Comparative study of the performance of photovoltaic and photovoltaic thermal solar systems: Case study in El Jadida

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Abstract. The productivity of photovoltaic (PV) and photovoltaic thermal (PVT) systems depends on environmental conditions and can vary considerably depending on the geographical area. In this study, we evaluated and compared the actual performance of a commercial water-based PVT system (PVT Dualsun Spring) with that of a PV system (PV Dualsun Flash) under the specific conditions of the city of El Jadida. The results show that the PVT system offers better performance than the PV system, mainly thanks to the cooling that reduces the temperature of the cells. When irradiance reaches a maximum of 1055.6 W/m², the PVT system generates 3.92% more electrical power than the PV system. In addition, its electrical efficiency is 4.11% higher than that of the PV system.

1 Introduction

Solar panels are an effective response to the energy crisis caused by the growing use of fossil fuels. The efficiency of solar cells improves every year thanks to technological advances. However, the efficiency of PV modules decreases as their operating temperature rises. Cooling PV modules with water or air helps to improve this efficiency [1]. Increasing the efficiency of PV modules has economic benefits, such as reducing the payback time and extending the lifetime of systems [2]. PVT hybrid solar collectors represent innovative technologies in energy production, enabling solar radiation to be efficiently converted into thermal and electrical energy. Research into these systems began in the mid-1970s, with the main aim of improving the efficiency of PV panels [3].

Many factors can influence the performance of PVT systems [4,5], divided into three main categories: design parameters, operating parameters and environmental parameters. Key design parameters include the choice of PV cells, the design of the thermal collector and the working fluid used. Operating parameters include the temperature of the working fluid at the collector input and the mass flow rate of the coolant.

On the other hand, environmental conditions play a crucial role: solar irradiation absorbed by the PV cells, wind speed, ambient temperature (AT), as well as factors such as dust accumulation, dirt, shading and humidity. These aspects show that the productivity of PV and PVT systems can vary considerably from one geographical area to another. For

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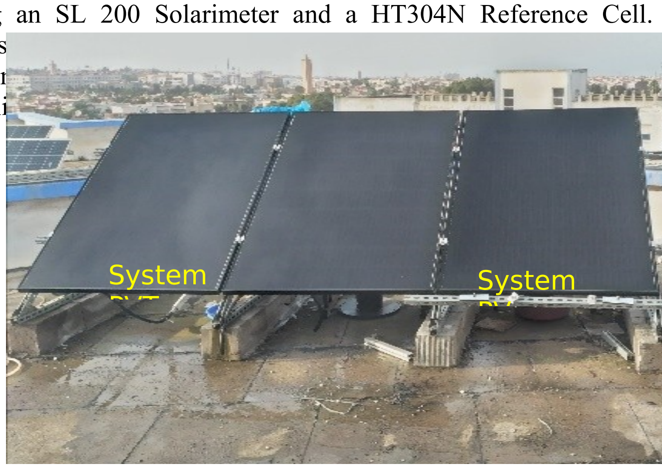
example, regions close to the equator benefit from more direct and constant sunlight, resulting in greater solar energy production. On the other hand, regions far from the equator receive more oblique sunlight, which can reduce the energy conversion efficiency of solar systems.

The main objective of this experimental study is to compare the actual performance of a commercial water-based PVT system (PVT-S) with that of a PV system under the specific operational conditions of the city of El Jadida. The systems under investigation are PVT Dualsun Spring and PV Dualsun Flash, both equipped with PERC monocrystalline silicon solar cells to ensure accurate and fair comparison results.

2 Materials and methods

2.1 Experimental setup

The experimental system (shown in Fig. 1) was installed on the roof of the laboratory of the physics department of the Chouaïb Doukkali University (UCD) in El Jadida, Morocco. The PV and PVT systems were mounted on a stable support and oriented towards the south at an angle of 33°. The system types used were Dualsun Spring (PVT) and Dualsun flash (PV), and their specifications under standard laboratory test conditions (STC) are listed in Table 1. To measure the temperature of the front and back of the PVT and PV systems, four K-type sensors were used, each connected to an Arduino Mega board to record the temperature every minute. At the same time, the inlet water temperature was recorded every 10 minutes using a mercury thermometer. To assess water flow, a MAG-VIEW MVM-030-PA flow meter was used in conjunction with a flow control valve. Solar radiation was measured using an SL 200 Solarimeter and a HT304N Reference Cell. The ambient temperature was … cteristics, i.e. maximum curre… short-circuit current and maxi…



