Experimental Study of Enhancing The Performance of PV Panel Integrated with Solar Thermal System

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***Abstract*— The maximum electricity conversion efficiency of the Solar Photovoltaic panel is 8-18% under the Standard Test Condition (STC) temperature of 25˚C. The atmospheric temperature of Indian climatic condition is mostly above 30˚C - 45˚C, it incites 30˚C-80˚C heat over the panel since black body of the PV panel observe more heat, and this temperature majorly affect the electrical efficiency of the panel. The newly designed Glass to Glass Photovoltaic Thermal System (G2G-PVTS) is a combined Photovoltaic (PV) and Flat Plate Solar Water Heating System (FPSWHS). In this technology, the water act as a coolant inside the Copper fins and it absorb the heat of the PV panel and stored in the insulated storage tank by way of natural flow of water. The test result shows that the G2G-PVT electrical efficiency was 0.7% higher than conventional G2T- PV panel, and in addition that 44.37% of thermal efficiency was also stored. The simultaneous conversion of electrical and thermal energy was obtained by this system with effective space utilization. The overall efficiency of the G2G-PVTS panel was improved.**

Keyword-Glass to Tedlar (G2T) PV Panel, Glass to Glass Photovoltaic Thermal System (G2G-PVTS), Flat Plate Solar Water Heating System (FPSWHS), Solar Irradiation, Temperature, Electrical Efficiency and Thermal Efficiency.

I. INTRODUCTION

Researches on the area of combined PV/T system have been started since 1970s for improving the efficiency of PV panel by decreasing the temperature on it. The combined PV/T system was more suitable for observing the temperature of PV Panel to improve the electrical yield. Air and/or water were used as a coolant in thermal system; PVT system converts the solar energy into heat energy and electrical energy in the same area simultaneously. In order to increase the efficiency of the PV panel, the energy payback time (EPBT) gets reduced.

Kern and Russell [1] gave innovative idea of combining the PV/T system for removing the heat of PV panel for improves the efficiency. Zondag et al. [2] analysed the four different models; one 3D dynamical model and three steady state model of 3D, 2D and 1D, the simulation of the thermal yield were calculated. They conclude that the time dependent model is required for accurate prediction. Again Zondag et al. [3] performed with nine different designs, they were evaluated. The thermal efficiency of the uncovered collector was 52% and the thermal efficiency of the single cover sheet-and-tube design was 58%, while the channel above PV design typically has 65% thermal efficiency. The electrical performance of other three systems was somewhat lower due to the additional glass and water layers on top of the PV panel. Finally, they conclude the one cover sheet-and-tube design was a good alternative in design. Wei He et al. [4] carried out the test in an aluminium-alloy flat-box type hybrid solar collector. The test results indicated that the 40% of thermal efficiency obtained by natural water circulation. Mohd.Yusof Othman et al. [5] analysed the finned double-pass PV/T system experimentally and theoretically. It consisted of monocrystalline silicon cells pasted on the absorber plate with fins attached at the other side of the absorber surface, air was used as heat removing fluid. They obtained reasonable close agreement between experimental and theoretical results.

Anand and Arvind Tiwari [6] analysed the hybrid PV/T parallel plate air collector for cold climatic condition of India. It observed that the instantaneous energy and exergy efficiency of PV/T air heater varied between 55-65 and 12-15 percent respectively. Anderson et al. [7] analysed and discussed a novel combined PV/T system for building integrated (BIPVT) solar collector. The efficiency of the mono and polycrystalline silicon cells was decreases with increasing temperature by approximately 0.5%/˚C. They concluded that while installing the BIPVT system was ideally suited to the environment where facade space with suitable solar access is limited or where large numbers of people share a single building. Skoplaki et al. [8] attempted a review of efficiency and power correlations of the photovoltaic module dependence on the temperature. Kostic et al. [9] experimentally demonstrated the physical characteristic of flat plate solar radiation concentrator made of Al sheet and Al foil. The daily concentration factor of solar radiation intensity was 43.6% and 65.6% respectively the concentrator made of Al sheet and Al foil. The maximum efficiency of 17.1% was obtained when the concentrator made upon Al foil.

