Comparative Analysis of Solar Photovoltaic Thermal (PVT) Water and Solar Photovoltaic Thermal (PVT) Air Systems

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Abstract— *The present commercial photovoltaic solar cell (PV) converts solar energy into electricity with a relatively low efficiency less than 15%. More than 80% of the absorbed solar energy is dumped into the surroundings as heat after photovoltaic conversion. The electrical efficiency of photovoltaic system drops as its operating temperature rises and for this reason PV cooling is necessary. Therefore, stabilizing the temperature of photovoltaic modules at low level is highly desirable to improve the efficiency. Hybrid solar technology has the advantage of increasing the energy output per unit installed collector area. India as a tropical country is deemed to have a good potential of applying this technology. In this paper, solar PVT (Photovoltaic-Thermal) air and water collector hybrid systems were designed by using a poly crystalline silicon PV module as solar absorber and the comparative study was carried out. Air and water cooling of a commercial PV module configured as PVT air solar collector and PVT water solar collector by forced flow is studied. The energy and exergy performance of the PVT systems has been experimentally determined for various mass flow rates of fluids. The experimental result shows that the combined PVT system has got better performance than the simple PV and solar PVT water hybrid system has better efficiency than both. These systems are simple and suitable for building integration providing space heating depending on the season and for low temperature heating application.*

Keywords—Solar Photovoltaic, Solar PVT, Hybrid System, Energy Analysis, Exergy Analysis.

I. INTRODUCTION

Currently energy is an important issue all over the world. Due to increased industrial activities in developing and developed countries the demand for fossil fuel has grown steadily. Estimating the world energy demand may increase by 45% between 2006 and 2030, the rate of increase will be 1.6% per year. It is suggested that renewable energies including solar energy, wind power, hydropower, biofuel, geothermal energy will provide a solution to resolve the global warming problem and reduce the potential of energy crisis. When the renewable energies become popular in the energy market the demand of fossil fuels will be reduced. In the near future when the renewable energies will replace fossil fuels potential climate change will be mitigated.Solar photovoltaic and thermal hybrid system is a combination of solar photovoltaic and solar thermal system which at a time produce both electricity and thermal energy simultaneously. A photovoltaic-thermal (PV-T) system is defined as the integration of photovoltaic and solar thermal technologies into one single system, in that both useful heat energy and electricity are produced. In PV-T systems, solar thermal collectors are combined with PV cells which form hybrid energy generating units that simultaneously produce two types of energy required by most consumers: low temperature-heat and electricity. The absorbed solar radiation from the sun is partly converted to electricity by the PV cells and part of the excess heat generated in them is transferred to the heat exchanger in thermal contact with the PV cells while the rest is lost to the ambient.

The present commercial photovoltaic solar cell (PV) converts solar energy into electricity with a relatively low efficiency less than 15%. More than 80% of the absorbed solar energy is dumped into the surroundings as heat after photovoltaic conversion. The electrical efficiency of photovoltaic system drops as its operating temperature rises and for this reason PV cooling is necessary. Therefore, stabilizing the temperature of photovoltaic modules at low level is highly desirable to improve the efficiency. Hybrid solar technology has the advantage of increasing the energy output per unit installed collector area. India as a tropical country is deemed to have a good potential of applying this technology. There are several advantages of using solar photovoltaic thermal hybrid system some of which are listed below:

- Two Forms of Energy can be obtained from One System at a time.
- It increases service life of system
- It increases the overall efficiency of the system
- Overall cost of the system will be reduced.
- The total area used to extract a given amount of electricity and heat may be smaller than for two separate systems.
- The materials used for a PV-T plant, and thus the total energy and economy balance, may be better for separate units.

The objective of this study is as follows:

- To study the thermal and electrical efficiency of the PV-T air and PV-T water collector system.
- To study the overall efficiency of both the systems.
- To perform exergy analysis and energetic efficiency analysis of PV-T air and PV-T water collector system
- To compare the performance of PV-T air, PV-T water collector system and ordinary solar PV.

II. METHODOLOGY

2.1 Experiment Methodology

The experiments were carried out under the climatic conditions of Bhopal. Air and waterare used as a coolant in the system with a varying mass flow rate. Ambient temperatures, relative humidity, V_w, G, V_{oc}, I_{sc}, P_m, front side and back side temperature of module, fill factor, voltage and current at maximum power, inlet and outlet temperature of air and water were measured every one hour for solar PV, solar PV-T air and Solar PV-T water systems.

2.2 Experimental Setup

The solar PV/T air and solar PV-T water systems were constructed using 37 W polycrystalline silicon solar panel. The area of panel is 0.3216 sq. m. The solar PV-T air system was constructed by enclosing solar panel in a mild steel box with glass cover at top. The enclosure is acting as an absorber. At the bottom a 12V DC fan is used to circulate the air in the system. Glass partitions are used for uniform cooling on the front surface of the panel. Solar PV-T water system was constructed by providing copper sheet and copper tubes as the back of solar panel through which water is circulated.

