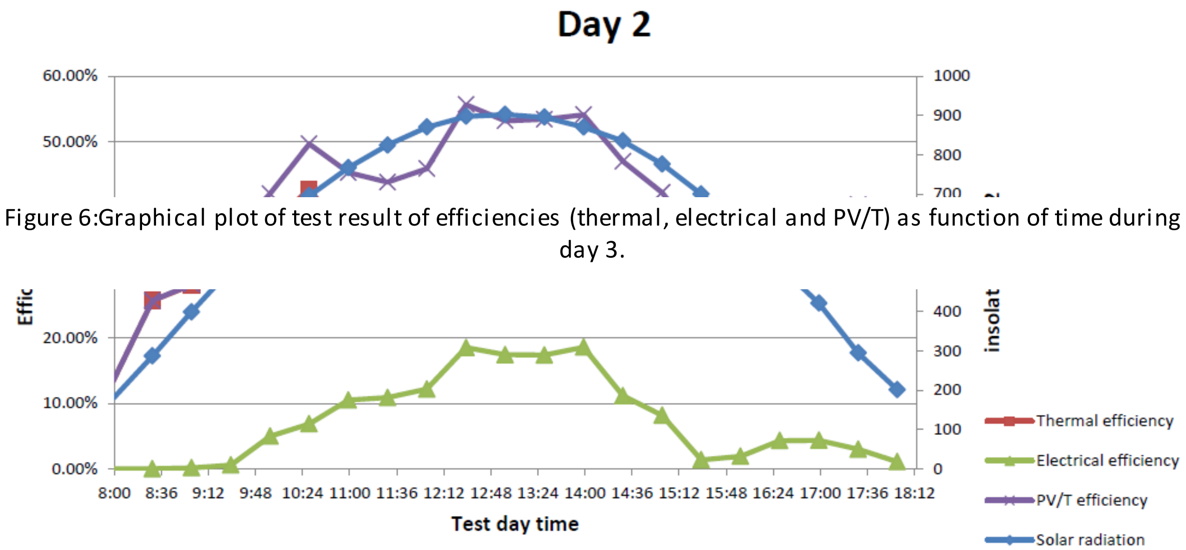
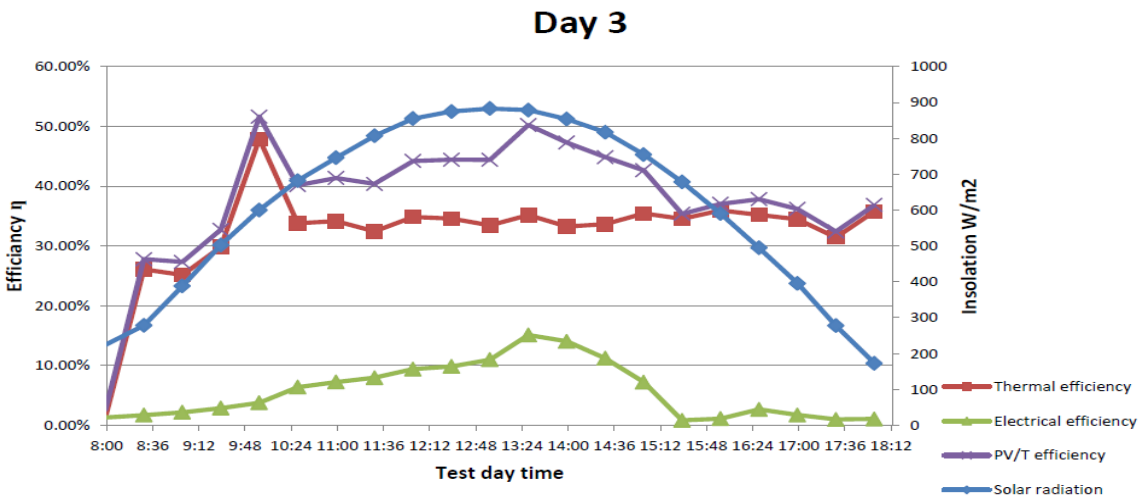


Figure 6:Graphical plot of test result of efficiencies (thermal, electrical and PV/T) as function of time during day 3.

