AN EXPERIMENTAL PERFORMANCE OF PHOTOVOLTAIC THERMAL COLLECTOR AND PHOTOVOLTAIC SYSTEM

Shafura Shariff[1], Norlie Yuzanna Ibrahim[2] and Normazlina Mat Isa[3]

[1,3]Electrical Engineering Department, Politeknik Merlimau Melaka
shafura@pmm.edu.my,
normazlina@pmm.edu.my

[2]Electrical Engineering Department, Politeknik Port Dickson, Negeri Sembilan
nollybanting@gmail.com

ABSTRACT. All over the world, photovoltaic technology is being used to generate electricity due to its economic and environmental advantages. Photovoltaic (PV) and photovoltaic thermal (PV/T) systems are widely used in residential, commercial, and industries. This is because PV and PV/T generate solar heat and electricity essentially free of carbon dioxide (CO_2) emissions and are considered a green technology that supplies renewable electricity and heat to residential and commercial buildings. This paper presents a simple experimental work and results for the photovoltaic thermal collector compared to the photovoltaic. It is comprised of the PV and PV/T description as well as followed by the results tabulation. The analysis methodology is done in simple Excel software where it is illustrated the significant performance of PV and PV/T compared to the PV where it is believed that it can give more benefits to the residential and commercial building to utilize the PV/T as one of their energy supply systems**.**

KEYWORDS: photovoltaic; thermal; solar

1 INTRODUCTION

Around the world, PV technology has been famously used to generate electricity due to its economic and environmental benefits. The use of solar energy will help to reduce the consumption of fossil fuels, requiring low maintenance and operating costs, a long life, a reduction in CO_2 emissions and will contribute to a clean environment for future generations. However, there are also some challenges in solar power generation, especially the changes in the intensity of solar radiation received by the solar panels, which can affect the reliability of the grid. Photovoltaics is commonly used to convert solar energy (light) into direct current electrical energy (DC). In PV technology, the smallest unit is called a solar cell, and they are connected in series and parallel to form a PV module. PV modules are also connected in series and parallel to form a PV arrays.

Several studies have shown the impact of climate conditions on PV performance including a study by (Katsumata et al., 2011) informed that the performances of PV modules is depend on three environmental factors such as irradiance, solar spectral distribution and module temperature. Also, a study by Hussein in (Kazem, 2015) discuss the impact of relative humidity on the output of solar photovoltaic where the findings show that the parameters of PV's current, voltage and power output are decreased when the relative humidity increased. In addition, there are several studies that discuss that differences in geographic location directly affect the intensity of solar radiation as wind speed, humidity, dust, and air pollution are deposited on the PV panel. Each of these variables causes low productivity and performance variations in photovoltaics. In this regard, the changes or increase in air temperatures cause a significant voltage drop and an insignificant increase in the current value, resulting in a significant reduction in the power generated. For this reason, several researches have been carried out to remove the heat caused by the high temperatures on the panel by using cooling fluids such as air and water and try to use them in other applications (Noxpanco et al., 2020). This technology is called hybrid PV/T solar panel, which can heat water or air or both at the same time. The hybrid PV/T system converts solar radiation into electrical and thermal energy at the same time. The basic form of this system consists of an open solar collector with a plate surface equipped with a cell surface. The PV cells absorb the sunlight and generate electricity, while the remaining portion is transferred to the coolant (air or liquid) flowing through the collector. This hot fluid can be used at low or medium heat applications including the space heating, domestic hot water and drying. The efficiency of PV/T systems is depends on the factors like cooling fluid type, the dimensions of the system, the PV type used, in addition to operational factors such as fluid flow rate, the type of the application used, and indeed the weather conditions (Al-waeli et al., 2017). This paper analyses the results of a simple experiment to measure and compare the performance which caused of different parameters between PV and PV/T technology.

2 METHODOLOGY

This study started with the development of the PV circuit as it is shown in Figure 1. Besides, the principle concept and the construction of the PV/T is adapted from the PV/T experiment work reviewed in (Al-waeli et al., 2017) which is illustrated in Figure 2.

