An empirical investigation of the electrical and thermal performance of photovoltaic-thermal hybrid sensor (PV/T)

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Abstract: - The combination photovoltaic-thermal solar collector produces at the same time electricity gratitude to photovoltaic solar energy and warmth gratitude to thermal energy because it is known that the traditional photovoltaic panel produces three times more heat than the electricity. The increase in warmth inside the module is one of the principal reasons of the reduced performance of photovoltaic solar panels. Thus the necessity for a thermal evacuation technique. The benefit of a hybrid technique is the cooling of the photovoltaic cells gratitude to the circulation of a fluid, which will be warmed during its passage via the sensor. The novelty of this study is to recover this thermal energy by heating or drying. Previous dryers worked with thermal sensors thanks to the greenhouse effect, which gives only heat. The purpose of this paper is the realization experimental of a PV/T sensor and so the examination of the impact of different parameters on the energy performance of the PV/T sensor. The impacts recommend that this kind of collector is a nicely alternative to photovoltaic modules and thermal collectors seated individually.

Key-Words: - Photovoltaic cell, solar energy, hybrid solar collector, experimental investigation, Electrical efficiency – Thermal efficiency.

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1 Introduction

Today, the world tends towards the exploitation of renewable energy resources, including Algeria, it is strongly called to be up to date thanks to its natural potential in this field. Among its renewable energies, solar energy where Algeria has already given it great importance for years.