PV/T efficiency, solar radiation) with time assessed in Day 3. The curves of thermal efficiency show a brutal drop point from 48% to 33% between 9:30 to 10:30; and the electrical efficiency curve shows an intense peak at 13.30pm with an efficiency of 15.09 %. These results are explained by the presence of the mixture of water in the system.Also, from 10:30 to 18:00 the

Thermal efficiency swings slightly up and down like between 33% and 36%. The PVT shows the exact intense peak but with greater efficiency, while the electrical efficiency became quickly efficient compares to on day 1 and 2, reach its higher value around 13:30 sensibly of 16%.The same observation as Figure 6 was done on the Figure 7 as shown below, but with slightly



differences on the time where the electrical efficiency occurred, the thermal efficiency dropped and a little change on the solar radiation. The parabolic curve observed from 9:30 to 15:30 on the electrical efficiency was due to the solar radiation. On the other hand, the thermal efficiency reached a maximum between 9:30 and 10:30 of 48%, before dropped and started rise to 42% from 11:30 to 18:00. The maximum value of the PV/T efficiency was observed at 11:00.

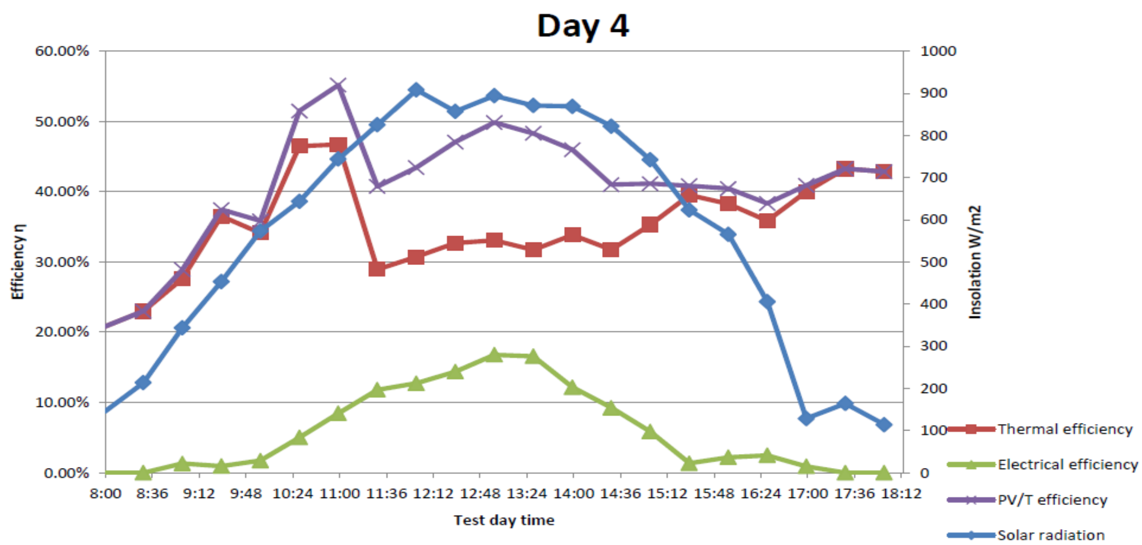


Figure7: Graphical plot of test result of efficiencies (thermal, electrical and PV/T) as function of time during day 4.

Moreover, the parabolic increase and decrease behaviour of solar radiation observed between 08:00 am and 18: 10 pm was due to the angle of the panel facing the sun.

In Figure 8, the quick rising of the electrical efficiency observed could be explain by the high insolation from 9:00 to 17:30, it varied and reached a maximum value of 13%. The thermal efficiency reached its peak to 62% at 10:30.