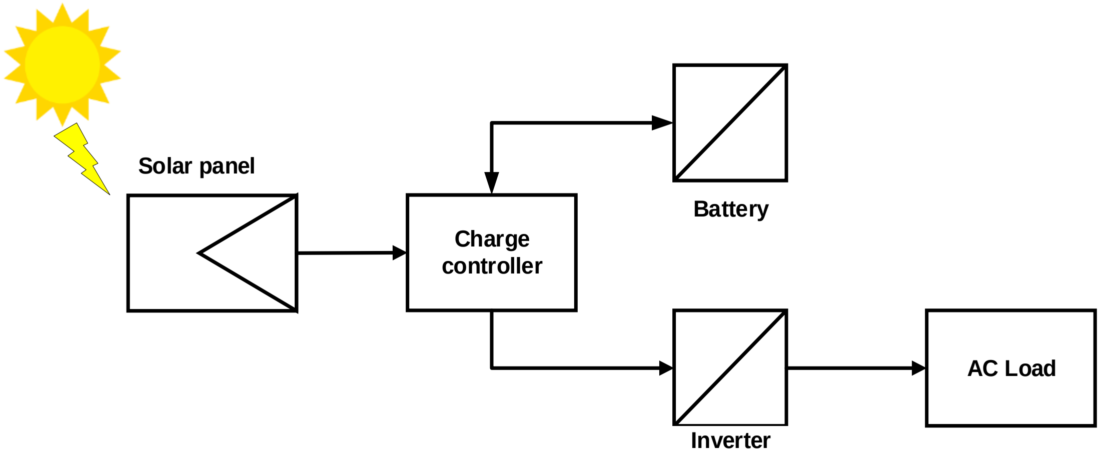

Figure 1: General block diagram in PV system

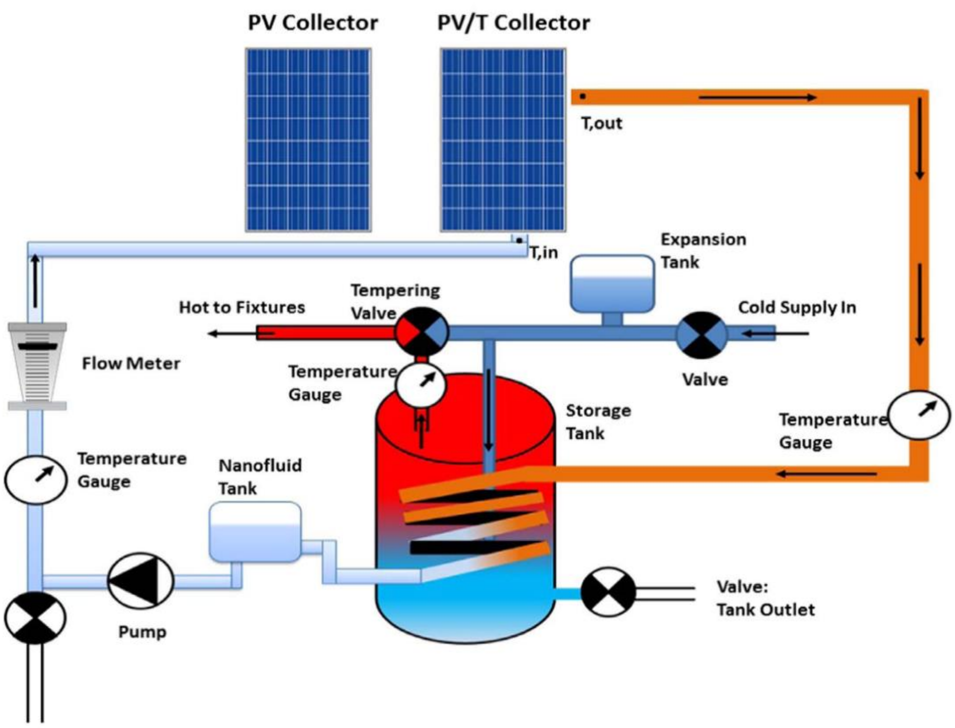

Figure 2: PV/T system with heat exchanger, insulated storage tank and sensors(Al-waeli et al., 2017)

2.1 System overview

Photovoltaic energy is defined as the energy absorbed by the PV system, which is given by equation 1. During the experiment, all the photovoltaic (PV) and thermal photovoltaic (PVT) parameters needed were recorded at the station.

$$E_r = \tau_g \alpha_{sc} P_{sc} G A \quad (1)$$

where A = area of the PV surface (m^2)

$\boldsymbol{E_r}$ = received energy at module top surface (W)

$\boldsymbol{G}$ = Solar irradiance (Wm^{-2})

$\boldsymbol{P_{sc}}$ = packing factor module

$\boldsymbol{\alpha_{sc}}$ = Absorptivity of PV module

$\boldsymbol{\tau_g}$ = transmit of glass

If η_{sc} is the cell efficiency, output power can be calculated as in equation (2) :

$$E_p = \eta_{sc} P_{sc} \tau_g \alpha_{sc} G A \quad (2)$$

The specifications and constants of the PV and PV/T are listed in Table 1.

Table 1: Specification and the constants used in the calculation.

Number of cells	60
Size of cell	156 x 156 mm
Specific heat of water at constant pressure, Cp	4184 J/Kg.°C
Water density, ρ	995.65 Kg/m^3
PV cell absorptivity, αc	1.0
Packing Factor, Pc	1.0
Glass transmissivity, τg	1.0
1 LPM	1.66667×10^{-5} m^3/s
1Ω (Irradiance)η	15.74904 W/ m^3

The block diagram of solar collector experiment is shown in Figure 3, as well as the mathematical equation used in the experiment were expressed in equation 3 to 7 as they are referred to article by (Zhang et al., 2012). Moreover, the collected data solar irradiation is tabulated in Table 2.

Table 2: The collected data for solar irradiation

Time	10.27AM	10.29AM	10.31AM	10.33AM	10.35AM	10.37AM
Irradiation (W/m)	612.6377	669.3342	636.2612	157.4904	200.0128	702.4072

Heat energy (Q) required to heat water to the desired temperature:

$$Q = mC_p \left(T_f - T_i\right) \quad (3)$$

where C_p is capacity of flowing medium, m is a average mass flow rate, T_f is temperature at outlet and T_i is temperature at outlet.

Heat from working fluid (water), Q_f:

$$Q_f = mC_p(T_{out} - T_{in}) \tag{4}$$

where C_p is capacity of flowing medium, m is a average mass flow rate, T_{out} is temperature at outlet and T_{ni} is temperature at outlet.

Heat from solar collector:

$$Q_{u,coil} = A_c F_R [I_T(\tau\alpha) - U_L(T_{in} - Q_e] \tag{5}$$

where F_R is the heat-removal factor which is connected with the efficiency factor, A_c is the collector area, U_L is the overall thermal loss efficient, Q_e is the electrical energy generated from the PVs and $\tau\alpha$ is transmittance-absorption effort of glazing cover.

