An Experimental Investigation on Energy Performance of The Hybrid Photovoltaic Thermal System

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An Experimental Investigation on Energy Performance of The Hybrid Photovoltaic Thermal System

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Abstract. Climate change is a worldwide recognized problem, and its mitigation identified as one of the most significant challenges. The way to achieve this purpose is to reduce greenhouse gases (GHG) emissions through the energy system using renewables. The change from an energy system based on fossil fuels to renewable sources-based one is necessary on which the world community agrees. A photovoltaic thermal (PV/T) panel is a system that can produce both electricity and thermal energy simultaneously in one integrated system. This paper deals with hybrid energy systems, specifically a hybrid system to produce power and thermal energy from solar sources consisting of photovoltaic thermal modules. The hybrid system consists of 7 hybrid photovoltaic panels installed on the roof of the laboratory. This paper presents a study for experimental data obtained from a measurement campaign of the thermal and electrical behavior of a PV/T system in single and series models.

1 Introduction

In the last decades, there is a critical desire to change the energy supply, since this involves a decrease of the emissions associated with fossil fuel that leads to more extensive environmental and health concerns. PV is one of the most extensively utilized renewable power sources all around the world. Currently, the development of PV investments has been remarkable [1-3]. Moreover, the most significant challenge development of the solar photovoltaic industry is High production cost and Low efficiency of photovoltaic power generation. Commercial PV electrical conversion efficiency is of 6 to 15%.[4] Improving the efficiency performance of solar energy collection by developing a hybrid photovoltaic/thermal solar collector has been investigated by several researchers [5-10]. Herrando et al. [11] have analyzed the energy and economic performance of PV/T used to provide the energy demands of single-family indicating homes in three European cities,

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This research highlights that these systems can provide about 65% of electricity requirements and between 30% and 60% of thermal demands. Van Helden et al. [12] Carried out that PV/T modules' total efficiency is higher than the sum of the separate PV and solar thermal systems. PV/T can add to the decrease in fossil fuel consumption in the built environment in a more cost-effective approach. Hegazy et al. [13] investigated a thermal, electrical, hydraulic, and overall design of four types of PV/T air collectors. The numerical analysis described that while the channel above PV mode has the lowest performance, the other three have similar energy yields. Also, single-pass channels with PV in-between consume the slightest fan power. Alzaabi et al. [14] Presented a design to develop a PV panel's electrical efficiency utilizing a water hybrid PV/T system. The system made of a polycrystalline PV panel with a solar thermal collector adhered to its backside. The outcomes confirmed that the PV/T system's electrical power output increased by 15–20% compared to the PV panel. The system's thermal efficiency was calculated from measured data and reached values close to 60%–70% was achieved. Bahaidarah et al. [15] described the water PV/T system's effectiveness in the hot weather area of Dhahran, Saudi Arabia. Consequences demonstrated that PV temperatures decreased by 20.0% using a water-cooling system, and PV efficiency is increased by 9.0%. The present work focuses on a hybrid PV/T performance in the laboratory at Sapienza University. The hybrid system consists of 7 hybrid photovoltaic panels installed on the roof of the laboratory. The panels are electrically installed in series, the previous studies did not compare to series, and a single photovoltaic/thermal system include experimental or numerical investigations from the electrical and thermal energy. This research aims to estimate the electrical and thermal production in two different modes for the dwelling.

2 System description

This research consists of seven PV panels installed on the laboratory's rooftop at the Sapienza University. The schematic of the experimental campaign of PV panels is presented in Fig.1. As indicated in fig.2. The back of the board features the aluminum coil that captures the thermal energy. The dimensions of the hybrid panel are standard 1000x1652, precisely like any conventional photovoltaic panel. Electrical and thermal characterization are shown in Tables 1 and 2, respectively**.**

Fig. 1. General view of the PV panels**.**

Fig. 2. Plate heat exchanger PV

2.1 Electrical characteristics

Table 1 presents the electrical characteristics of the panel declared by the manufacturer.

Table 1. Electrical Parameters

Peak power Pm(W)	230W
Voltage MPP Vm(V)	30
Current MPP Im(A)	7.67
Open circuit voltage Voc (V)	36.8
Closed circuit current Isc (A)	8.34
Maximum system voltage (VDC)	1000
Panel efficiency (%)	13.9%
Maximum surface load	2400N/m
power temperature W %°C	-0.45 %/°C
voltage temperature Voc %°C	-0.36 %/°C
current temperature Isc % °C	+0.05 %/°C

2.2 Thermal characteristics

The thermal characteristics were taken directly from the manufacturer's data.