Majed Ben Ammar et al. [10] simulated the dynamic simulated model of photovoltaic and water heating system. This technology improves an electrical efficiency ranging between 2% and 4% compared to other technologies. Boubekri et al. [11] numerically analyzed the performance of hybrid PV/Thermal collector by finite difference method. Ewa Radziemska [12] analyzed the energy and exergy rate of PV/T integrated system and he concluded that the relative increase in solar cells efficiency as the result of cooling was in order of 10-30%. Chow [13] reviewed the different possible methods of air and water cooling method for PV panel. After all summarized, there existed no perfect rules in the correct use of PVT collector and/or system, all depends on geographical location and actual application case by case. PVT/air can be useful and cost effective for space heating; PVT/water can be useful for providing year round water pre-heating services. Still the following point are the major barriers like product reliability, suitable product materials, manufacturing technique, analytical tool, testing and training requirement, potential customers and market strength and so on for developing the PVT system. Goh Li Jin et al. [14] evaluated the single-pass rectangle tunnel absorber for PVT system. The result of 10.02% and 54.70% of electrical and thermal efficiency was obtained in that system. Saidur et al. [15] evaluated analytically the efficient usage of solar energy. By increasing the mass flow rate leads to an increment in exergetic efficiency in PVT system. Mohsen Mahdavi Adeli et al. [16] experimentally tested the PVT system by air cooling system with two DC fans works like a blower. There was a good agreement between simulated and experimental result. The thermal efficiency of 51.5% and electrical efficiency of 5.5 to 7.5% was received from PVT system. Mortezapour et al. [17] analytically calculated the performance two-way of glass to glass and glass to tedlar type panels. The experiment was conducted on the glass to tedlar type PV panel were found 10.35, 57.9 and 84.5% respectively electrical thermal and overall efficiency of the system.

David el al. [18] experimentally compared the Simple Flat plate (FP-PVT) and Compound Parabolic Concentrating solar PVT (CPC-PVT). These systems are tested under the steady state conditions using solar simulator. The electrical conversion efficiency was 7.8% which was 0.4% higher than the value obtained in FP-PVT system. Zagorska et al. [19] experimentally investigated the PVT system over 55 days, from that 23.01kwh of electrical and 43˚C of maximum water temperature were obtained. Tomas Matuska [20] studied the simulation model of Building Integrated Solar Liquid PV-T Collectors. He suggested that 15%-25% and 8%-15% of electricity increment in warm and moderate climate respectively. Jin-hee Kim and jun-tae Kim [21] experimentally compared the glazed and unglazed PVT collectors. The result shows that the thermal efficiency of the glazed PVT system was higher than unglazed system, but the glazed PVT system produced higher electrical efficiency than unglazed system. Farideh Atabi et al.[22] investigated the technical, economical and environmental feasibility of the system by simulation. The system saves natural gas, green house gases emission reduction by producing thermal energy from PVT system. Tripannagnostopoulos [23] performed the test on water cooled PV/T system and the Life Cycle Analysis (LCA) on it.

The Glass to Glass type PVT was analytically discussed in [17] distant that enduring papers were analytically and/or experimentally evaluated the glass to tedlar type PV panel used for their study. This paper deals the designing process of Glass to Glass PVT (G2G-PVT) system and compares the performance experimentally with Glass to Tedlar PV panel (G2T-PV). The experimental setup and acquired results are discussed.

II. Design of Glass to Glass PVT System

This system consists of G2G PV panel combined with thermal system. Fig. 1 shows the G2G type PV panel, it works as like the conventional PV panel and it directly converts the light energy in to electrical energy. At the same time the bottom glass of G2G - PV panel stores more heat energy in it, which is greater than the heat at the bottom of G2T type PV panel. The thermal system placed behinds the PV panel observes the heat energy and reduce the temperature of the G2G-PV panel. The heat observed by the water was retained in the hot water storage tank. By this method the temperature of PV panel was reduced for improve the electrical efficiency.