Total useful energy:

$$Q_{total} = Q_u + Q_{u,coil} \tag{6}$$

where Q_u is useful thermal energy and $Q_{u,coil}$ is useful energy at coil.

Thermal efficiency of the solar collector

$$\eta_e = \frac{Q_{total}}{I_T A_P} \tag{7}$$

where Q_{total} is a total useful energy and $I_T A_P$ is the overall incident irradiation.

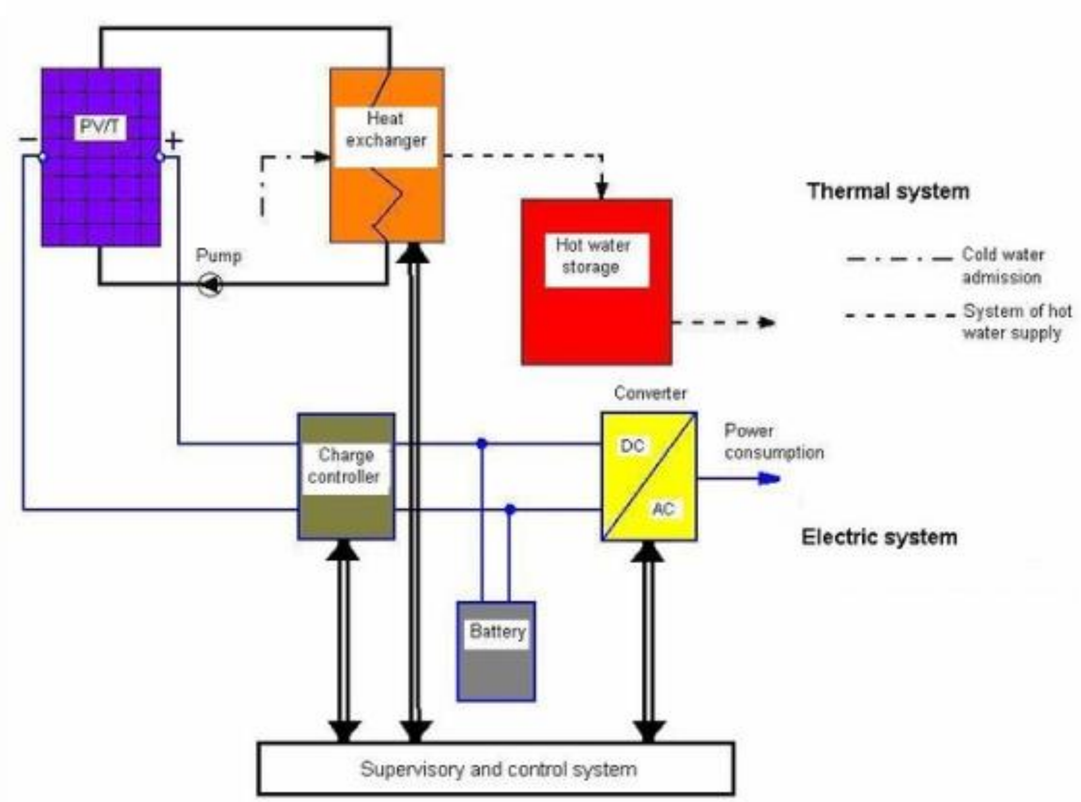

Figure 3 : Block diagram of photovoltaic thermal system

3 RESULTS AND DISCUSSION

3.1 Photovoltaic experiment results

This project used the designed diagram as in (Cuenca et al., 2010) whereas the block diagram for the Thermal Photovoltaic (PVT) system is shown in Figure 3. The collected data of power for both PV and PVT system during the experiment is tabulated in Table 3 (a) and (b). Moreover, the results of collected data and the plotted graph as well as the analysis discussion were presented in the following section.

Table 3 (a): The collected data for Photovoltaic (PV) and Photovoltaic Thermal (PVT)

		D1	D2	D3	D4	D5	D6
	Time	10.27AM	10.29AM	10.31AM	10.33AM	10.35AM	10.37AM
PV	I^2 (W/m)	612.6377	669.3342	636.2612	157.4904	200.0128	702.4072
	Power, EP(W)	93.1700	89.6300	103.3000	31.5000	0.4500	105.0000
PVT	I^2 (W/m)	612.6377	669.3342	636.2612	157.4904	200.0128	702.4072
	Power (W)	70.8200	66.6600	113.2500	40.7000	1.5900	110.4100
	m (kg/s)	0.5	0.5	0.5	0.5	0.5	0.5
	T_{in} (◦C)	31.4	31.5	32.0	32.1	32.1	32.2
	T_{out} (◦C)	33.8	33.7	33.9	34.9	34.9	34.6

Table 3 (b): The calculated data for Photovoltaic (PV) and Photovoltaic Thermal (PVT)