Solar panels (PV) are a solution for isolated places, not connected to the electricity grid and to make installations autonomous. Solar energy can also be very advantageous in the case of installations in private homes. However, solar panels are currently not cost-effective for large-scale generation, owing to numerous limitations. In the utilization of solar energy, the low density of energy and the intermittent nature of the latter is due to variations in climatic conditions. Most of the research is devoted to the development of photovoltaic modules and solar thermal collectors. The photovoltaic thermal (PV/T) hybrid collector is a good alternative to separately installed solar thermal or photovoltaic collectors, as it not only combines two complementary functions, but also offers dual functionality in a single collector. The performance of a solar collector, designed to transform solar energy to thermal energy, depends on its shape, the technique chosen, and the way in which heat losses are reduced on its surface. There is a broad scale of solar air collectors with different absorber arrangements. For our study, we chose a sensor with the air passage located between the absorber and the insulation. Air solar collectors are important in applications requiring low and moderate temperatures, such as space warming and the drying of many products (food, building materials, wood, etc.). Our work consists in realizing and characterizing a hybrid sensor (PV/T) to use it for the drying of agricultural products. Hybrid collectors utilizing air and water as warmth transfer fluid have been evaluated economically and experimentally. The relatively simple PV/T air solar collector consists of an absorber layer with an insulated back, cooled by a current of air circulating between the absorber and a glass cover. Its heat exchange surface can be increased either by giving the absorber a high emissivity or with a ribbed or grooved surface. In 2006, Tiwari et al. [1] suggested an academic and empirical steady-state investigation of a PV/T solar collector with naturally or mechanically ventilated air. This solar collector is composed of two PV modules of 0.61m² every, attached in series and mounted on a non-corrosive insulating layer of Tedlar. The PV module is constructed up of photovoltaic cells stuck jointly via a coating of EVA and covered by a coating of glass. Fans placed at the entry to the air hole located between the Tedlar and an insulating coating of wood permit the forced ventilation of the PV modules on the rear face. The electrical energy produced is stored in an electric battery. This analysis demonstrated that the further healing of the thermal energy produced enhances the general efficiency of the air PV/T system by around 18%. In 2007, Tripanagnostopoulos [2] maintained the analysis of combination PV/T solar collectors whose warmth transfer fluid is any air or water. The purpose of their employment was to reduce the operational temperature of PV modules, raise the generation of preheated air and decrease warmth losses via the isolation on the underneath of the constituent. For this, the design of a solar PV/T air collector has been changed at an inferior cost. In general, two kinds of PV/T collectors can be distinguished: PV/T collectors with glass cover, which produce high-temperature heat, but with a slightly lower electrical efficiency, and PV/T collectors without glazing which produce relatively low-temperature heat and which have high electrical performance [2, 3]. Hybrid collectors without additional glass deliver relatively low temperatures and must be combined with heat pumps to heat ambient air or water [4, 5]. One of the applications of photovoltaic modules in non-direct combination with thermal collectors is in SDHW (Solar Domestic Hot Water) systems which generally consist of supplying the internal resistance necessary for heating the water with the electricity generated by the photovoltaic modules [6]. Work (2003 - 2004) has been devoted to aspects of the simultaneous production of heat energy and electrical energy by photovoltaic modules [7]. Hybrid sensors based on amorphous silicon, which have a low photovoltaic conversion efficiency (nearly 7%), have been studied by Adamoto and his team [8]. Elswijk et al. [9] concluded in a study that in housing, a hybrid PV/T collector needs 38% less roof space than a combined system of photovoltaic modules and thermal collectors with the same approximate efficiency. The thermal efficiency was found to be around 77%, with a heat loss coefficient of 23 W/m^2K (work by Bakker et al. [10]). Zondag et al. [11] investigated the influence of thermal resistance on the result of the hybrid sensor. It can be considered, that for hybrid sensors, a total conversion efficiency as being the totality of the thermal efficiency and the electrical efficiency. Tripanagnostopoulos applied the system based on the cooling of photovoltaic modules to hybrid collectors with concentrators [12]. Arslan et al. [13] worked on the realization and testing of a new conception of a finned air-fluid photovoltaic-thermal collector. Utilize of different mass flow rates to perform numerical and experimental analysis. The electrical efficiency increased by 0.42% thanks to the cooling of the photovoltaic panel. Choi et al. [14] suggested a novel PV/T air hybrid sensor design with a single-pass dual-flow air trough to study electrical and thermal performance under natural weather conditions. To enhance the warmth transmission result between the PV module