This can be explained by the usage of a closed loop system because of the mixture of cold and warm water provoked a rising of inlet temperature which at a certain time of the day does not

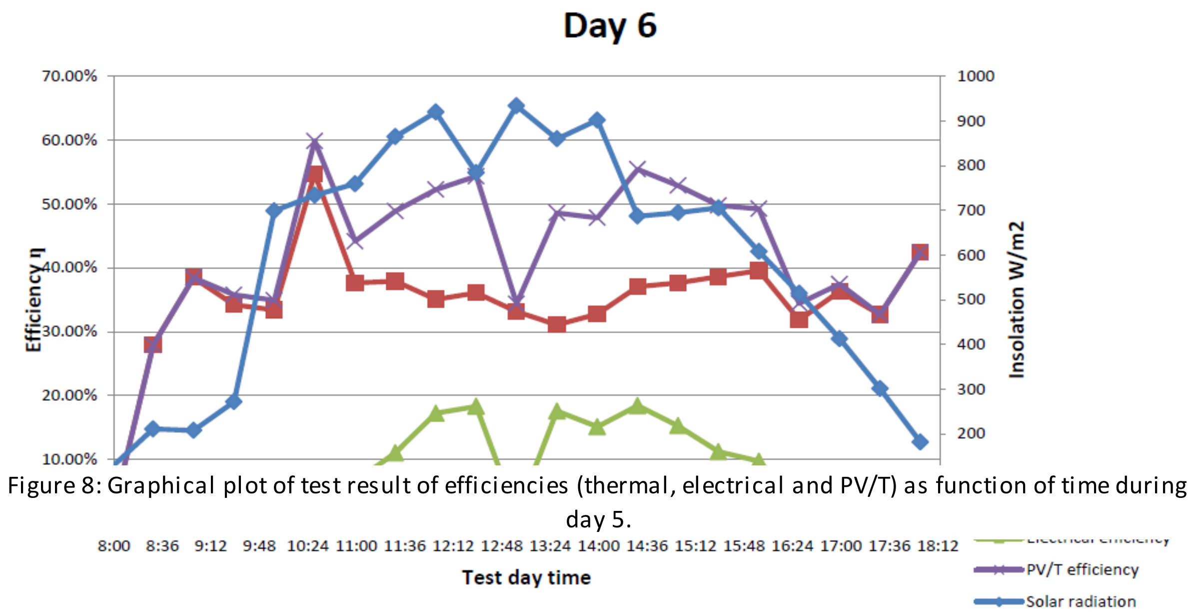
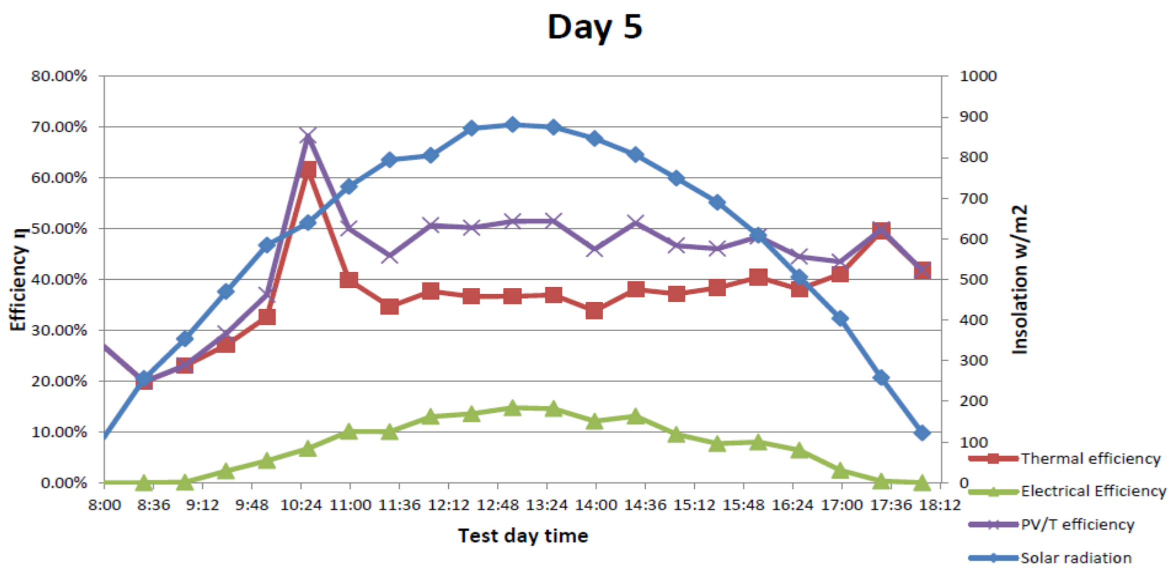