The solar collector area size of G2G PV panel was 775mm×650mm and the thickness of the panel was 7mm. This G2G PV panel was placed over the frame of the thermal system in the size of length, breath and height of 805mm×680mm×95mm respectively. The cooling system inside the frame with six numbers of copper fins in the size of 640mm length and 118mm breath was placed as shown in the Fig.2

Fig.1. Glass to Glass Type PV panel

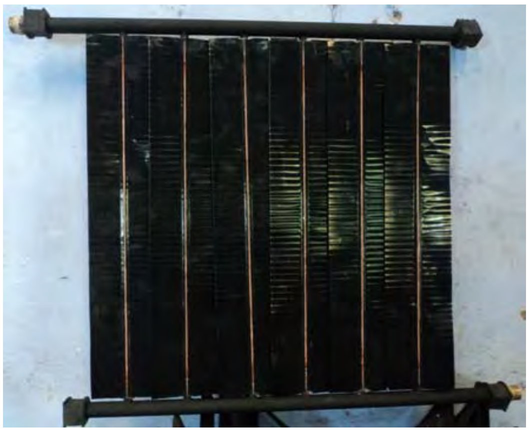

Fig.2. Copper fins arrangement between header tubes

III. Experimental Setup

In order to quantify the efficiency of the PV panels, testing was conducted on the roof top of the building in our institution. The test was conducted on 15th March 2013. The hardware setup was arranged on the rooftop as shown in Fig.3. Two 74W capacity panels are used for testing; the different tests were conducted on the panel separately are discussed as follows.

A. Temperature Test

The test was conducted on the G2G PV panel before fixing over the thermal system. The G2T PV panel also tested at the same time. The top and bottom temperature of the panels are measured. The test data are tabulated in Table. I.

B. Electrical Test on PV Panels without Thermal System

The V-I test was conducted on both the G2T and G2G type panels. The Rheostats were connected as a variable resistive load (R) with the panels separately and by varying the R value, the values of voltage and current are noted down. From the test values, the maximum power point was calculated with the equation (1). The test was conducted on the panel one hour once from 10.30AM to 4.30PM. Simultaneously, the irradiation also measured. The powers generated by the G2G –PV panel were slightly low when compared with G2T-PV panel due to high temperature.

$$P_{\max} = V_{\max} \times I_{\max} \qquad (1)$$

$$\text{Electrical Efficiency } \eta = \frac{P_{\max}}{P_{in} \times A} \qquad (2)$$

$$\text{Fill Factor} = \frac{I_{\max} V_{\max}}{I_{sc} V_{oc}} \qquad (3)$$

Where,

P_{max} was the maximum power when the voltage and current are in maximum (V_{max}) and (I_{max}), P_{in} solar irradiation power in W/m^2 , A is the area of the panel in m^2 , I_{sc} and V_{oc} are the short circuit current and open circuit voltage.

The electrical efficiency depends on temperature was calculated with the following equation (4)

$$\eta_e = \eta_0[1 - 0.0045(T_c - 25)] \qquad (4)$$

The thermal efficiency of the PVT system was calculated with the equation (5)

$$\text{Thermal Efficiency} = \frac{mC(T_{out} - T_{in})}{GA} \qquad (5)$$

Where, m and C are respectively, the mass flow rate and specific heat capacity of the coolant, A is the collector aperture area, T_{in} and T_{out} the coolant temperature at the inlet and outlet, G the incident solar irradiation normal to surface. The total system efficiency η_o, which is the direct sum of the thermal efficiency η_t and the electrical efficiency η_e