	TIME	10.27AM	10.29AM	10.31AM	10.33AM	10.35AM	10.37AM
PV	Irradiation	38.9	42.5	40.4	10	12.7	44.6
	Irradiation (W/M2)	612.6377	669.3342	636.2612	157.4904	200.0128	702.4072
	Cell Temperature	45.6	47.5	49.9	48.2	49.1	42.6
	Water Flow Rate	0.5	0.5	0.5	0.5	0.5	0.5
	Water Flow Rate In KG/S (M)	0.00830	0.00830	0.00830	0.00830	0.00830	0.00830
	Solar Power (Ein)	894.5490	977.3350	929.0432	229.9612	292.0507	1025.6269
	Electrical Power (Ep)	93.17	89.63	103.3	31.5	0.45	105
	Electrical Efficiency (Ne)	10.4153	9.1709	11.1190	13.6980	0.1541	10.2376
	Thermal Energy Gained (Et)	0	0	0	0	0	0
	Thermal Efficiency (Nt)	0	0	0	0	0	0
	Overall Pvt Efficiency (No)	10.4153	9.1709	11.1190	13.6980	0.1541	10.2376
PVT	Irradiation	38.9	42.5	40.4	10	12.7	44.6
	Irradiation (W/M2)	612.6377	669.3342	636.2612	157.4904	200.0128	702.4072
	Cell Temperature	45.8	47.4	48.7	48.9	48.4	43.5

	TIME	10.27AM	10.29AM	10.31AM	10.33AM	10.35AM	10.37AM
	Water Inlet Temperature	31.4	31.5	32	32.1	32.1	32.2
	Water Outlet Temperature	33.8	33.7	33.9	34.9	34.9	34.6
	Water Flow Rate	0.5	0.5	0.5	0.5	0.5	0.5
	Water Flow Rate In KG/S (M)	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083
	Solar Power (Ein)	894.5490	977.3350	929.0432	229.9612	292.0507	1025.6269
	Electrical Power (Ep)	70.82	66.66	113.25	40.7	1.59	110.41
	Electrical Efficiency (Ne)	7.9168	6.8206	12.1900	17.6986	0.5444	10.7651
	Thermal Energy Gained (Et)	83.3177	76.3745	65.9598	97.2039	97.2039	83.3177
	Thermal Efficiency (Nt)	9.3139	7.8146	7.0998	42.2697	33.2832	8.1236
	Overall Pvt Efficiency (No)	17.2308	14.6352	19.2897	59.9684	33.8277	18.8887

The plotted graph for the output power vs irradiation, cell temperature vs irradiation, PV efficiency versus time, Output power (PVT) versus irradiation, PVT versus time and Cell temperature for PVT versus irradiation is shown in Figure 4 to 9, respectively.