and the airflow, an irregular section rib has been placed on the back cover of the PV module. The results showed that the middle thermic efficacy of the PV/T collector and the average electrical efficacy raised with rising mass flow rate of air. Shahsavar et al. [15] analyzed the exergy and energy performance of a photovoltaic-thermic (PV/T) air collector with natural ventilation. They investigated glazed and unglazed types of PV/T collectors. To increase the heat absorption at the photovoltaic panels, a thin sheet of aluminum was placed in an air channel. The conclusions were that there is an optimal sensor length and an optimal channel depth to who the absolute energy and exergy efficacy are maximum. Singh et al. [16] sported the semi-transparent dual-channel PV/T system (DCSPV/T) into which air streams via two channelers, one channeler below PV and the other channeler above PV to absorb the heat-related to the upper and lower sides of the photovoltaic cell and compared to another system, which has only one passage under the photovoltaic cell. The results indicated that the dual-channeler design has an overall electrical efficacy, heat gain, and exergy efficiency of 30.49%, 35.63%, and 3.19% respectively. Better than a single channel system. Kaiser et al. [17] used an unglazed unique pass PV/T sensor composed of a single PV module, to apply an experimental study and detect the extent of the whole size effect on the PV cell temperature and its effectiveness. In the case of natural and forced ventilation. The results showed that in the case of natural ventilation, they obtained a factor ratio (duct deep/duct height) of approximately 0.11 to undervalue the temperature of the PV cell. Whereas in the case of forced ventilation, it has been found that smaller dimensions can be utilized. While for constant factor proportion, air velocity was located to strongly affect PV cooling. For a duct speed V = 6 m/s, a power increase of 19% is observed compared to the case of natural ventilation (V = 0.5 m/s). Khaled and Mohamed [18] concluded that the porous medium has an influence on the performance of the double-pass PV/T hybrid sensor. The research showed the efficiency of the porous media as the heat exchange area was enlarged and thus raised the thermic efficacy and the temperature of the air leaving the hybrid solar collector. While the combination's efficacy raised by (3%). The most increased value for everyday thermic and electrical efficacy was 80.23%, 8.7% in the sensor which utilized absorbent media and glass cover, while the highest value for thermic efficacy and electrical was 51.25%, 10.91% without absorbent media and glass cover. Singh et al. [19] investigated the influence of the shape factor of the absorber plate and the mass flowing rate on the execution of the PV/T collector in air. The results showed that the efficiency of the PV/T system is highest when the form factor is in the range of 1.3 to 2.0 (absorber with curved groove). Sahlaoui et al. [20] generated a simulation program to calculate the thermic and electrical parameters of a PV/T hybrid sensor and validated them by experimental results. The consequences showed that the overall efficiency of the PV/T sensor is 98% for a mass flow of 0.073Kg/s, the efficiency increases when the number of fins and its height decreases. Slimani et al. [21] worked on four solar devices to compare thermic and electrical performance using the mathematical analysis method. The solar devices are a single photovoltaic module (PV-I), conventional air PV/T collector (PV/T-II), glazed gnce-through PV/T air collector (PV/T- III), and a double-pass glazed PV/T air sensor (PV/T-IV). Overall electrical, thermal, and energy efficiency results were presented. Saygin et al. [22] experimentally studied an air-cooled PV/T solar collector, air enters it through a hole in the middle of the collector and from opposite directions. The thermic and electrical performances of the solar collector were obtained at a space in mid the PV module and the covering of 3 cm and 5cm. Mojumber et al. [23] conducted experiments on a hybrid air PV/T collector through a single pass with fins. Experimental results showed thermic and electrical efficacy of 56.19% and 13.75% respectively, at 700 W/m2 solar radiation. Naqvi [24] increased the electrical efficacy of the solar panel, converting it to a hybrid PV/T air-powered solar collector by adding a wood duct to the back of the panel, with fins placed interior the duct to increase the warmth. The empirical impacts demonstrated that the electrical efficiency of the hybrid PV/T air-to-air solar collector and the solar panel was 14.8% and 14.4% with a thermal efficiency of 64.6%. Prabhakar et al. [25-26] studied the theoretically performance of photovoltaic thermal air collector in the climatic condition of North East, India. They found that exergy gain improves by almost 100% in summer compared to winter. Bagheri et al. [27] assessed the power generation capability of a PVTAC for two different climate zones in Iran. It was found that the system has the potential to generate power of 2179.51 kWh and 2007.65 kWh. Fudholi et al. [28] presents a review of the exergy and sustainability index of solar thermal systems. They presented the theoretical approach of photovoltaic thermal (PVT) air collector with ∇-corrugated absorber is presented. The predicted results are consistent with the results obtained from the experiments. The exergy and sustainability index for various mass flow rates and solar radiations are obtained.