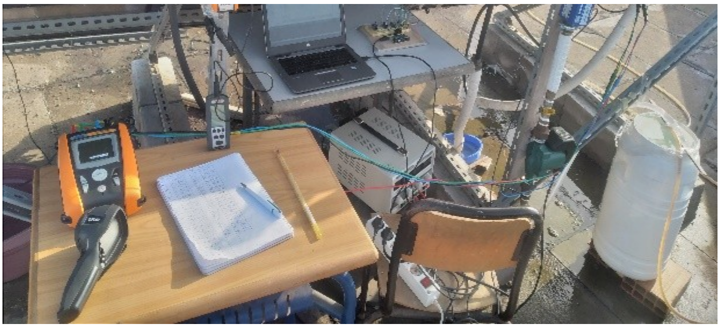


Fig. 1. Experimental configuration of PV and PVT systems with measurement equipment.

Table 1. Technical characteristics of PVT and PV systems under standard test conditions (STC)

Details	**Value**
Module area (m^2)	1.876
Nominal power (W)	375
Efficiency (%)	19.989
V_{mpp} (V)	40.4
I_{mpp} (A)	9.28
V_{oc} (V)	48.9
I_{sc} (A)	9.89
Temp. coeffi of V_{oc} (%/°K)	-0.27
Temp. coeff. I_{sc} (%/°K)	0.04
Temp. coeff. Power (%/°C)	-0.34

2.2 Performance analysis

The instantaneous efficiency of the PV system is defined as follows [6]:

$$\eta_{el} = \qquad (1)$$

Where G is the solar radiation intensity (W/ m²) and A is the surface area of the PV system (m²).
The maximum output power can be given by the equation below [7-9]:

$$P_{max} = V_{oc} \,.\, I_{sc} \,.\, FF = V_{mpp} \,.\, I_{mpp} \qquad (2)$$

The thermal efficiency (TE) of the PVT-S is calculated using the following formulae [6,7]:

$$\eta_{th} = \qquad (3)$$

The useful power is evaluated using an enthalpy balance [6,7]:

$$Q_u = D_f \, . \, C_f \, . \, (T_s - T_e) \quad (4)$$

C_f (J/kg K) is the heat capacity of the fluid, D_f (kg/s) is the water flow rate and T_s and T_e (°C) are the output and input temperatures of the PVT-S.
The total efficiency of the PVT-S is determined by the following equation [6,7,10,11]:

$$\eta_o = \eta_{el} + \eta_{th} \quad (5)$$

3 Results and discussion

The analysis of the two systems was carried out during a sunny day in El Jadida, Morocco. The flow rate chosen for cooling the PVT-S is 60 l/h. During this day, we took readings of atmospheric parameters such as solar radiation and AT every 10 minutes from 10h59 to 17h39.

Fig. 2 shows the temporal evolution of AT and solar irradiance (G) over the course of a sunny day. Measurements began at 10h59. with a minimum G of 847,3 W/m² and an AT of 26.8°C. They peaked at around midday. They reached their peak around midday. The measurement period ended at 17h39, with an G of 272,06 W/m² and an AT of 25.2 °C, as shown in Fig. 2. This figure also illustrates how the inlet water temperature changes over time for the PVT-S.

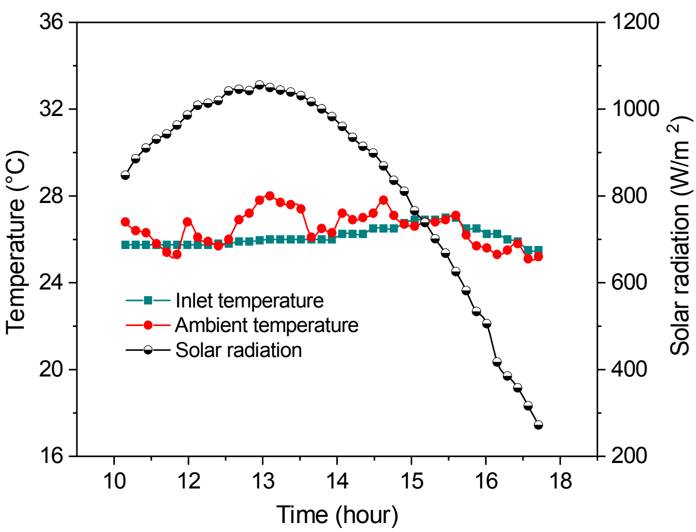


Fig. 2. Variation in AT, water inlet temperature to the PVT-S and solar irradiation over time.