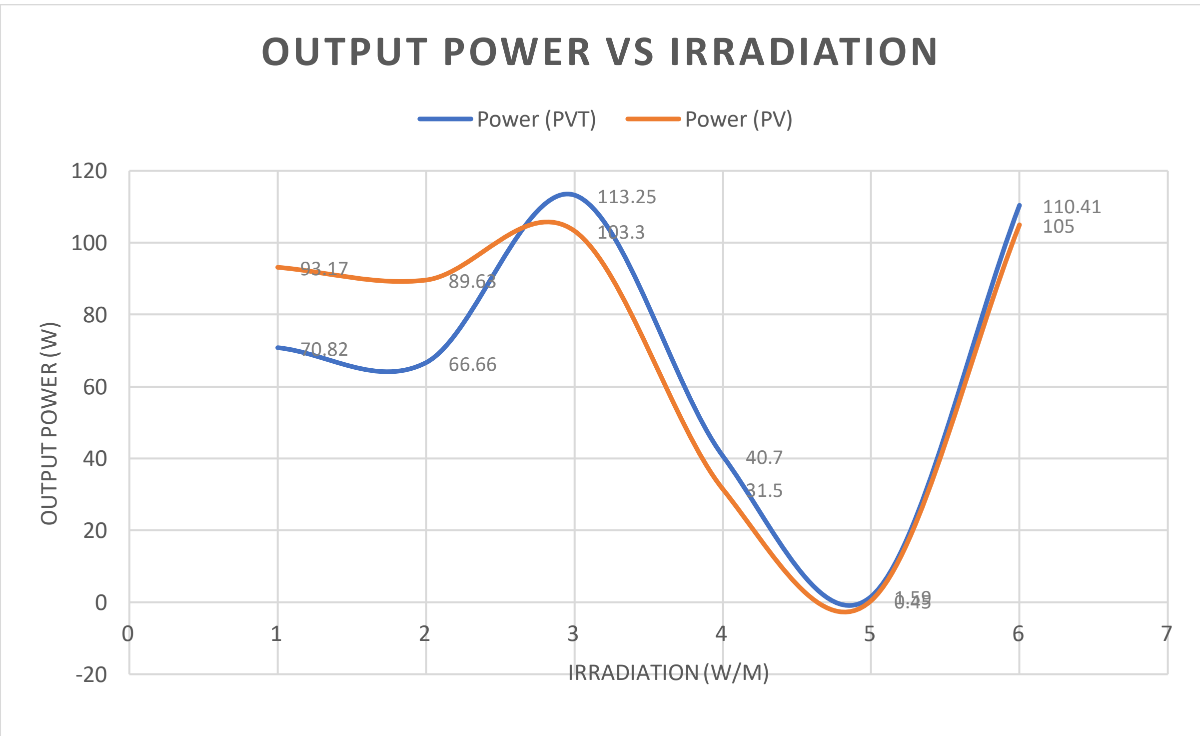

Figure 4: Output power versus irradiation for PV and PVT

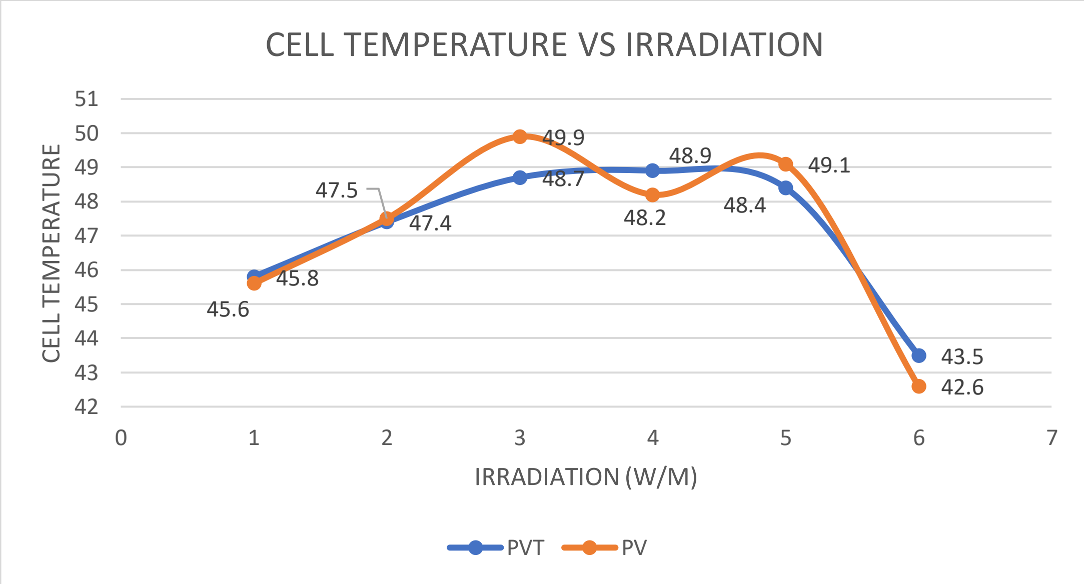

Figure 5: Cell temperature versus irradiation for PV and PVT

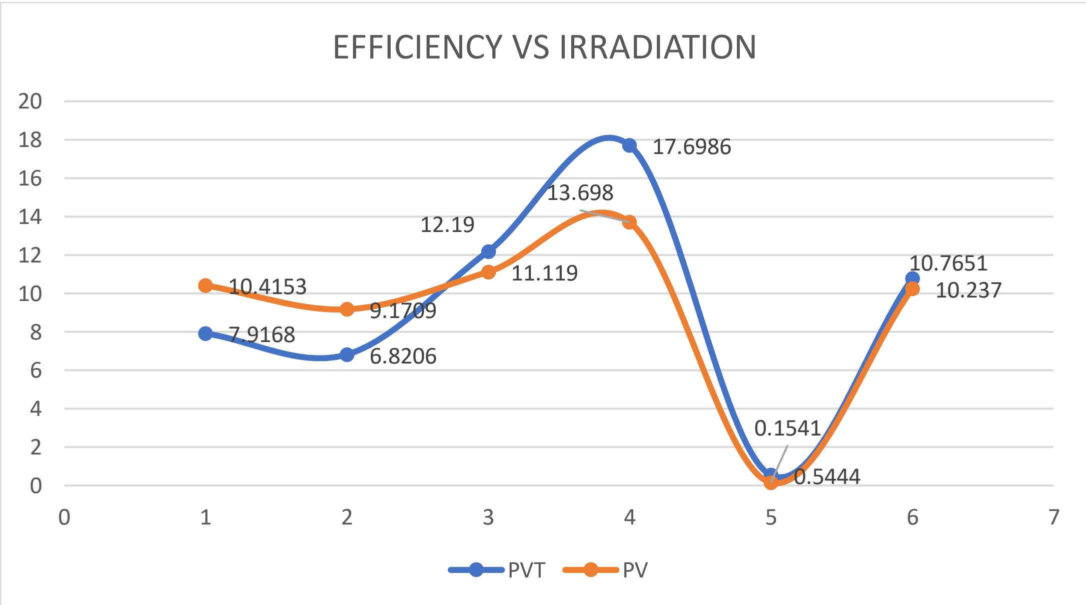

Figure 6: Efficiency versus irradiation for PV and PVT

Based on the findings shown in Figure 4, the output power generated from the PVT system slightly higher compared to the PV system, as it has the ability to absorb the heat compared to normal PV system. In Figure 5, the cell temperature for PVT system is significantly balance during the peak hours compared to the PV system. This is due to the condition of PV system sensitivity to the solar sunshine. The efficiency of PVT system in generating the heat is better compared to the PV system as it is clearly shown in Figure 6. The comparison of PV and PVT on PV & PVT efficiency versus time, PV & PVT efficiency versus irradiation, PV & PVT output power versus irradiation and PV & PVT cell temperature versus irradiation is shown in Figure 7 to Figure 10, respectively.