$$\text{Overall Efficiency } \eta_0 = \eta_e + \eta_t \quad (6)$$

$$\eta_{e,t} = \frac{\eta_e}{C_f} \quad (7)$$

$$\eta_{overall} = \eta_t + \eta_{e,t} \quad (8)$$

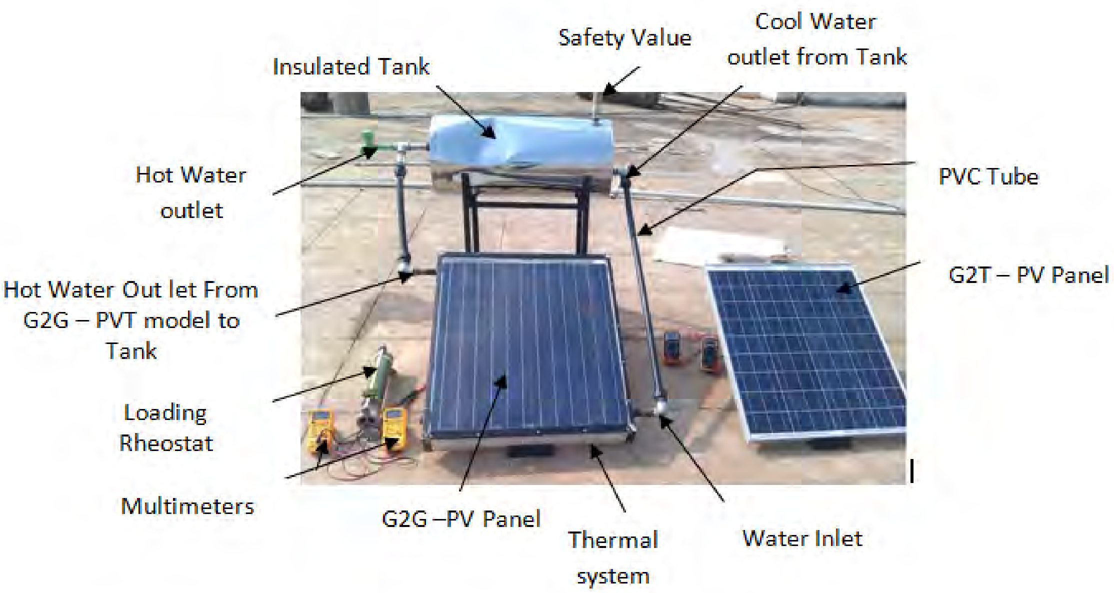

Fig.3. Experimental Setup of G2G-PVT and G2T PV Panels on the Roof Top

C. Electrical Test on G2T and G2G - PVT Systems

The G2G-PVT and the G2T PV panel also placed closely at an angle of 30˚ degree slope. The inlet and outlet pipes are connected with G2G-PVT as shown in Fig.3. Then, the tank and tubes connected with the system and filled with water as a coolant, again the same V-I test was conducted on both the PV panels simultaneously one hour once. The voltage and current values are noted and the maximum powers produced by the panels were calculated for equal intervals as shown in table.2. The hot water flows naturally upwards inside the tube due to increasing the temperature of water. At the same time the irradiation and temperature of the inlet and out water was measured.

TABLE I
TEMPERATURE TEST RESULT ON G2G AND G2T PANELS

Time	**G2G Temp in ˚C**		**G2T Temp in ˚C**	
	Top (T_{Tg1})	**Bottom(T_{Bg1})**	**Top (T_{Tt2})**	**Bottom(T_{Bt2})**
10.30AM	51	54.3	53.9	47.2
11.30AM	55.8	65.1	53.5	50.1
12.30PM	62.5	71.4	56.7	49.2
1.30PM	68	72.5	59.5	55.3
2.30PM	51.5	66.5	57.5	51.5
3.30PM	56.6	60.8	51.6	43.2
4.30PM	43.8	48.3	44.9	43.7

D. Testing Equipments

The temperature of the panel was measured with help of the digital industrial thermometer DTM902 in the range of 40˚C to 572˚C. The solar radiation was also measured with help of Light meter LX-101A and four numbers of MAS830L Multimeters were used for measuring voltage and current.

IV. RESULTS AND DISCUSSION

The thermal test results measured between the times from 10.30AM to 4.30PM were tabulated in the Table.1. It shows that the temperature of the top and bottom of G2G and G2T panel was gradually increased up to the peak time of 1.30PM and then the temperature decreased.

A. Thermal Effect

In the case of G2G type panel, the Fig.4 shows that the top glass temperature was always lower than the bottom glass. It shows that the G2G type panel observes more heat and it was conducted to the bottom of the panel. The observed heat was accumulated at the bottom glass. The maximum temperature of 72.5˚C was measured at the bottom, When the glass is covered by insulation layer the total amount of heat was stored inside the insulated box, this will be used for the purpose of water heating.

$$T_{Tg1} < T_{Bg1} \qquad (9)$$

$$T_{Tt2} > T_{Bt2} \qquad (10)$$

$$T_{Bg1} >> T_{Tt2} \qquad (11)$$

In the case of G2T type panel, the Fig.5 Shows that the top of glass temperature was always higher than the bottom of the panel. The temperature at the top of the panel was not conducted to the bottom of the panel through tedlar because of the character of tedlar. So the maximum temperature of 55.3˚C was arise at the bottom of the panel when the temperature of 59.5˚C at the top of the panel.