Figure 8: Graphical plot of test result of efficiencies (thermal, electrical and PV/T) as function of time during day 5.



cool the PV module anymore to affect the electrical efficiency and the PV/T efficiency. Equally, from 11:00 to 18:00 the PV/T and thermal efficiencies repetitively increased and progressively decreased with PV/T dominating over thermal efficiency until the electrical efficiency were nil.

Figure 9: Graphical plot of test result of efficiencies (thermal, electrical and PV/T) as function of time during day 6.

The results on Figure 9 are completely different. Solar radiations dropped at 12pm from 902 W/m^2 to 785.1 W/m^2 , with a dramatic slip of the electrical and PV/T efficiencies at 12:30. As the inlet temperature increased the thermal efficiency decreased and became more or less constant with a peak of 55% at 10:00. The fluctuation of the electrical efficiency remained very low compared to thermal efficiency, but more important compare to the previous days with five plotted value over 15% of efficiency. Finally, from 08:00 to about 9:30, the electrical efficiency was 0% and steadily rose to 13% from 10:00 am to 12:30 and drastically dropped to 0% from 12: 30 before rise again from 12:30 to 18% and progressively dropped till 18:00 pm.

In figure 10 as shown below, several peaks related on or to the different efficiencies are noticeable, therefore the reaction which occurs on solar radiations dropped at 12:00, 13:00 and 15:30 lead to the yield observed for these efficiencies. The Electrical efficiencies are low and not constant compared to thermal efficiency and it depends more on the solar radiation at the time of the day. Two peaks occurred for the electrical efficiency with the best efficiency of 19% at 13:00. In general , electrical efficiency varied between 0% to 18.89%, thermal efficiency from 0.76% to 61.65%and for the PV/T water solar collector efficiency between 1% to 68% with an average value of 41%., Figures above are the perfect illustration of it. During testing days, the water got warm to a maximum temperature of 44°C.