Table 2. Thermal Parameters

Load loss	150 mbar
Maximum allowed operating temperature	80 °C
Maximum operating pressure	3 bar
Recommended flow rate	1,2 l/min
Volume of fluid in the panel	0,8 l
surface area	1,52 m2
Absorber surface	1,46 m2
Optical efficiency	η =0,513
Linear heat loss coefficient	a 1 =7,680 W/(m2°K)
Quadratic heat loss coefficient	a2=0,014 W/(m2°K2)

3 Experimental procedures

The following methods were conducted from 11 AM to 4 PM for the seven panels. In the single and series model, the results were recorded every 30 minutes. The system is installed on the roof, connected with the detects solar radiation result carried out by entering the panel data. The sampling of the data Are as follows:

1. The water flow rate in the circuit [m3 / h]
2. Input and output temperature (Tin and Tout exchanger [° C])
3. ΔT Primary hydraulic circuit
4. Thermal power [W]
5. Solar irradiation [W / m2], inclination β = 23 °, azimuth angle = 50 ° N, f) Solar cell temperature TPV [° C]
6. Voltage [V]
7. Current [A]

The characterization of the hybrid PV/T solar module was conducted by evaluating the parameters from which it can recognize the thermal, electrical, and first principle efficiency within a parametric investigation. However, we studied calibrating the characterization of parameters that most influence a PV/T hybrid solar collector's operational operation. We constructed a corrected ΔT*, which was an expression of the temperature difference between the photovoltaic plate Tpv and the average of the fluid in the printed plate heat exchanger, normalized on the incident radiation. It was possible to achieve the equations of the efficiency characteristic curves that characterize the PV/T. The purpose of this investigation is to see what happens by setting several modules in series.

3.1 Evaluation of the electric efficiency η_{el}

1) Electrical efficiency of the solar module, such as:

$$\eta_{el} = \frac{P_{el}}{G_t} \quad)1($$

2) ΔT* correct, i.e. normalized on radiation:

$$\Delta T^* = \frac{(T_{pv} - T_m)}{G_t} \quad)2($$

Then

$$\eta_{el} = -10846\Delta {T^*}^3 + 150.28\Delta {T^*}^2 + 2.2329\Delta T^* + 0.1343 \quad)3($$

3.2 Evaluation of the thermal recovery efficiency η_t

1) Thermal efficiency of the solar module, such as:

$$\eta_t = \frac{P_t}{G_t} \quad)4($$

2) ΔT* corrected, i.e. normalized on radiation

$$\Delta T^* = \frac{(T_{pv} - T_m)}{G_t} \quad)5($$

Then

$$\eta_t = -320732\Delta {T^*}^3 + 12167\Delta {T^*}^2 - 142.68\Delta T^* + 1.2589 \quad)6($$

3.3 Performance evaluation of first principle η_{cog}

The First Principle Efficiency curve corresponds to the point-by-point sum of the η_t and η_el curves as a function ΔT^*:

$$\eta_{cog} = \eta_{el} + \eta_t \quad)7($$

The interpolated curve has an even maximum point $\eta_{cog} = 0941$ around $\Delta T^* = 0.016$s

4 Result and discussion

The result parameters single panel data, as illustrated in Table 3, also. Fig.3 is shown the parametric curves thermal and electrical from experimental data for a single panel.

Table 3. Single panel data used for comparison with the 3 panels series

HOURS [h]	FLOW [m3/h]	Tin [°C]	Tout [°C]	ΔT [°C]	Thermal power [W]	Irr. [W/m2]	Tpv [°C]	V [volt]	I [Ampere]	Electric power [W]
11.00	0.209	36.5	33.3	3.2	802	670	47.5	25.58	6.57	168.1
11.30	0.21	37.4	34.4	3	730	673	47.6	25.52	7.02	179.2
12.00	0.21	37.8	34.5	3.3	760	684	47.8	25.58	6.83	174.7
12.30	0.209	38.2	34.8	3.4	807	690	48	27.3	6.01	164.1
13.00	0.209	37.2	35.1	2.1	436	369	46.8	28.4	3.52	100.0
13.30	0.211	38.8	35.7	3.1	783	701	47.9	25.08	7.12	178.6
14.00	0.212	39	36	3	730	672	47.8	25.5	6.96	177.5
14.30	0.21	39.5	36.7	2.8	742	679	47.9	26.66	5.64	150.4
15.00	0.212	39.3	36.4	2.9	714	583	45.5	27.3	5.26	143.6
15.30	0.212	39.2	36.7	2.5	617	452	43.9	27.4	4.45	121.9
16.00	0.211	39	36.7	2.3	575	401	42.2	27.87	3.82	106.5

Table 4. Parametric analysis of for a single panel

Ren.Term	Ren.El	Ren. First Principle
0.7388981	0.154837479	0.893735581
0.66956506	0.16431897	0.833884028
0.68587106	0.157670385	0.843541441
0.72195384	0.146782072	0.86873591
0.72936532	0.167232092	0.89659741
0.6894912	0.157244149	0.846735352
0.67056143	0.163029101	0.833590535
0.67455772	0.136695576	0.811253296
0.75598755	0.152042437	0.908029985
0.84261991	0.166516443	1.009136349
0.88513285	0.163885656	1.049018503

