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Research Article

Design of an Energy System Based on Photovoltaic Thermal Collectors in the South of Algeria

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The objective of this work is the design of a new energy system where the energy source will be provided by solar photovoltaic thermal (PV/T) hybrid collectors. This system will be applied to a habitation in the region of Ghardaïa in the south of Algeria. The cold water reaches the thermal storage tank and then will be heated by the hybrid collector. The hot water will be used directly as sanitary water. The electric power produced by the hybrid collector will be used to charge the battery and will be delivered to the load (electrical appliances, lamps, etc.). Two types of loads are considered: a DC load and the other alternating current. The fans located adjacent to the radiators supplied with hot water will provide warm air to the house in winter.

1. Introduction

Research on hybrid solar collectors began in the 70s and was intensified in the 80s. Thus, the work of Wolf [1] in 1976 performs the analysis of a solar thermal collector with PV modules based on silicon and coupled to a heat storage system. Subsequently, the study of Kern and Russel in 1978 provides the basics of using solar water or air as coolant in PV/T systems. Hendrie, in 1982 [2], develops a theoretical model of PV/T hybrid based on correlations related to solar standards. In 1981, Raghuraman [3] presents numerical methods for predicting the performance of flat solar PV/T water or air. In 1986, Lalovic et al. [4] proposed a new type of amorphous a-Si cells as transparent economic solution for the construction of PV modules. Various experimental and theoretical studies have been conducted, then, for the development of PV/T hybrid [5]. In 2005, Zondag [6, 7] proposes a state of the art on the solar PV/T hybrid based on the report of the European Project PV-Catapult. Among the first studies reviewed by Zondag [6], some focus on the evolution of the geometry and other components of the modeling methods are studied. In 2007, Tiwari and Sodha [8] proposed a parametric comparative study of four types of solar air close to the system presented above. Tripanagnostopoulos [9] conducted, at the University of Patras, the study of solar PV/T hybrid of which the coolant is either air or water and can be integrated to the frame. The objective of this work was to reduce the operating temperature of PV modules. In Algeria, the work of Touafek et al. [10–12] is the important research done on PV/T systems. They have studied various configurations in many conditions. This work is the application of the hybrid collectors studied in detail in previous papers [11, 12].

2. General Outline and Constitution of the System

We begin by studying a single system composed of a single new hybrid collector configuration discussed in [11, 12]. Figure 1 shows an overview of the system.

Figure 1 shows an energy system that can be applied to a habitation. The cold water reaches the thermal storage tank and will be heated by heat convection transfer fluid that transports heat from the hybrid collector. The hot water will be used directly as sanitary water. The electric power produced by the hybrid collector will be used to charge the battery and will be delivered to the load (electrical appliances, lamps, etc.). Two types of loads are considered: a DC load and the other alternating current. The fans located adjacent to the

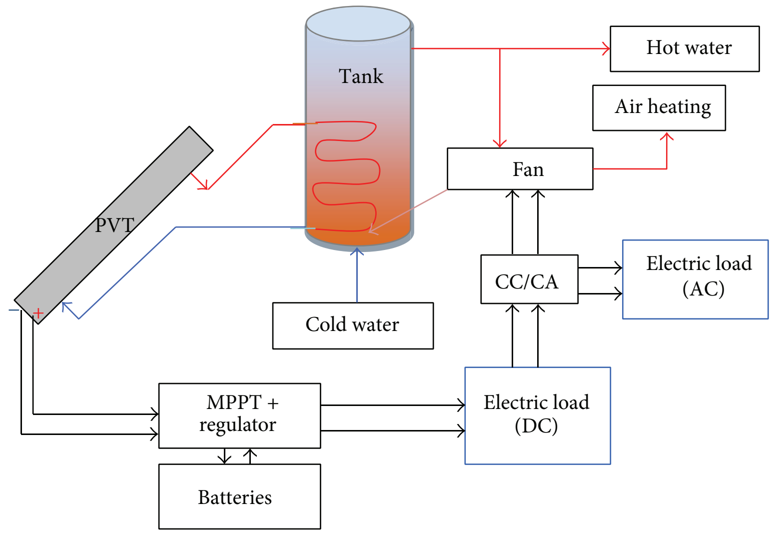

FIGURE 1: Diagram of the energy system based on the new collector PV/T.