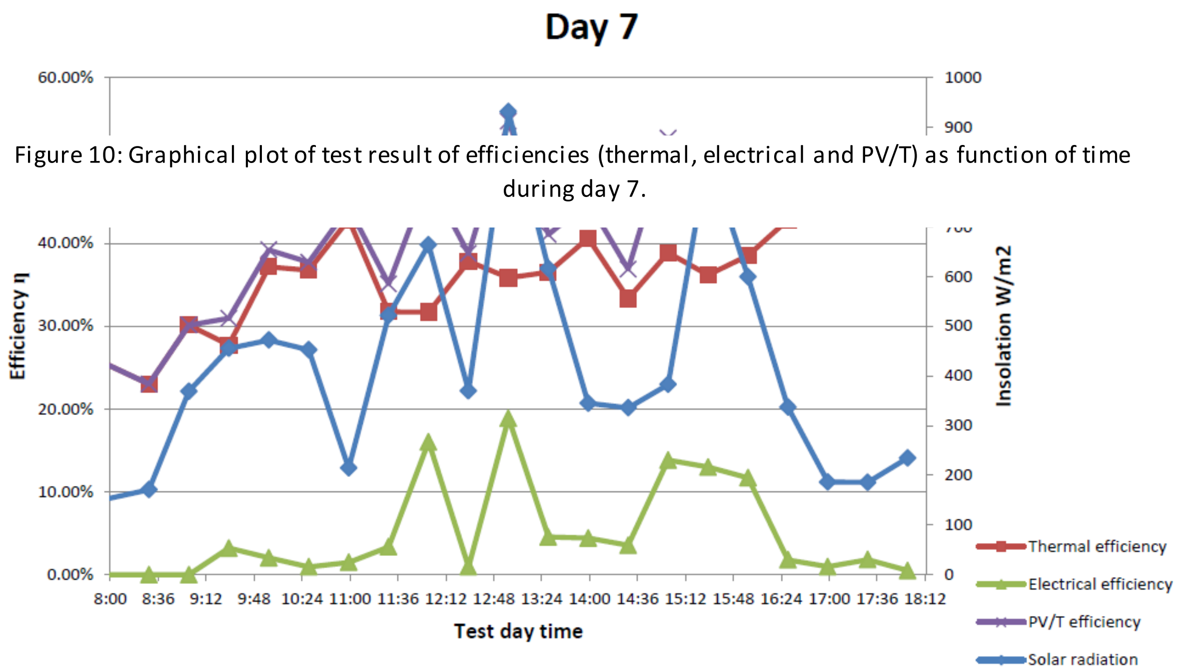


Figure 10: Graphical plot of test result of efficiencies (thermal, electrical and PV/T) as function of time during day 7.

III. CONCLUSION

The impact of low energy efficiency of PV module in the market globally and particular in INDIA increases the payback period of the system and increase the cost of energy produced. The main objective of this research was to develop, build and test a solar energy system that can help on resolving the problem of low efficiency. A literature review on available works, experiments, and analyses of PV/T liquid systems using water as fluid was presenting a low increase in electrical efficiency but a considerable yield on the overall PV/T efficiency, because of the simultaneous operation of this system coupling with a thermal collector. Design and constructed PV/T were described.

The electrical efficiency of the PV/T was obtained from the ratio of the output electricity to the incident solar radiation with a maximum value of 18.89%. The thermal efficiency of the water PV/T was defined as the ratio of the output heat to the incident solar radiation with a maximum temperature of water heated at 44°C. From the PV/T model, it was found that the results of thermal efficiencies were more favourable to be used, This showed that the effect could not be neglected in the calculation of the global PV/T efficiency. It was also shown that using water to cool the PVT system could help increase the electrical efficiency to a better performance with decrease of solar radiations on the PV module.

Additionally, the PV/T presented a considerable yield on the overall PV/T efficiency, because of the simultaneous operation of the PV module and the thermal absorber even if the results still need to be improved. The fact of enhanced the energy efficiency on the PV/T will increase the competitiveness of PVT collectors and utilization of renewable energy devices.

IV. 5.5 RECOMMENDATIONS

Future work should have different approaches, especially on the system itself. The principle of using a coolant should have met the expectation on the electrical efficiency at a certain temperature if the system was not a closed loop using the same circulating water. The eventual heat capacity of water should be considered non constant since it can change according to the ambient temperature to determine the mass flow rate. The celling between the PV module and the absorber should be properly done instead of usage of cheap glue, it will be probably better to well if the materials choose match. Also extend the period and time of experimentation to have a strong view during the four seasons (winter, summer, autumn and spring).