Fig. 3 shows the evolution of the back surface temperature of the two systems, PV and PVT, over time. It can be clearly seen that the PVT-S has a lower backside temperature than the PV system, due to cooling which reduces the temperature of the solar cells. The PV panel reaches a maximum temperature of 59.75 °C at 11h29, while the PVT-S reaches a maximum of 58 °C at 11h29. This reduction in temperature for the PVT-S results in better electrical performance compared with the PV panel.

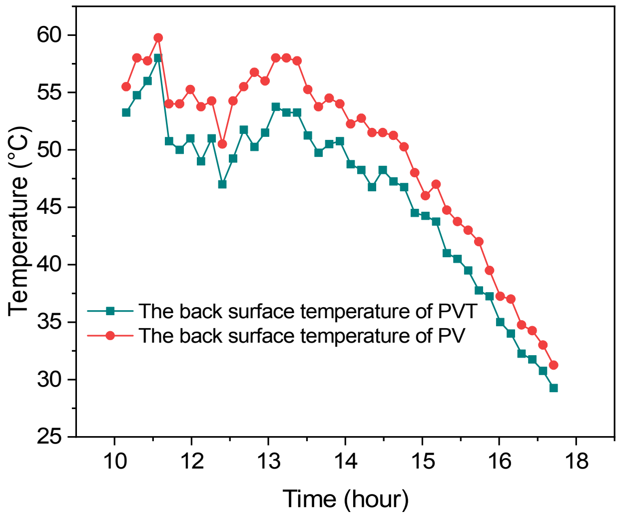


Fig. 3. Evolution of the temperature of the back surface of the PVT and PV system over time.

Figure 4 illustrates the impact of variations in the level of solar irradiation on the electrical power of the PV and PVT system. It can be seen that the electrical power increases as the level of solar irradiation increases. This increase is the result of both voltage and current increasing with G (see Fig. 5). The rate of increase in current is linear and significantly higher than that of voltage. At a maximum G of 1055.6 W/m², the PV module produces 342.49 W, while the PVT-S generates 356.47 W. The maximum difference between the power outputs of the PV and PVT systems is 17,01 W, recorded at 11h29.

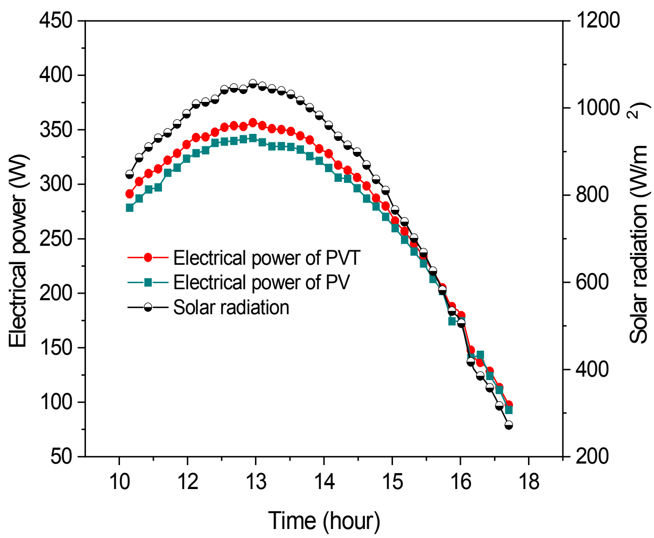


Fig. 4. Effect of solar irradiation on the electrical power of the PVT and PV system.

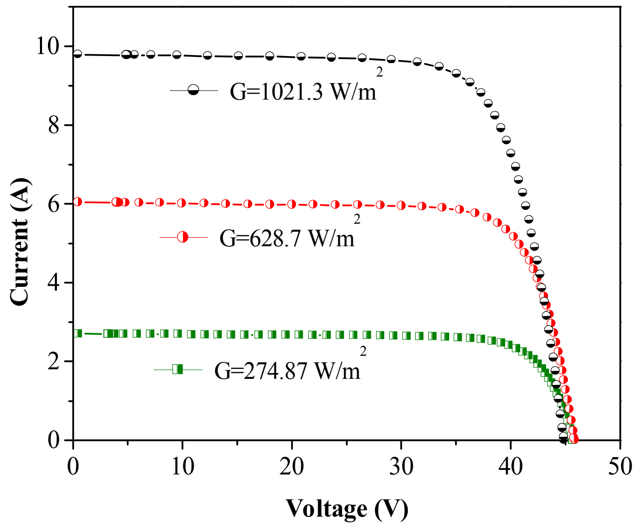


Fig. 5. Effect of G on the I=f(V) characteristic.