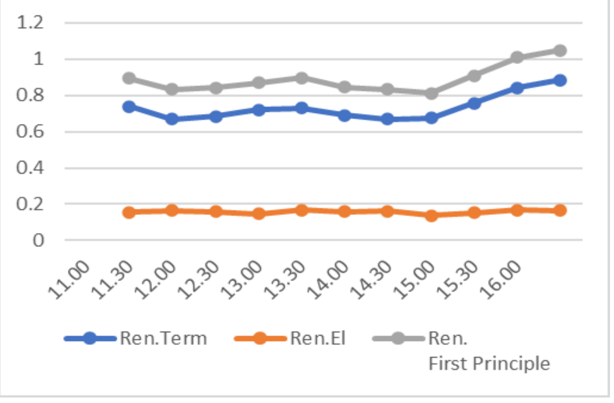

Fig 3. Parametric curves from experimental data for single panel

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Table 5 presents the investigated result experimental campaign series form of three PV/T panels, Fig.4 reveals a comparison for parametric performance curves from experimental data for the series of 3 panels.

Table 5. Series data from 3 panels used to compare the single panel

HOURS [h]	FLOW [m3/h]	Tin [°C]	Tout [°C]	ΔT [°C]	Thermal power [W]	Irr. [W/m2]	Tpv1 [°C]	Tpv2 [°C]	Tpv3[°C]	V [volt]	I [Ampere	Electric power [W]
11.00	0.14	43.4	33.7	9.7	1586	622	64.8	48.3	61.8	75.46	6.32	476.9
11.30	0.14	44.6	34.7	9.9	1637	646	62.8	46.5	57.1	74.53	6.59	491.2
12.00	0.14	45.7	35.8	9.9	1577	645	66.6	51.3	60.5	75.82	6.5	492.8
12.30	0.141	46.1	36.5	9.6	1595	623	65.5	48.1	59.8	75.1	6.55	491.9
13.00	0.142	46	36.8	9.2	1476	632	64.1	47.8	58.6	76.68	6.3	483.1
13.30	0.14	45.8	37.4	8.4	1385	616	61.8	47.5	57.4	77.25	6.06	468.1
14.00	0.14	45.7	37.9	7.8	1255	489	59.2	47.3	53.9	77.32	5.05	390.5
14.30	0.142	45.5	38.4	7.1	1115	563	57.1	46.9	52.9	77.6	5.59	433.8
15.00	0.14	44.5	38.1	6.4	1041	516	54.2	46.1	50.3	79.75	5.14	409.9
15.30	0.142	44.2	38.1	6.1	1003	471	54.3	46.5	50.2	79.96	4.72	377.4
16.00	0.14	42.5	37.3	5.2	835	409	45.3	46.1	50.8	80.39	4.12	331.2

Table 6. Parametric analysis of series of 3 panels

Ren.Term	Ren.El	Ren. First Principle
0.524658277	0.157763752	0.682422029
0.521410644	0.156439979	0.677850622
0.503078445	0.157217597	0.660296041
0.526788604	0.162463917	0.689252522
0.480543835	0.157278481	0.637822316
0.462628935	0.15637025	0.618999185
0.528078635	0.164300201	0.692378836
0.40750243	0.158536354	0.566038784
0.415111494	0.163458624	0.578570118
0.438171127	0.164876063	0.60304719
0.42007506	0.16662481	0.503078445

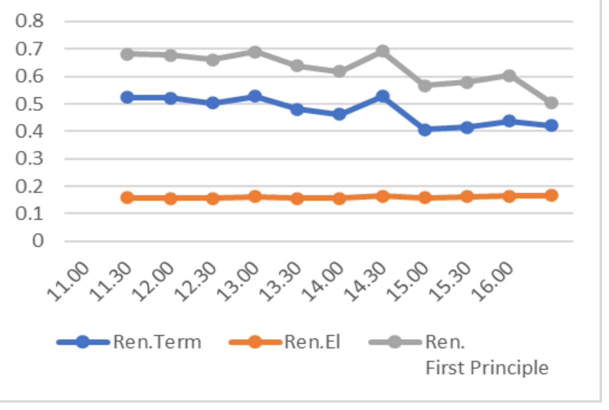

Fig 4. Parametric performance curves from experimental data for the series of 3 panels

By highlighting the first-principle results, we can analyze the differences: Fig .5 reveals a comparison for the first principle of the single and three panels in the PV/T. It is clearly shown that the first principle performance is significantly higher in the single module compared with other works.