V. REFERENCES

1. Anderson, T.N., Duke, M. & Carson, J.K. 2008. *Designing photovolaic/thermal solar collectors for building integration*. Nova Science Publishers, Inc.
2. Andrews, J.W. 1981. *Evaluation of flat-plate photovoltaic/thermal hybrid systems for solar energy utilization*. Department of Energy and Environment, Solar Technology Group, Brookhaven National Laboratory.
3. Anon. Determination of Optimum Tilt Angle and Orientation of a Flat Plate Solar Collector for Different Periods in Kano.
4. Baljit Singh, M.Y.O. 2009. A review on photovoltaic thermal collectors. *Journal of Renewable and Sustainable Energy*, 1(6).
5. Baltas, P., Tortoreli, M. & Russell, P.E. 1986. Evaluation of power output for fixed and step tracking photovoltaic arrays. *Solar Energy*, 37(2): 147–163.
6. Betts, T.R., Zdanowicz, T., Prorok, M., Kolodenny, W., Moor, H.D., Borg, N. v d, Stellbogen, D., Hohl-Ebinger, J., Warta, W., Friesen, G., Chianese, D., Montgareuil, A.G.D., Herrmann, W., Berrade, J.D., Moracho, J., Cueli, A.B., Lagunas, A.R.R. & Gottschalg, R. 2006. Photovoltaic Performance Measurements in Europe: PV-Catapult Round Robin Tests. In *2006 IEEE 4th World Conference on Photovoltaic Energy Conference*. 2006 IEEE 4th World Conference on Photovoltaic Energy Conference. 2238–2241.
7. Chang, T.P. & others. 2008. Study on the optimal tilt angle of solar collector according to different radiation types. *International Journal of Applied Science and Engineering*, 6(2): 151–161.
8. Charalambous, P.G., Maidment, G.G., Kalogirou, S.A. & Yiakoumetti, K. 2007. Photovoltaic thermal (PV/T) collectors: A review. *Applied Thermal Engineering*, 27(2–3): 275–286.
9. Chow, T.T. 2010. A review on photovoltaic/thermal hybrid solar technology. *Applied Energy*, 87(2): 365–379.
10. Daghigh, R., Ruslan, M.H. & Sopian, K. 2011. Advances in liquid based photovoltaic/thermal (PV/T) collectors. *Renewable and Sustainable Energy Reviews*, 15(8): 4156–4170.
11. Dg, K. 2002. Convection heat transfer between a horizontal surface and the natural environment. Du, B., Hu, E. & Kolhe, M. 2012. Performance analysis of water cooled

concentrated photovoltaic (CPV) system. *Renewable and Sustainable Energy Reviews*, 16(9): 6732–6736.

12. Moradi, K., Ali Ebadian, M. & Lin, C.-X. 2013. A review of PV/T technologies: Effects of control parameters. *International Journal of Heat and Mass Transfer*, 64: 483–500.
13. Nalis, A. & others. 2012. Quasi-Dynamic Characterization of Hybrid Photovoltaic/Thermal (PV/T) Flat-Plate Collectors.
14. POPESCU, A., PANAITE, C.-E. & STADOLEANU, O.-V. 2013. Combined Photovoltaic and Thermal Solar Panels-Enhanced Energy Conversion and Heat Transfer. *TERMOTEHNICA Supliment*, 1.
15. Radziemska, E. 2009. Performance Analysis of a Photovoltaic-Thermal Integrated System. *International Journal of Photoenergy*, 2009: 1–6.
16. Rosli, M., Misha, S., Sopian, K., Mat, S., Sulaiman, M.Y. & Salleh, E. 2014. Parametric analysis on heat removal factor for a flat plate solar collector of serpentine tube. *World Applied Sciences Journal*, 29(2): 184–187.
17. Rouholamini, A., Pourgharibshahi, H., Fadaeinedjad, R. & Moschopoulos, G. 2013. Optimal tilt angle determination of photovoltaic panels and comparing of their mathematical model predictions to experimental data in Kerman. In *Electrical and Computer Engineering (CCECE), 2013 26th Annual IEEE Canadian Conference on*. IEEE: 1–4.
18. Skoplaki, E. & Palyvos, J.A. 2009. On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. *Solar Energy*, 83(5): 614–624.
19. Srinivas, M. & Jayaraj, S. 2013. Investigations on the performance of a double pass, hybrid-type (PV/T) solar air heater. *Journal homepage: www. IJEE. IEEFoundation. org*, 4(4): 687–698.
20. Stoffel, T., Renne, D., Myers, D., Wilcox, S., Sengupta, M., George, R. & Turchi, C. 2010. *Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data (csp)*. National Renewable Energy Laboratory (NREL), Golden, CO.
21. Takashima, T., Tanaka, T., Doi, T., Kamoshida, J., Tani, T. & Horigome, T. 1994. New proposal for photovoltaic-thermal solar energy utilization method. *Solar Energy*, 52(3): 241–245.
22. Tiwari, G.N. & Dubey, S. 2010. *Fundamentals of photovoltaic modules and their applications*. Royal Society of Chemistry.