The goal is therefore twofold: to raise the electrical effectiveness of the module and to exploit two types of energy: electrical and thermal. We implemented a hybrid sensor prototype and studied it experimentally to evaluate its electrical and thermal performance. For this, we have developed and produced a prototype of a hybrid sensor, and we have started measurement campaigns: temperature, electrical power, and solar radiation over a period, which has enabled us to determine all the electrical and thermal characteristics of this sensor.

The characteristic I (V) determined by experimentation for the two sensors made it possible to compare the electrical performance of the hybrid sensor with a control photovoltaic module left free on the same structure.

2 Methodology

2.1 Experimental setup

This new design hybrid air PV/T collector has a once-through air channeler. Figure 1 illustrates the real view and diagram of the hybrid PV/T air collector. The PV/T hybrid air sensor includes of PV module, "polystyrene" insulation, aluminum tape, and a wooden box. The dimensions of the photovoltaic thermal PV/T hybrid solar collector utilized in this embodiment are the length, width, and thickness of 167 cm, 100.1 cm, and 22 cm, respectively.

The PV photovoltaic unit employed in this investigation is commercially obtainable. The length, width, and thickness of the PV module were 167 cm, 99.2 cm, and 3.5 cm, respectively. More details on the electrical characteristics of the "TWINSEL" solar module according to the norm examination conditions (Solar intensity 1000 W/m^2, module temperature 25 °C, AM 1.5), are indicated in table 1. A heat transfer fluid "air" can circulate inside the box of the PV/TH hybrid collector to cool the solar cells.

Table 1 Characteristics of the "TWINSEL" solar module under standard test conditions.

ITEM NO.	SYP270S
Rated Maximum Power (Pmax)	270W +3%
Power Sorting	0~4.99W
Voltage at Pmax	31.2V
Current at Pmax	8.66A
Open-circuit Voltage (Voc)	38.2V
Short-Circuit Current (Isc)	9.20A
Maximum System Voltage	DC 1500V
Cell type	Polycrystalline
Mechanical Load Test	5400Pa
Weight	18 kg
Dimensions	165×99.2×3.5 cm
All technical standard test condition	AM1.5 E=1000W/m^2 Tc=25°C
Safety application class	Class A

Fig. 1 Schematic of the PV/T air hybrid sensor

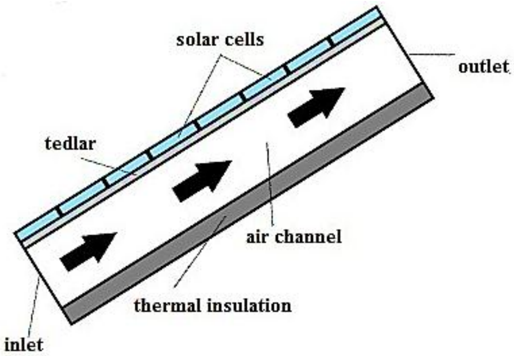


Fig. 2 Schematic representation of a photovoltaic-thermal hybrid collector with an air gap.

2.3 Method of manufacturing hybrid PV/T sensor

The solar air collector studied is a simple 270W power solar panel. Its construction consists of the following elements: Wood, electric saw, book angles, black paint, drill, polystyrene, aluminum, and adhesive. The manufacturing processes of the PV/T hybrid collector go through four stages as follows [29]:

Step one: We cut the wood with an electric saw into 5 pieces to form two pieces of dimension (101 cm × 22 cm × 2 cm), two pieces of (163 cm × 22 cm × 2 cm), and a single piece : (167 cm ×101 cm), then, we comb the wooden blocks, finally, , the parts are fixed to form a rectangular dimensional wooden box (167 cm ×101 cm ×22 cm) according to the dimensions of the solar panel used.

Fig. 3 Cutting and preparation of wood used according to the dimensions of the panel

Step two: We form four holes in the lower part (bottom side of the rectangular box), so that each hole has a diameter of 7 cm, between the hole and the other a distance of 14 cm for between the air. Conversely, a lateral hole with a diameter of 10 cm is drilled in the upper part to release the hot air.

Fig. 4 Formation of holes in the lower and upper part of rectangular box

Step three: The polystyrene is placed inside the board (rectangular box) on all sides as thermal insulation to limit heat losses, and then it is fixed with aluminum tape.

Fig. 5 Fixing polystyrene and aluminum

Step four: We put the simple solar panel on the wooden box and install it ready to have a hybrid aerovoltaic solar panel. The objective of this study is twofold, to increase the electrical efficiency of the sensor, that is to say its electrical output, and at the same time to use this heat for the drying of food products. The following figure shows the hybrid solar panel from our study ready to be tested and compared with a simple solar panel, after the test should be set up in the drying chamber.