From this result it shows that, when designing the solar PVT system G2G type panels are more suitable due to higher thermal absorption capacity of glass. The thermal conduction of the tedlar material was poor; So G2T type panels will not give better result compare with G2G panel.

B. Electrical Performance

The test results in the Table. II. Shows that the power produced by the both panels are gradually increased up to 1.30PM and then decreased according to the solar irradiation falls on the panel. The Fig.6 shows the power produced by the G2G-PVT panel always higher than the G2T - PV panel.

As a result of the water cooling arrangement with the G2G-PVT panel the temperature of the panel decreased and the electrical output increased. The test was conducted periodically one hour once from 10.30AM to 4.30PM. The total power produced by the G2G PVT panel is 260.08W and G2T PV panel is 243.97W. The results are the instantaneous values of power at the particular time alone, even though the total power generation difference was 16.11W higher. The whole day power generation of the G2G PVT panel will be more than the G2T PV panel.

The efficiency of the panels at different time period was calculated by equation (2) and tabulated in Table.III. It is gradually increased form morning to noon and then it decreased. But always the efficiency of the G2G-PVT was higher than G2T-PV panel. It shows that the performance of the G2G-PVT was better than G2T-PV panel due to reduction of temperature of the panel by cooling system. The efficiency of the panels was shown in Fig.7.