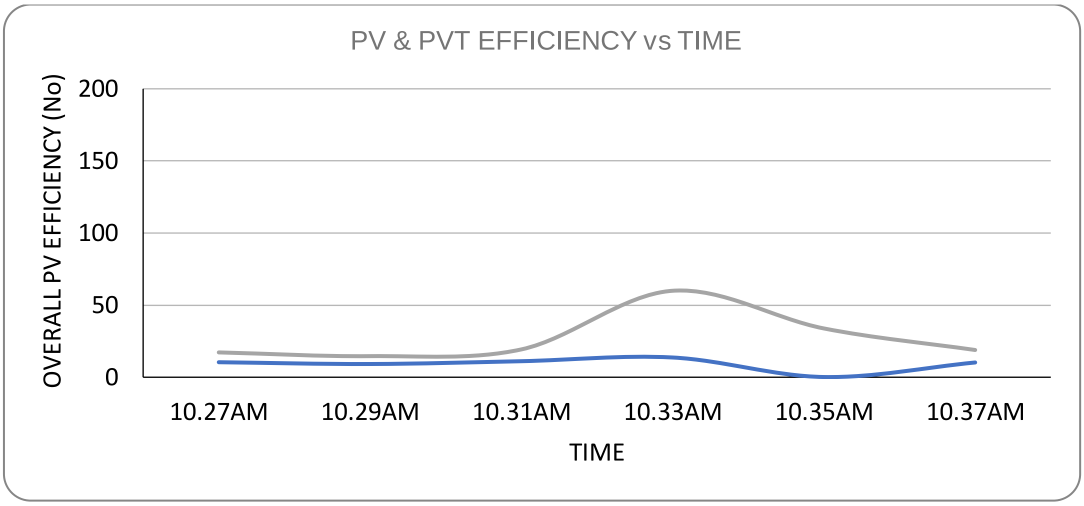

Figure 7 : PV & PVT efficiency versus time

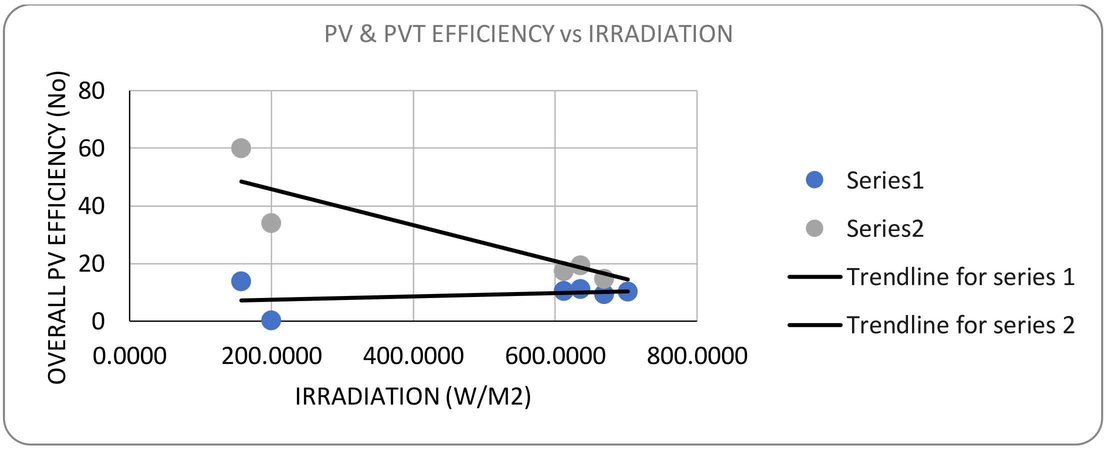

Figure 8: PV and PVT efficiency versus irradiation

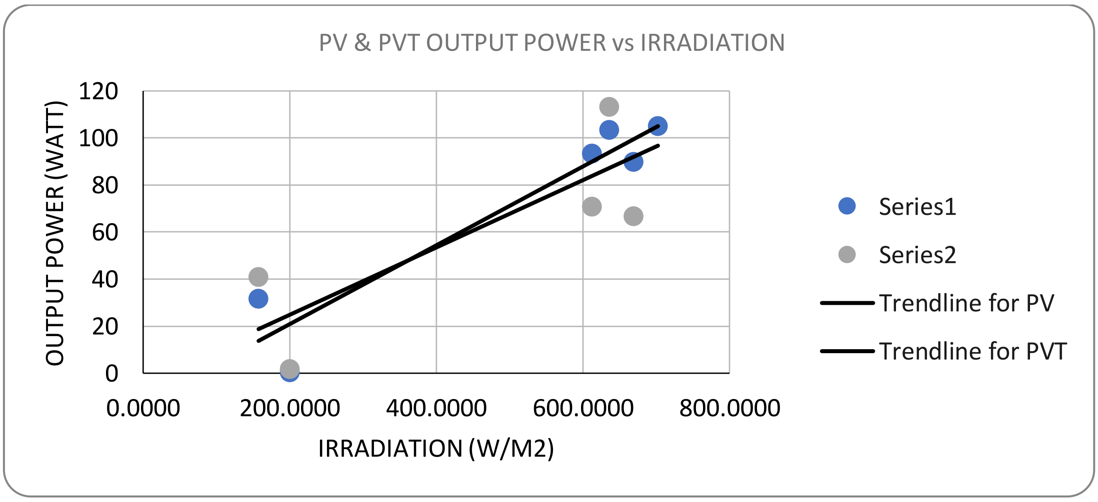

Figure 9 :PV & PVT output power versus irradiation

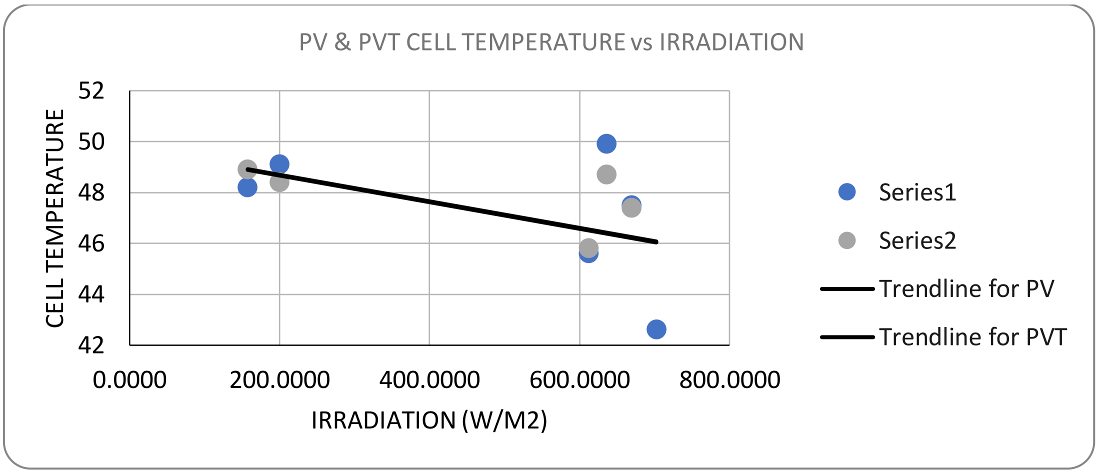

Figure 10: PV & PVT cell temperature versus irradiation

3.2 Photovoltaic Thermal Collector

The data obtained from the were including the results for solar water heater efficiency versus time, solar water heater output power versus irradiation, solar water heater cell temperature versus irradiation and solar water heater efficiency versus irradiation were plotted as shown in Figure 11 to Figure 14.