Fig. 6 shows the impact of variations in the level of solar irradiation on the electrical efficiency (EE) of the PV and PVT system. It can be seen that the EE decreases as the level of solar irradiation increases. The EE curves show a minimum value at solar noon, with higher electrical efficiencies observed at the beginning and end of the measurements. The increase in G at midday leads to an increase in the temperature of the solar cells, thus reducing EE. The maximum difference in EE between the PV and PVT systems reached 0.94 % at 11h09. Note that the optimum EE of the PVT-S is 19.1 % at 17h19.

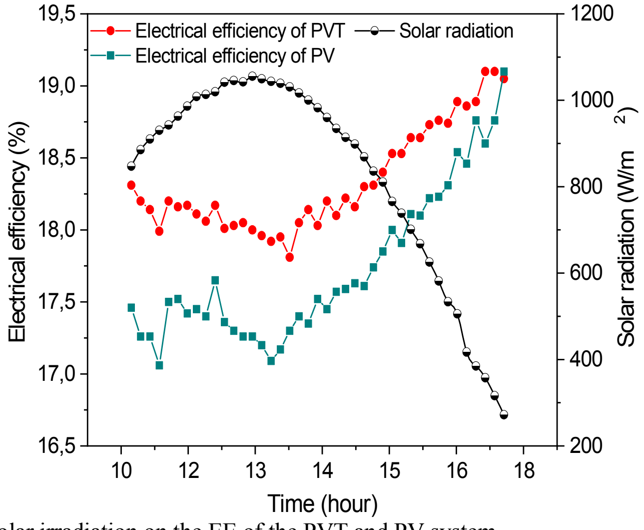


Fig. 6. Effect of solar irradiation on the EE of the PVT and PV system.

Variations in the thermal and total efficiencies of PVT-Ss as a function of time are shown in Figure 7. As can be seen from this figure, the thermal and total efficiencies increase progressively over time. Interestingly, the average temperature of the PVT-S increases with time. This increase in temperature improves the TE, although it decreases the EE. However, the increase in TE remains dominant. For the PVT-S, the maximum TE reached 38.63% at 14h49, and the total efficiency reached 56.85% at the same time.

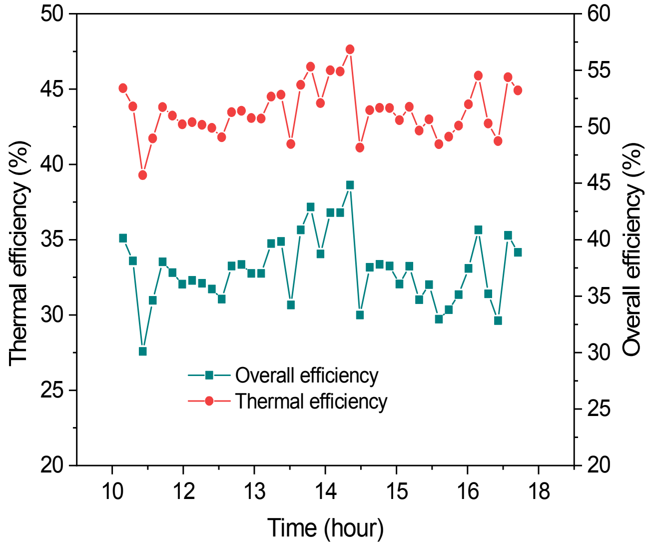


Fig. 7. Evolution of the thermal and total efficiency of the PVT and PV system over time.

4 Conclusion

In this study, we compared the actual performance of a water-based PVT-S (PVT Dualsun Spring) and a PV system (PV Dualsun Flash) in the specific conditions of the city of El Jadida. Here are the main conclusions:

- The temperature of the PVT-S cells was systematically lower than that of the PV system cells. The average temperatures reached were 46.18°C for the PVT and 49.7°C for the PV.
- An increase in solar irradiation improves electricity production, but also increases the temperature of the PV system, reducing their efficiency.
- The greatest difference in power output between the PV and PVT systems was 17,01 W, measured at 11h29.
- The greatest difference in EE between the PV and PVT systems was 0.94 % at 11h09.

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