Fig. 6 Air hybrid PV/T solar collector test bench

2.4 Experimental Instruments

High temperatures negatively affect the electrical effectiveness of PV solar cells. This problem can be solved by circulating air under solar cells to improve electrical efficiency. Temperature readings were measured by RTD-PT-100 type temperature sensors at the summit and near the PV module, the temperature of the inlet, the outlet, the surface of the PV/T absorber, and the ambient air. Fans give forced airflow inside the rectangular air duct through the inlet to cool the PV cells. Using a Davis-type weather station, the values of solar radiation, wind speed, external temperature and humidity are obtained throughout the duration of the experiment. Using a solar meter, the values of solar radiation under the solar panel are obtained throughout the duration of the experiment. We recorded the current and voltage values using a digital multimeter.

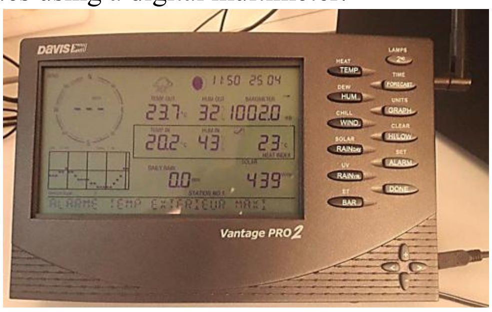


Fig. 7 Davis-type weather station

(a) (b)

Fig. 8 (a) Solar meter and (b) Multimeter used in the experiment

3 Results

During these tests, we measure the temperatures of each hybrid thermal sensor component such as the temperatures of the inlet and outlet of the air cover, the temperature of the absorber, and the bottom of the sensor, and the temperature of the middle of the cover. The purpose of these tests is to show the thermal behavior of the hybrid system, and its thermal efficiency. Measurements were taken at the University of M'sila located in southern Algeria (latitude: 35.32° N; longitude: 4.23E) altitude 471 m. This site has a Mediterranean climate with hot summers. The data is measured and stored every quarter of an hour as a minimum, the global horizontal and diffuse solar irradiance in W/m², each value is measured with a Pyranometer. Other meteorological parameters such as ambient temperature, relative humidity, wind speed and direction are all measured using a weather station placed on site. We took the data during the test day.

The experimental investigation allowed us to determine the electrical and thermic characteristics of the PV-T hybrid solar panel. For define the performance of empty PV and empty and charged PV/T panels the three types of panels were experimentally experimented within an hour and a half. The panels are positioned at a 35° angle approximately equivalent to the latitude of the place to capture the maximum solar energy.

The variation (current/voltage) of the PV and PV/T module with cell temperature was studied. Figure 9 illustrates the evolution of solar energy gauged in one hour as a function of time. The solar meter positioned in two positions; (1) above the solar collector roof to gauge incident solar energy and (2) straight under the solar collector roof to gauge the lowering in solar energy as it pass into by the acrylic roof. The figure demonstrates that the happening solar energy raises steadily until the afternoon, peaking at approximately 848 W/m^2 about 12:30 p.m. The radiation gauged underneath the roof observes a comparable movement. On middle, the magnitude of solar energy diminishes by approximately 13.5% as it passes via the acrylic roof. This is principally owing to the low reflectance and absorbing estate of acrylic roofing material. There is a borderline deviation in the irradiance measures at the high of the roof, as illustrated in the figure showing that the weather conditions are nearly constant throughout the data collection period. In addition, there is the tiniest change in the solar irradiance gauged underneath the collector roof.

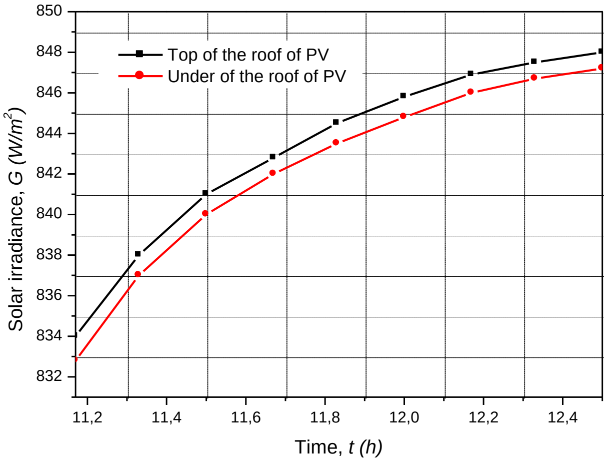


Fig. 9 Solar energy gauged on top and under the collector roof (PV).