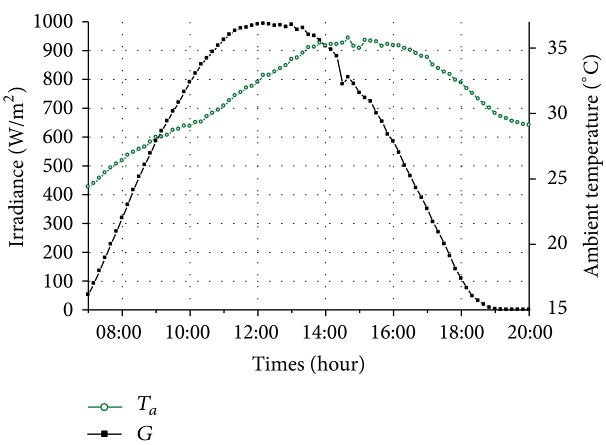

FIGURE 2: Global irradiance and temperature tests.

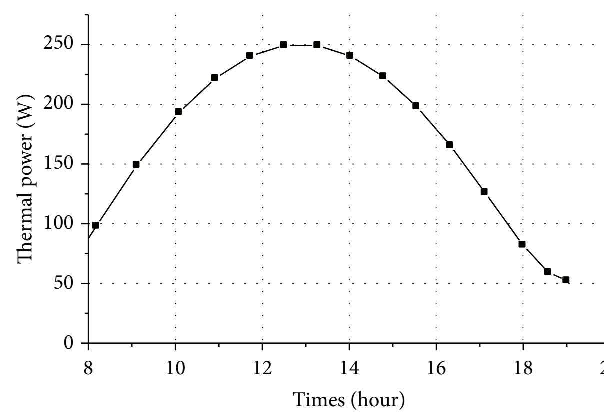

FIGURE 3: Thermal power produced daily by the hybrid collector.

radiators supplied with hot water will provide a warm air to the house in winter.

3. Daily Production of Hybrid Collector

The daily production of hybrid collector includes a heat energy and electrical energy. The change in global irradiance and ambient temperature of that day is shown in Figure 2. It is a sunny day.

Under these conditions, the hybrid collector produces heat energy in addition to electric power.

3.1. Daily Heat Production. The daily thermal energy is the amount issued by a hybrid collector for a given day. The hybrid collector used is studied in [11, 12].

Figure 3 shows the variation of the instantaneous thermal power of a single hybrid collector for the day of September 14, 2008. For an input temperature of water of 25°C, the power output reaches 250 W. It is the instantaneous power generated by the hybrid collector. The day chosen is a typical day. The experimental thermal efficiency based on the reduced temperature is shown in Figure 4.

The instantaneous thermal efficiency of the collector used is equal to 68% when the input temperature of water is equal to ambient temperature.

The energy production is determined by multiplying the average power by the hours of sunshine. Note in Figure 3 that, during the period from 10 h to 17 h, the instantaneous power exceeds 150 W. We can take this value as a reference and we can say that the hybrid collector can produce at least (150 W) × (7 hours) = 1050 Wh. This value is for the collector surface of $0.42\,\mathrm{m}^2$. So the daily production is $1050\,\mathrm{Wh}/0.42\,\mathrm{m}^2 = 2500\,\mathrm{Wh}/m = 2.5\,\mathrm{KWh/m}^2$. For one month, the collector can produce (1050 Wh) × (30 days) = 31.5 KWh.

3.2. Daily Electric Production. The hybrid collector mainly produces electric power. This energy is determined by multiplying the instantaneous power for the duration of sunshine daily. The instantaneous power can be calculated by two

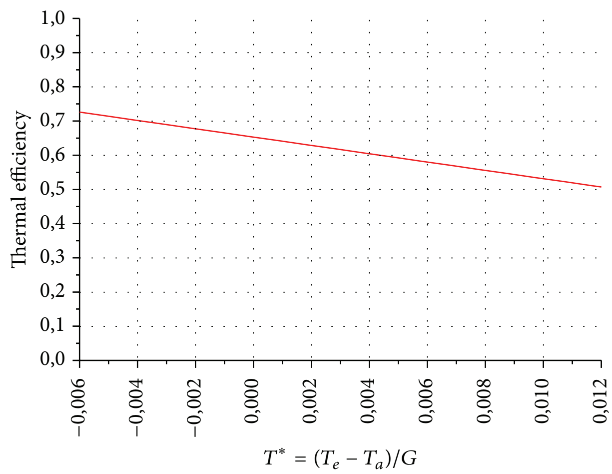

FIGURE 4: Thermal efficiency as a function of reduced temperature for the day of testing.