23. Tripanagnostopoulos, Y. 2007. Aspects and improvements of hybrid photovoltaic/thermal solar energy systems. *Solar Energy*, 81(9): 1117–1131.
24. Tripanagnostopoulos, Y., Souliotis, M., Battisti, R. & Corrado, A. 2003. Application aspects of hybrid PV/T solar systems. *Physics Department, University of Patras, Patras*, 26500.
25. Zeman, M. 2003. Introduction to photovoltaic solar energy. *Delft University of Technology*, 2(6).
26. Zondag, H.A. 2008. Flat-plate PV-Thermal collectors and systems: A review. *Renewable and Sustainable Energy Reviews*, 12(4): 891–959.
27. Zondag, H.A., Van Helden, W.G.J., Bakker, M., Affolter, P., Eisenmann, W., Fechner, H., Rommel, M., Schaap, A., Soerensen, H. & Tripanagnostopoulos, Y. 2006. PVT roadmap. A European guide for the development and market introduction of PVT technology.
28. Erdil, E., Ilkan, M. & Egelioglu, F. 2008. An experimental study on energy generation with a photovoltaic (PV)–solar thermal hybrid system. *Energy*, 33(8): 1241–1245.
29. Hammond, R.L. & Everingham, S. 2003. Stationary batteries in cycling photovoltaic applications. *Proceedings of Battcon*..
30. Hasan, M.A. & Sumathy, K. 2010. Photovoltaic thermal module concepts and their performance analysis: A review. *Renewable and Sustainable Energy Reviews*, 14(7): 1845–1859.
31. Van Helden, W.G.J., van Zolingen, R.J.C. & Zondag, H.A. 2004. PV thermal systems: PV panels supplying renewable electricity and heat. *Progress in Photovoltaics: Research and Applications*, 12(6): 415–426.
32. Huizinga, F.S. 2013. Combined Photovoltaic and Solar Thermal (PV-T) systems, Design optimization and thermal annealing.
33. Ibrahim, A., Othman, M.Y., Ruslan, M.H., Mat, S. & Sopian, K. 2011. Recent advances in flat plate photovoltaic/thermal (PV/T) solar collectors. *Renewable and Sustainable Energy Reviews*, 15(1): 352–365.
34. Iordanou, G. 2009. *Flat-plate solar collectors for water heating with improved heat transfer for application in climatic conditions of the Mediterranean region*. Durham University.
35. Jack, J.J.B., Noble, D. & Tsien, R.W. 1975. *Electric current flow in excitable cells*. Clarendon Press Oxford.
36. Kalogirou, S.A. 2004. Solar thermal collectors and applications. *Progress in Energy and Combustion Science*, 30(3): 231–295.

37. Kalogirou, S.A. & Tripanagnostopoulos, Y. 2006. Hybrid PV/T solar systems for domestic hot water and electricity production. *Energy Conversion and Management*, 47(18–19): 3368–3382.
38. Miroslav Bosanac, B.S. Photovoltaic/Thermal solar collectors, and their potential in denmark.
39. Mittelman, G., Kribus, A. & Dayan, A. 2007. Solar cooling with concentrating photovoltaic/thermal (CPVT) systems. *Energy Conversion and Management*, 48(9): 2481–2490.
40. Moradgholi, M., Nowee, S.M. & Abrishamchi, I. 2014. Application of heat pipe in an experimental investigation on a novel photovoltaic/thermal (PV/T) system. *Solar Energy*, 107: 82–88.