Figures (10, 11, 12, and 13) illustrate the variations of current and voltage according to a means of solar illumination during a sunny hour G= 843.2 W/m^2 but characterized by cloudy periods. The measurements are taken on 25/04/2022, the ambient temperature of which is around 24°*C*, the humidity H= 34%, with a wind speed V= 20 *Km/h*. These figures illustrate the relationship of the intensity and voltage characteristics with the change of time for average solar radiation G. Sunlight is transformed into direct current thanks to a set of photovoltaic cells. These currents and voltages delivered depend on the power of the radiation received, G. Therefore, when the solar energy increases the currents increase over time in the two panels (PV and PV/T); hence the current delivered is very high for a value of sunshine equal to 890 W/m², aaccording to figures (9) and (10), on the other hand, when the solar energy increases the impoverished voltages, it can also be deduced that the temperature intervenes in the heating of the photovoltaic cells or in the drop in their efficiency. We note that the variation of the current is greater than the variation of voltage when the sunshine increases during a minute slice of 6 minutes, the temperature stripped linearly; this is due to the heating of the PV / T solar panel, which is in charge by incident radiation.

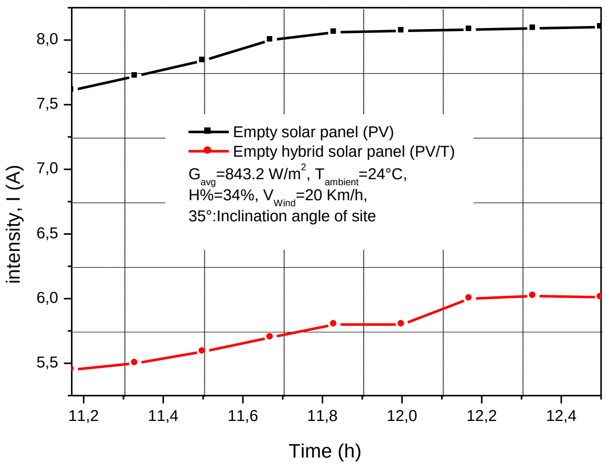


Fig. 10 Evolution of intensity as a function of time of PV and PV/T empty

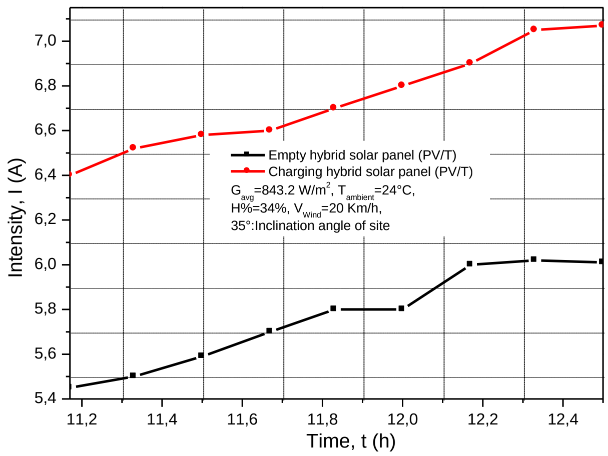


Fig. 11 Evolution of intensity as a function of time of the hybrid PV/T panels with empty and charging