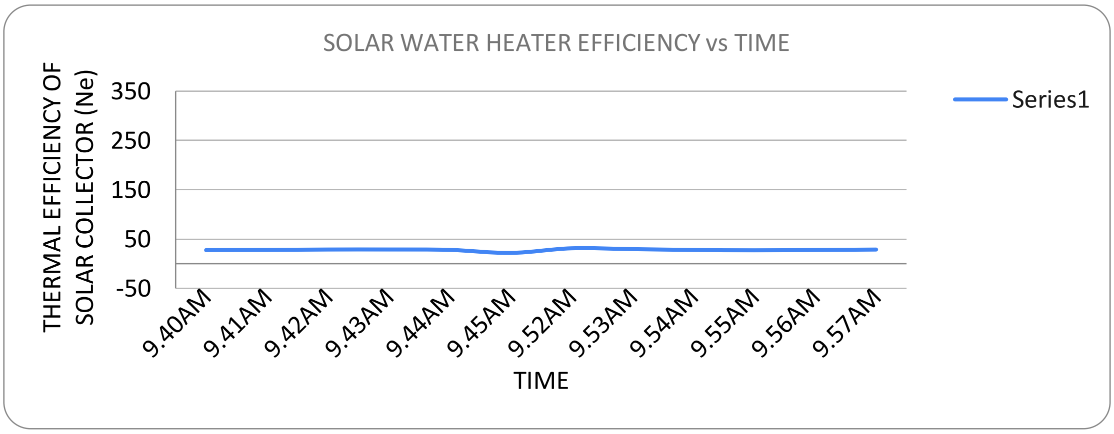

Figure 11: Solar water heater efficiency versus time

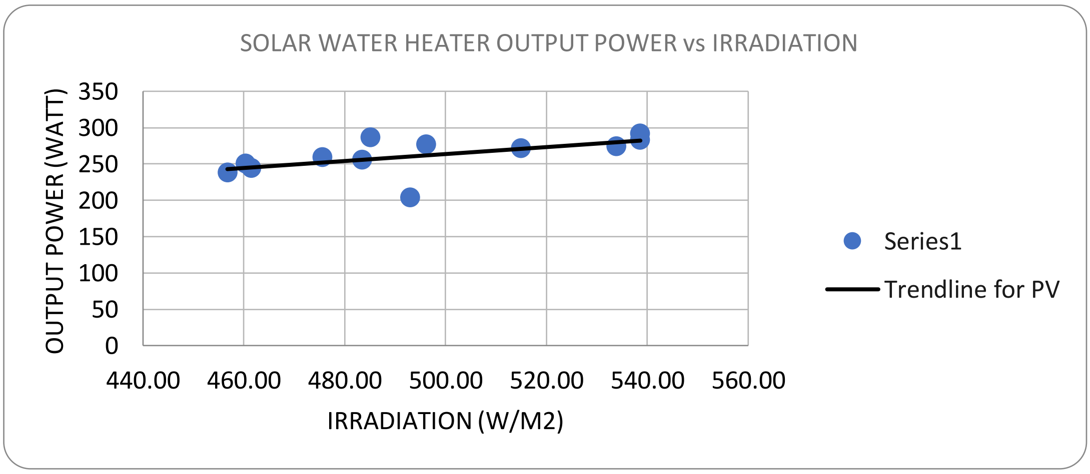

Figure 12: Solar water heater output power versus irradiation

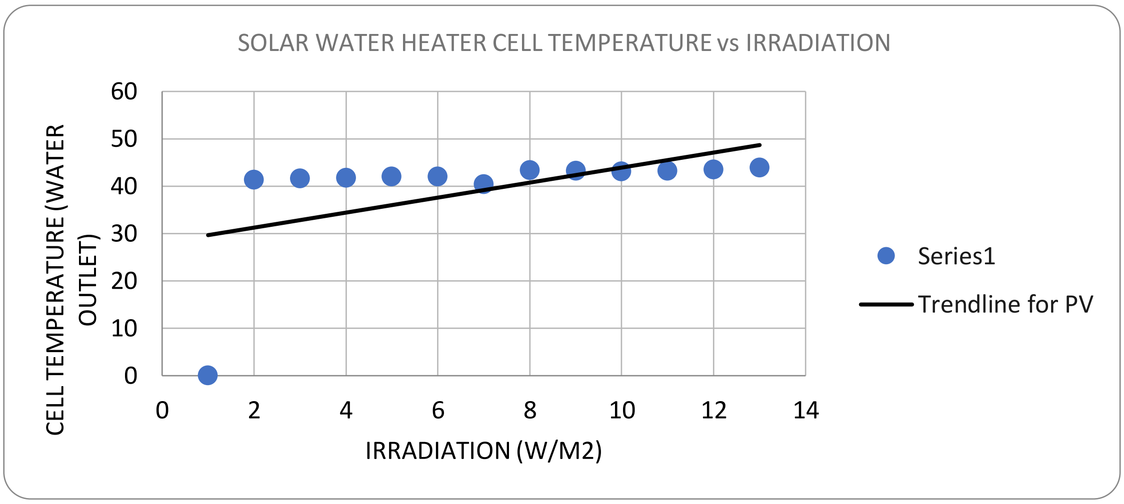

Figure 13: Solar water heater cell temperature versus irradiation

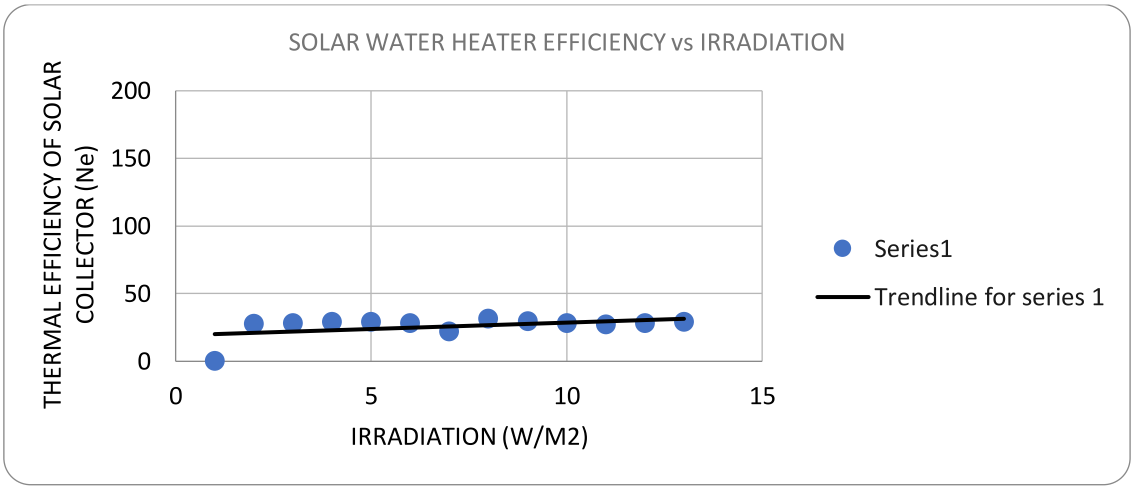

Figure 14: Solar water heater efficiency versus irradiation

4 CONCLUSION

As a conclusion, this experiment proved that this proposed photovoltaic thermal project can give advantages of solar radiation in rural areas, which are believed to be able to provide low- cost energy to communities. Based on the obtained experimental results, it was determined that the irradiation values of the thermal photovoltaic collector and the photovoltaic system both have almost the same irradiation and efficiency value. Photovoltaic-thermal systems (PV/T) and Photovoltaic have great potential for expansion and development. In addition, the mathematical design, which includes several basic equations used in this technical design step, can serve as a basis for developing and evaluating the compatibility of stand-alone photovoltaic electrification at any geographic location. It is believed that this simple design process can help improve the understanding of novice solar engineers.

REFERENCES