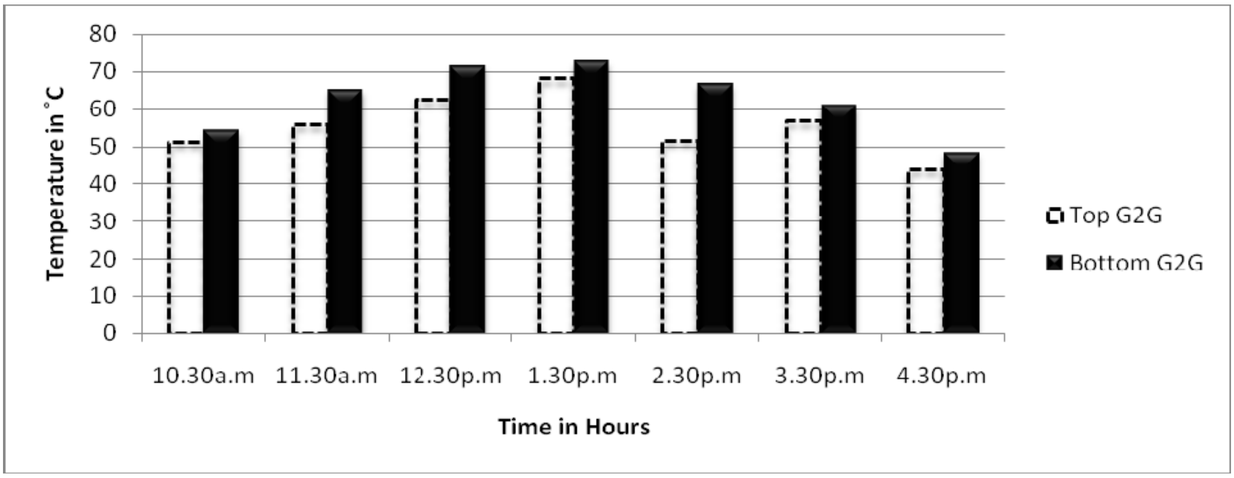

Fig.4. Top and Bottom Temperature of G2G PV Panel

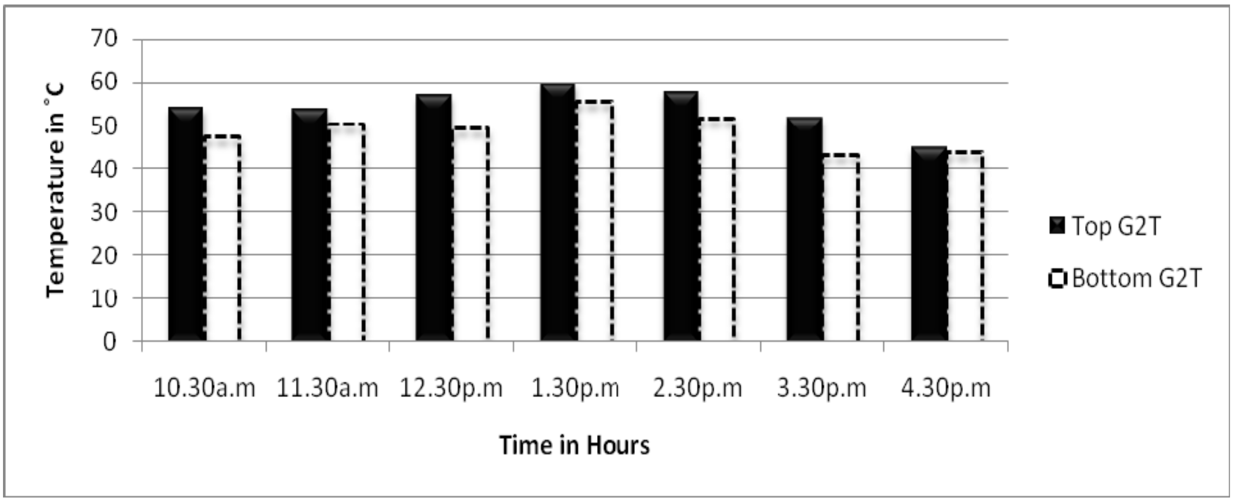

Fig.5. Top and Bottom Temperature of G2T PV Panel

TABLE II
TEMPERATURE TEST RESULT ON G2G AND G2T PANELS

Time in Hours	**Solar Irradiation (S_i) in W/m^2**	**Glass to Glass Type PV Panel**			**Glass to Tedlar Type PV Panel**		
		Voltage (V_{max}) in Volt	**Current (I_{max}) in Amp**	**Power (P_{max}) in Watt**	**Voltage (V_{max}) in Volt**	**Current (I_{max}) in Amp**	**Power (P_{max}) in Watt**
10.30 am	710	12.61	2.35	29.63	12.61	2.28	28.75
11.30 am	810	12.46	2.86	35.64	12.46	2.61	32.52
12.30 pm	927	13.04	3.58	46.68	13.04	3.28	42.77
1.30 pm	875	13.72	3.66	50.22	14.9	3.13	46.64
2.30 pm	750	14.4	3.31	47.66	14.44	3.17	45.77
3.30 pm	563	14.9	2.07	30.84	15	1.98	29.70
4.30 pm	392	15.4	1.26	19.40	15.1	1.18	17.82
	Total Power in Watt			260.08			243.97

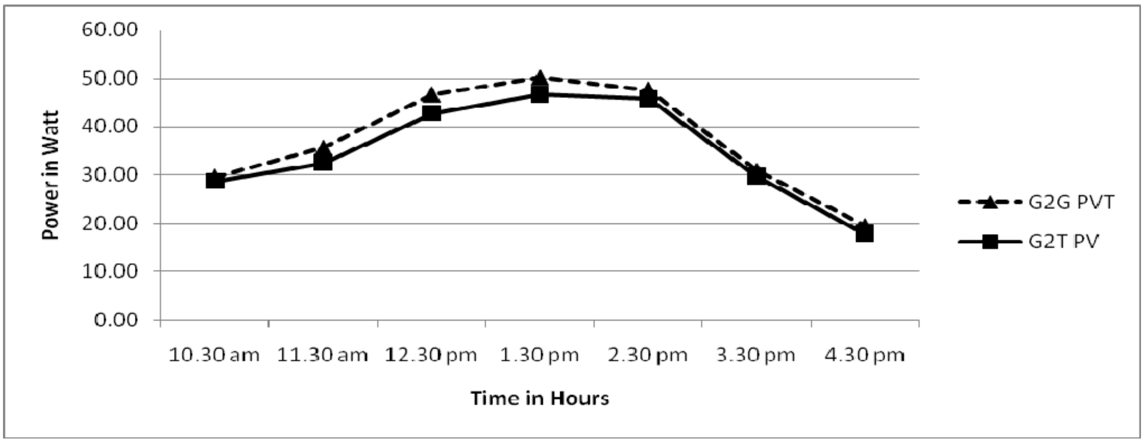

Fig.6. Maximum Power Production from G2G-PVT and G2T-PV Panel

TABLE III
EFFICIENCY OF THE PANELS

Time in Hours	% η G2G PVT	% η G2T PV	Diff in % η
10.30 am	9.52	9.24	0.28
11.30 am	10.04	9.16	0.88
12.30 am	11.49	10.53	0.96
1.30 am	13.1	12.16	0.94
2.30 pm	14.5	13.93	0.54
3.30 pm	12.5	12.04	0.46
4.30 pm	10.46	9.6	0.86