Fig.1: Experimental Setup

2.3 Instruments Used

Table 1: Instrument Used in Experiments

S. No.	Instrument	Accuracy	Range	Model Make
1	Solar Module Analyser	+/- 1%	0-0 V 0.01-10A	MECO 9009
2	Solar Power Meter	+/- 5%	0-1999 W/m^2	Tenmars TM-207
3	Humidity/Temperature meter	0.1% R.H. +/- 0.8 ^{0}C	R.H. – 0 – 80% & 0-50 ^{0}C	Lutron HT-3006A
4	IR Thermometer	+/- 2 ^{0}C	-18 to 400 ^{0}C	Raytec MT4
5	Mercury Thermometer	+/- 1 ^{0}C	-10 ^{0}C to 110 ^{0}C	Elite

2.4 Performance Evaluation

Combination of efficiency terms describes the performance of PV-T collector. Thermal efficiency and electrical efficiency are the basic ones. Thermal efficiency is the ratio of thermal gain of the system to the incident solar irradiation and electrical efficiency is the ratio of electrical gain of the system to the incident solar irradiation on the collector's surface area within a given period of time. Overall efficiency is the sum of thermal and electrical efficiency and is used to evaluate the overall performance.

Photo Electric conversion efficiency, $\eta e = \frac{I_m V_m}{GA}$ (1)

Thermal Efficiency, $\eta th = \frac{mc_p (T_f - T_i)}{GA}$ (2)

Where,
m is mass flow rate of air in kg/sec,
c_p specific heat of air (1005 J/KgK),
G is the daily global solar radiation on the collector surface,
T_i is inlet fluid temperature and
T_f is the outlet fluid temperature

Overall Efficiency, $\eta_o = \eta_{th} + \eta_e$ (3)

The energy saving efficiency $\eta_f$is also used: it is defined as:

Energy saving efficiency, $\eta_f = \eta_e / \eta_{power} + \eta_{th}$ (4)

Where η_{power} is the electric power generation efficiency of the conventional power plants; its value can be taken as 38%.

2.4.1 Energy Efficiency of Solar Panel

According to first law of thermodynamics,

$$E_{in} = E_{out} \quad (5)$$

General equation for the exergy balance:

$$EX_{in} - E_{out} = E_{loss} \quad (6)$$

Energy efficiency of the solar PV can be defined as the ratio of power output to energy input of the solar PV.

The energy conversion efficiency of the solar PV (η_{energy}) is calculated from the following equation: [1-2].

The current-voltage characteristics of the electric circuit of solar cell can be described by the following simplified equation

$$I = I_1 - I_0 \times \exp^{\left[\frac{q\times(V-IR_s)}{A\times K\times T}\right]} \quad (7)$$

The electric power output of PV is:

$$P_{el} = I \times V \quad (8)$$

The maximum power output is given by:

$$P_{max} = V_{OC} \times I_{SC} \times FF \quad (9)$$

$$P_{max} = V_{mp} \times I_{mp}$$

The solar energy absorbed by the PV modules is converted to electric energy and thermal energy, which is dissipated, by convection, conductive, and radiation.

A dynamic thermal model proposed by Duffie and Beekman, included a lump overall loss coefficient UL for a unit area [3]

2.4.2 Exergy Efficiency of Solar Panel

Exergy analysis includes a consideration of energy quality or capability, which permits evaluation of the most effective, not just most efficient, use of energy potential. For the steady-state flow process during a finite time interval, the overall exergy balance of the solar PV can be written as follows [4].

Exergy Input = Exergy Output + Exergy Loss + Irreversibility (10)

This degradation in the quality of energy is called exergy loss (availability loss). The exergy loss is also called irreversibility [5].

Exergy efficiency is the ratio of total output exergy to total input exergy [4, 6, 7]. An exergy efficiency of the solar PV can be defined as the ratio of the exergy gained by the solar PV to the exergy of the solar radiation [8].

$$\eta_{ex} = \frac{E_{xoutput}}{E_{x\ input}} \quad (11)$$

Inlet exergy of a PV system includes only solar radiation intensity exergy [8-9].

$$E_{x\ input} = AG\,[1 - (4/3)(T_a/T_m) + (1/3)(T_a/T_s)^4] \quad (12)$$

The exergy output of the system can be calculated as [10]

$$E_{x\ out} = E_{xthermal} + E_{xelectrical} \quad (13)$$

Thermal Energy

$$E_{x\ thermal} = Q\,[1 - (T_a/T_m)] \quad (14)$$

where, $Q = UA\,(T_m - T_a)$ (15)