Al-waeli, A. H. A., Sopian, K., Kazem, H. A., & Chaichan, M. T. (2017). Photovoltaic / Thermal (PV / T) systems : Status and future prospects. *Renewable and Sustainable Energy Reviews*, *77*(March), 109–130. https://doi.org/10.1016/j.rser.2017.03.126

Cuenca, L., Ortiz, A., & Boza, A. (2010). Hybrid Photovoltaic-Thermal Collectors: A Review. *IFIP Advances in Information and Communication Technology*, *314*(February 2016), 24–31. https://doi.org/10.1007/978-3-642-11628-5

Katsumata, N., Nakada, Y., Minemoto, T., & Takakura, H. (2011). Solar Energy Materials & Solar Cells Estimation of irradiance and outdoor performance of photovoltaic modules by meteorological data. *Solar Energy Materials and Solar Cells*, *95*(1), 199–202. https://doi.org/10.1016/j.solmat.2010.01.019

Kazem, H. A. (2015). *Effect of Humidity on Photovoltaic Performance Based on Experimental Study*. *10*(23), 43572–43577.

Noxpanco, M. G., Wilkins, J., & Riff, S. (2020). A review of the recent development of photovoltaic/thermal (Pv/t) systems and their applications. *Future Cities and Environment*, *6*(1), 1–16. https://doi.org/10.5334/fce.97

Zhang, X., Zhao, X., Smith, S., Xu, J., & Yu, X. (2012). Review of R & D progress and practical application of the solar photovoltaic / thermal (PV / T) technologies. *Renewable and Sustainable Energy Reviews*, *16*(1), 599–617. https://doi.org/10.1016/j.rser.2011.08.026