C. Thermal Performance

The observed thermal energy from the panel by water was stored in the insulated water tank by natural flow of water. The initial temperature of hot water received from the thermal system start from 35˚C and it reaches maximum up to 56.8˚ C. This may be utilized for the domestic applications. The thermal efficiency of the system was 44.37%.

D. Overall Performance

The average efficiency of G2G PVT and G2T PV Panels are 11.65% and 10.95% respectively. The efficiency of G2G PVT was 0.7% higher than G2T PV panel, in addition that the thermal efficiency of the G2G PVT system was 44.37%. So the overall efficiency of the system was the addition of both electrical (11.65%) and thermal efficiency (44.37%) is 56.02% for the instantaneous test reading for the particular time. So the combined system will give better performance with more efficient utilization of solar energy in the same area

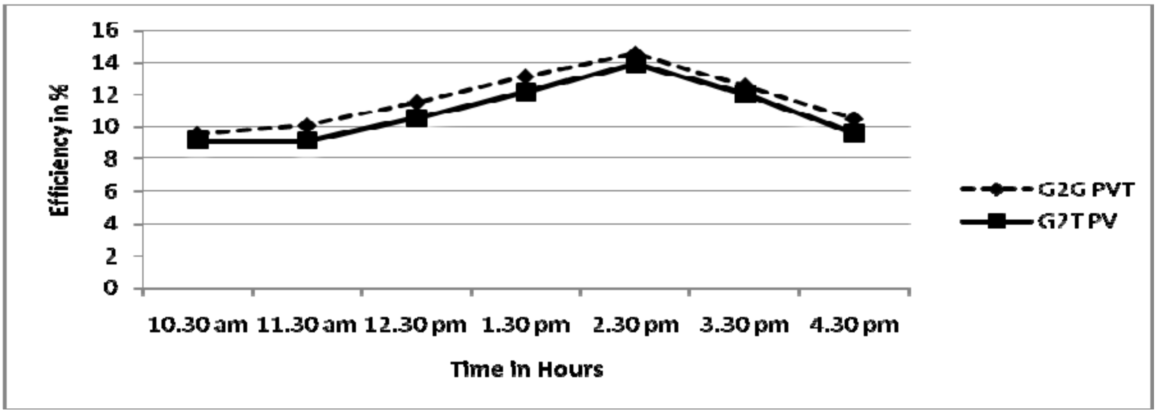

Fig.7. Efficiency of the G2G-PVT and G2T-PV Panels

V. CONCLUSION

The earlier period researches in combined PVT system, they are all used Glass to Tedlar (G2T) type of PV panel. The thermal conductivity of the tedlar is very low so the efficiency of the combined solar PVT system also low. This paper discusses the effects of temperature and solar irradiation on the G2G-PVT and G2T type panels. The result showed that when the solar radiation increased, the electrical output also increased along with temperature. The range of temperature increased between 44.9˚C to 72.5˚C on the PV cell in G2G-PV panel, it was above the STC temperature of 25˚C. At this temperature, the G2T panel power generation was slightly higher than G2G-PV. Then the G2G-PVT panel was tested with water cooling system then the efficiency gets increased (11.65% -10.95%) 0.7% over the G2T-PV panel. The heat observed from the G2G-PV panel was retained in the hot water tank. The additional thermal energy along with electrical energy was also received by this system. The efficiency of thermal energy was 44.37%. So, the overall efficiency of the new combined system was 56.02%. It was found that the electrical performance of the panel also depends on the temperature. By reducing the temperature of the panel closer to STC, the efficiency of the PV panel increased. Also this model has reduced complexity associated with all other PVT models. It is well suited to the location where the roof top space with suitable solar access is inadequate or where the large numbers of family share a single building like apartments in cities.

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