Overall heat loss coefficient of a PV module [11]

$$U = h_{conv} + h_{rad} \quad (16)$$

Convective heat transfer coefficient [12]

$$h_{conv} = 2.8 + 3V_w \quad (17)$$

Radiative heat transfer coefficient between PV array & surroundings [13]

$$h_{rad} = \varepsilon\sigma(T_{sky} + T_m)(T_{sky}^2 + T_m^2) \quad (18)$$

Temperature of the sky [13]

$$T_{sky} = T_a - 6 \quad (19)$$

Temperature of the module based on NOCT value.

$$T_m = T_a + (NOCT - 20).\,(G/800) \quad (20)$$

Electrical Exergy in the power output of PV module [12]

$$E_x\ electrical = V_{oc} \times I_{sc} \times FF \quad (21)$$

III. RESULTS AND DISCUSSION

3.1 Comparison of various average efficiencies of PV-T air system and PV

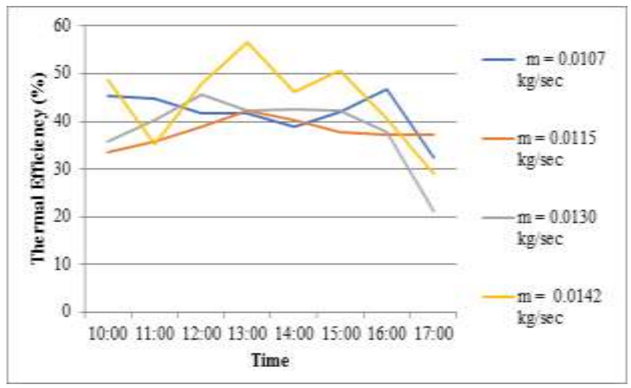

Fig.2: Variation of Thermal Efficiency for various mass flow rate of PVT

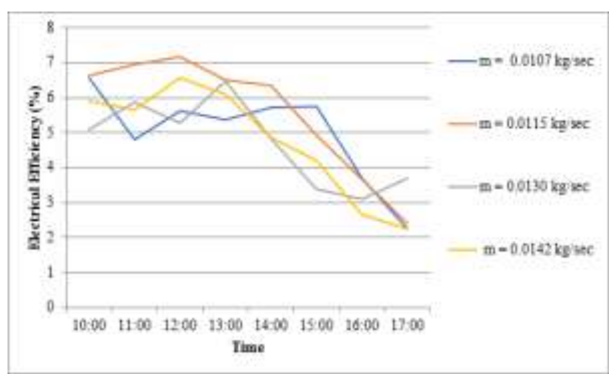

Fig. 3: Variation of Electrical Efficiency for various mass flow rate of PVT

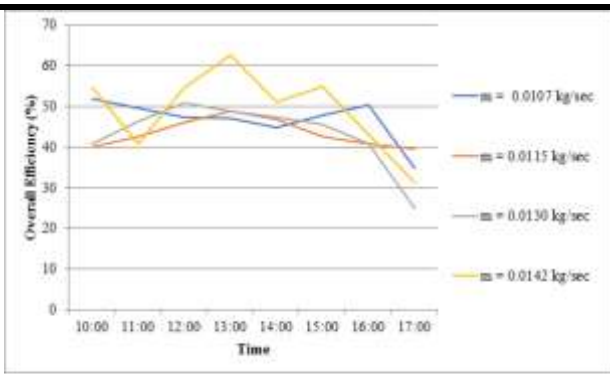

Fig. 4: Variation of Overall Efficiency for various mass flow rate of PVT

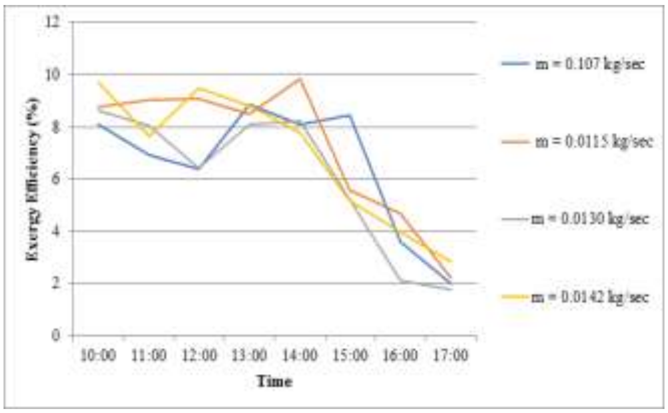

Fig.5: Variation of Exergy Efficiency for various mass flow rate of PVT

3.2 Comparison of various average efficiencies of PV-T water system and PV

Table 2: Comparison of various efficiencies of solar PV-T water and solar PV systems