Table 7. Difference between First principle returns of the single panel and the series of 3

Ren. Single panel	Ren Three panels	difference
0.85412663	0.682422029	17.1704601
0.833884028	0.677850622	15.60334053
0.843541441	0.660296041	18.32454
0.86873591	0.689252522	17.94833882
0.83269854	0.637822316	19.4876224
0.846735352	0.618999185	22.77361666
0.87425694	0.692378836	18.18781035
0.811253296	0.566038784	24.52145115
0.908029985	0.578570118	32.9459867
1.009136349	0.60304719	40.60891591
1.049018503	0.58669987	46.23186329
0.85412663	0.682422029	17.1704601
0.833884028	0.677850622	15.60334053
	Medium difference %	24.89126781

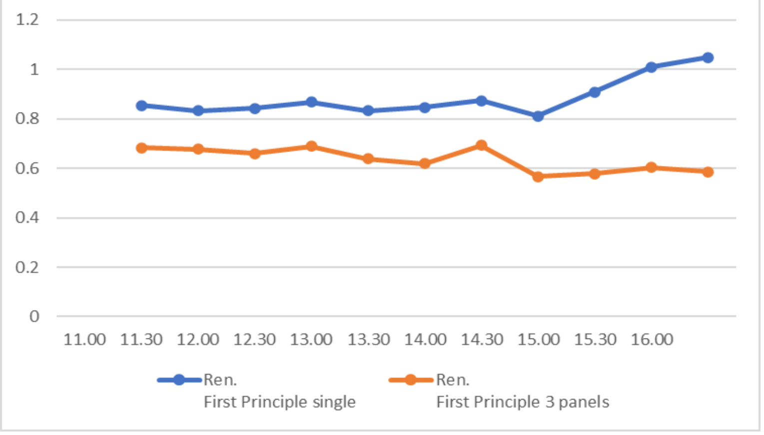

Fig 5. Difference between the first principle curves of a single panel and the series of 3 panels

5 Conclusions

This work's purpose was to conduct an experimental measurement project to characterize a hybrid PV/T solar panel's real operating conditions in single module configurations and three modules connected in electric hydraulic series. From the data obtained experimentally, we analyzed the behavior of the two types of designs, from which we could observe that:

1-Single panel works with optimal efficiency, providing an increase in the thermal level of the average temperature Tm (in the summer operating period), which infrequently exceeded 40°C, the solar cell temperature Tpv consequently lowers its thermal level changing between 40 and 50°C, the lowering of these temperatures allows the cell to perform at the point of most significant electrical and thermal efficiency.

2-Series of three panels can increase the average circuit temperature Tm (compared to the previous case). However, the average thermal system always below 43 ° C, compared to a solar cell temperature Tpv, which exceeds 60°C.

Consequently, the results can also be used to evaluate the advantages of deriving by installing PV/T plants compared with conventional PV solar systems.

References

1. S. Daisuke, Y. Noboru, Renew Sustain Energy Rev **104,** 151-166 (2019).

2. L. De Santoli, G. Lo Basso, Sh. Barati, S. D’ambra ,C. Fasolilli, Energy **193**, 116678 (2020).

3. A. Gagliano, G.M. Tina, S. Aneli, S. Nizetic, Cleaner Prod, 304–315 (2019)

4. B.J. Huang, T.H. Lin, W.C. Hung, F.S. Sun. Energy **70,** 443-448 (2001).

5. A.S. Joshi, A. Tiwari, Renew Energy **32,** 2223-2241 (2007).

6. T. Ma, H. Yang, Y. Zhang, L. Lu, X. Wang Renew. Sustain. Energy Rev **4,** 1273-1284 (2015).

7. N. Marc-Alain Mutombo, F. Inambao, G. Bright, Energy Southern Africa **27** (1), 28-38 (2016).

8. G. Mittelman, A. Kribus, A. Dayan, Energy Convers. Manage **48** (9), 2481-2490 (2007).

9. T. Nualboonrueng, P. Tuenpusa, Y. Ueda, A. Akisawa, Res. Appl **21,** 1204-1213 (2013).

10. B. Sandnes, J. Rekstad, Energy **72** (1), 63-73 (2002).

11. M. Herrando, A. Ramosa, J. Freeman, I. Zabalza, C.N. Markides, Energy Convers Manage **175** (1), 67-85 (2018).

12. Van Helden, R.J.C. van Zolingen, H.A. Zondag,: Res. Appl **12,** 415-426 (2004).

13. A.A. Hegazy, **S** 861-881 (2000).

14. A. Alzaabi, Nadine K. Badawiyeh, Hind O. Hantoush, A.K. Hamid, Energy, 385-3892014 (2014).

15. H. Bahaidaraha, A. Subhana, P. Gandhidasana, Energy **59,** 445-453 (2013).