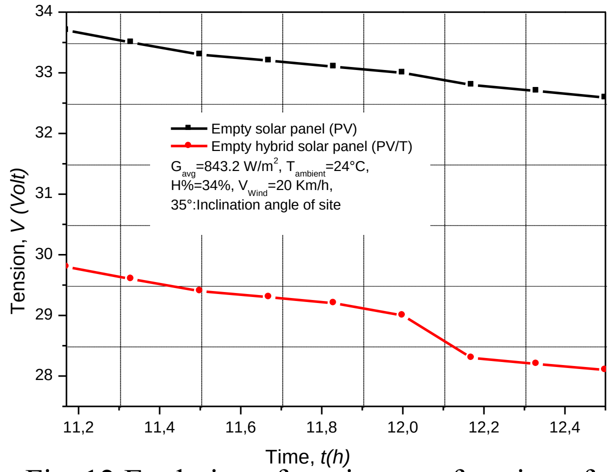


Fig. 12 Evolution of tension as a function of time of PV panel and PV/T panel empty

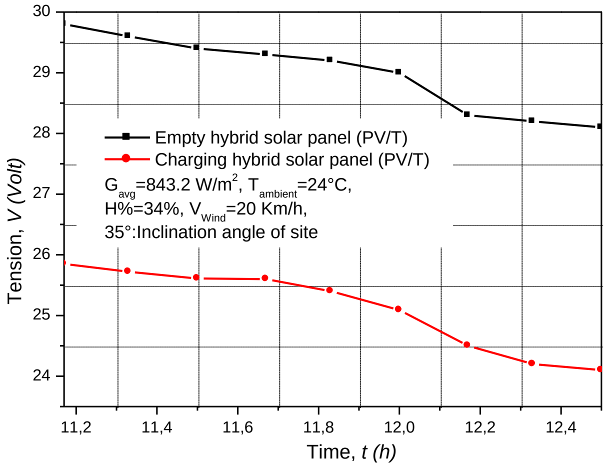
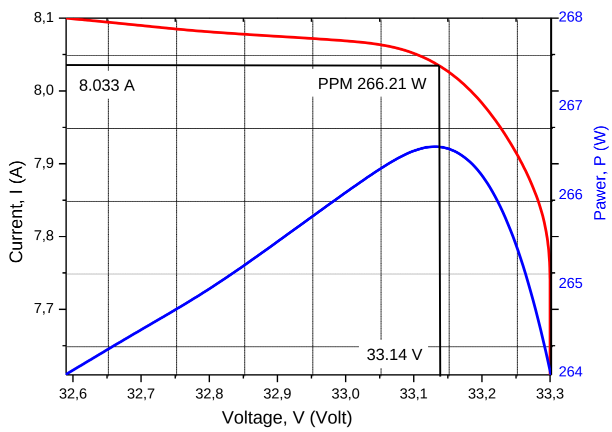


Fig. 13 Evolution of tension as a function of time of the hybrid PV/T panels with empty and charging

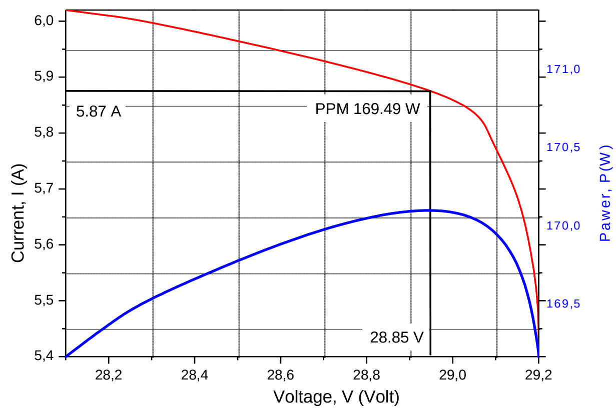
To see the influence of the additional cover on the electrical performance of the thermally insulated collector, we noted the characteristic I (V) respectively of the empty PV collector, hybrid PV in charge and insulated vacuum (figure 14).

The maximum power of the thermally insulated sensor has dropped by for an illumination of 846 W/m^2, which is very significant. The cover for hybrid PV/T has caused a drop in electrical efficiency compared to single non-isolated PV. Therefore, the downside covered is the drop in electrical performance. It is noted that the electrical efficiency of the covered hybrid sensor has dropped compared to the efficiency of the uncovered PV.