S. No	Solar PV/T Hybrid System						Solar PV
	Mass Flow Rate (kg/sec)	Average Electrical Efficiency (%)	Average Thermal Efficiency (%)	Average Overall Efficiency (%)	Average Energy Saving Efficiency (%)	Average Exergy Efficiency (%)	Average Electrical Efficiency (%)
1	0.002	7.54	52.30	59.84	52.49	11.26	7.59
2	0.0025	6.24	54.13	60.37	54.30	8.78	6.00
3	0.003	5.73	61.43	67.16	61.58	8.70	5.54
4	0.004	5.23	56.06	61.29	56.20	8.23	5.03
5	0.0025 with glass cover	6.39	50.11	56.49	50.27	9.48	7.50

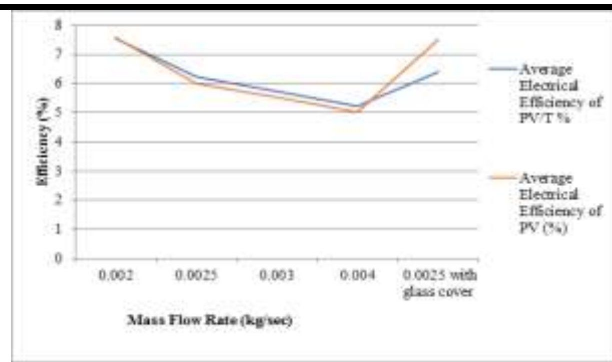

Fig. 6: Variation of average electrical efficiency PV and PVT for various mass flow rate

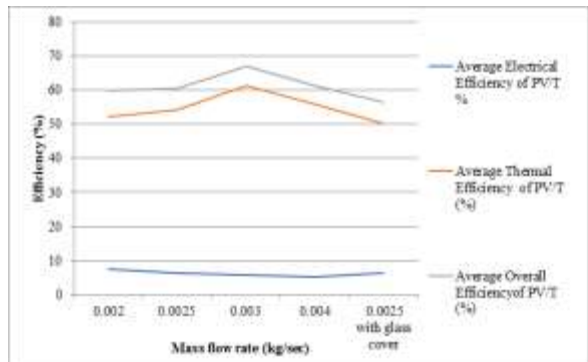

Fig. 7: Variation of average electrical, thermal and overall efficiency of PVT for various mass flow rate

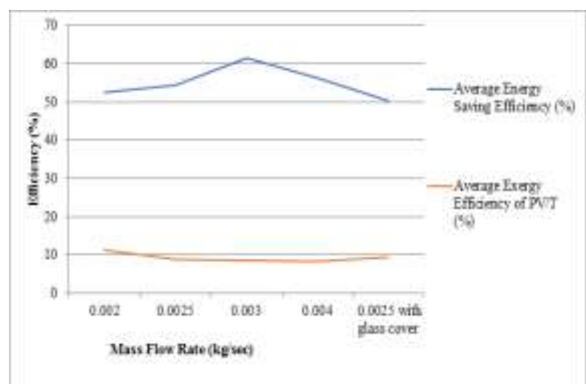

Fig. 8: Variation of average exergy and Energy saving efficiency of PVT for various mass flow rate

IV. CONCLUSION

This article has presented the comparison study of the thermal and electrical performance of the photovoltaic-thermal air and water collector. A preliminary study of applying this technology in a university building of MANIT, Bhopal has been described. Experiments are conducted with varying mass flow rate of fluid. With the proposed design and operating condition the daily electrical efficiency was about 6.56% and 7.54% for solar PV-T air and solar PV-T water respectively, the daily thermal efficiency was about 56.47% and 70% for solar PV-T air and solar PV-T water respectively, and the total efficiency of the system exceeded 62.57% and 70% for solar PV-T air and solar PV-T water respectively. The results show that by integrating the solar PV and thermal increases the overall performance of PV/T system than that of employing the PV alone. PV/T application can offer sustainable solution for maximizing the solar energy output from building integrated photovoltaic system. This kind of PV/T system is especially suitable for low temperature applications like hybrid green house, drying or space heating.

Many other designs of PV/T can be developed and tested for its efficiency. Further Research and development work is required to develop more efficient PV/T hybrid system for building applications. PV/T system can be integrated with both air and water concept in a single unit to enhance the performance. Design of PV/T air and water in a single unit can be taken as a future scope of the study. Another method to boost the overall efficiency of the PV module involves a plane reflector. When the output power increased, the payback period shortened. Therefore, payback period should be considered before making modification in the system. As a part of future work, it is suitable building integration providing hot air depending on the season and for low temperature air heating application.The air based photovoltaic/thermal collector system is particularly suitable for the warm climatic areas since the cooling effect is more effective. The heat of working fluid can be used directly or through use of heat exchanger transferring it to other fluid. Performance of system can also be evaluated by using different types of working fluid other than water such as ethylene glycol or transformer oil.

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