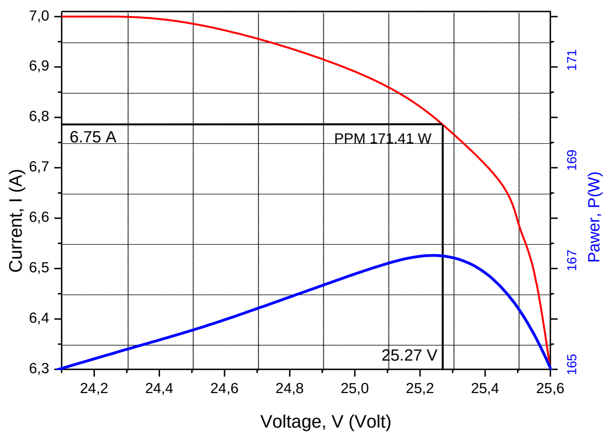
The maximum current delivered by the hybrid collector empty or on load under the same conditions of incident radiation and wind speed, and the uncovered PV module is presented in figure 14. It can be said that the presence of the cover increases performance hybrid sensor and negatively affects its performance.



(a) Simple PV panel in empty



(b) Hybrid PV/T panel in empty



(c) Hybrid PV/T panel in charging

Fig. 14 (**a**), (**b**), and(**c**) Characteristics I (V) of the simple PV and the two hybrid sensors under charged and under empty

Figure 15 shows the variations in temperature profiles inside the PV/T hybrid panel in load and in vacuum with solar radiation as a function of time. It can be seen that the temperature in the PV/T hybrid panel in vacuum increases with the increase in global solar radiation, on the other hand, the PV/T hybrid panel in charge increases slightly due to the forced convection due to the fan placed in the upper part of the panel (hot air outlet). This figure shows the outlet temperature to the drying chamber between 43.5°C and 44.8°C in the case of a PV/T hybrid panel under load and between 43.8°C and 47°C in the case of a vacuum PV/T hybrid panel. This increase in temperature can be used later for heating premises or drying food products. The variation between the PV/T panel outlet and inlet temperatures accentuates the role of the air channel, which chills every cell (the absorber) by convection impact.

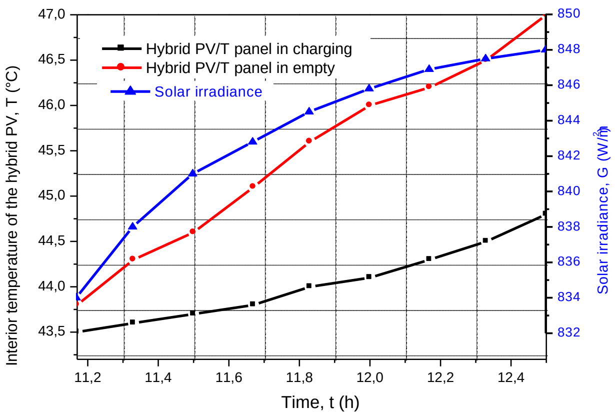


Fig. 15 Variation of the internal temperature of the PV/T under empty and charging.

4 Conclusion

We can conclude, according to the previous figures, that the daily variation of the sunshine shows us that the maximum irradiation is reached around 11h – 11h: 10 min.

This study, done in a humid zone, allows us to draw the following remarks:

-The temperature about the surface of the PV/T hybrid solar panel is a result of the ambient temperature as well as the intensity of the radiation captured by the PV/T absorber.

-The thermal module raises the inlet temperature (between 43.5°C and 44.8°C). This increase in temperature can be used later for heating premises or drying agro-food products.

-The change between the inlet and outlet temperatures accentuates the role of the air channel, which chills all the cells by convection influence.

The combination of photovoltaic panels with a thermal air collector improves its performance. The hot air can be used in various activities such as agricultural drying, home heating, etc., so it is useful to supplement the benefits of solar energy. A mix of energies where solar energy can be used to the maximum in addition to other renewable energies where the energy needs can be entirely produced by its use.

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