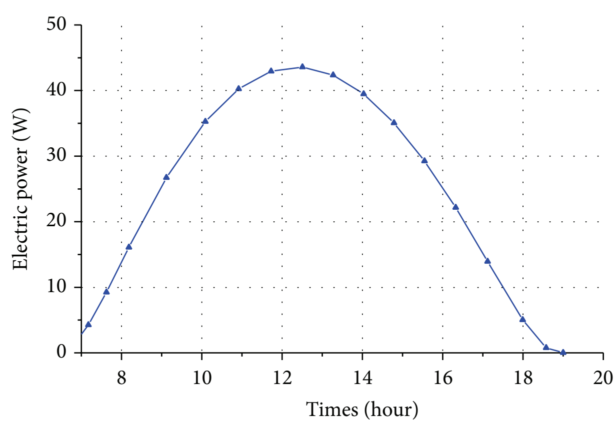

FIGURE 5: Electric power produced by the collector hybrid.

ways: the first is by calculating the voltage time's current product and the second using mathematical method and will be based on the temperature of solar cells. The second method is used in this study. Figure 5 shows the variation of the instantaneous electrical power during the day on September 14, 2008.

Note that, for at least seven hours in succession, the electrical power exceeds 25 W. The hybrid collector produces at least (25 W) × (7 hours) = 175 Wh. The daily production of the collector is at least equal to 175 Wh. For one month, the collector can produce 5250 KWh. For an area of 1 m^2, we have (175 Wh)/(0.42 m) = 416.67 Wh/m^2 (daily). The energy produced during a month is 12.5 kWh/m^2. The energy produced during a year is 150 kWh/m^2.

The hybrid collector thus produces a daily electric energy of 175 Wh and thermal energy of 1050 Wh.

The daily production of electric heat collector is the basis for sizing the energy system.

4. System Modeling

The proposed energy system consists mainly of hybrid collectors for heating water and water for electrical power generation and air collectors for space heating.

4.1. Water Heating. The tank of hot water contain a serpentine and an additional electrical resistor. The latter provides heat when the tank temperature is not high enough to heat the hot water temperature desired output. It is not easy to know the needs of hot water (DHW) of a family in a house. In general, it is estimated as 50 liters to 50°C per day per person but this can vary for about 20%. The volume of hot water tank mixed with electric backup should be able to cover 1.5 times the daily needs. The volume which must have the hot water tank is calculated by the following formula:

$$V = \left(\frac{\left(B_p \cdot N_p \cdot (T_{\text{es}} - T_{\text{ef}})\right)}{(T_{\text{st}} - T_{\text{ef}})} \right) \cdot 1.5, \tag{1}$$

where B_p = volume required per person per day, N_p = number of persons occupying habitation, T_{es} = temperature of water extraction (water for direct use), T_{ef} = temperature of cold water entering the reservoir, and T_{st} = average temperature of the water stored.

For example for 4 people with the needs of 50 liters/person/day

$$T_{\text{es}} = 40^{\circ}\text{C},$$
$$T_{\text{ef}} = 15^{\circ}\text{C},$$
$$T_{\text{st}} = 45^{\circ}\text{C},$$
$$V = ((50 \times 4 \times (40 - 15))/(45 - 15)) \times 1.5 = 250 \text{ liters}.$$

In general, the storage tanks have too much capacity and thus the maximum temperature reached with solar energy for the period from October to April is not large enough and necessarily requires the operation of the booster which could be avoided with a lower capacity.

The system studied in this paper consists of hybrid photovoltaic thermal collectors that produce a flow of heat for heating the water container in the thermal storage tank. The thermal power transferred between the system useful PV/T and thermal tank is given by

$$Q_u = \dot{m} \cdot C_p \left(T_{\text{eres}} - T_{\text{res}}\right), \tag{2}$$

where T_{eres} is the input temperature of the storage tank. The tank temperature decreases linearly with T_{res}, Q_u. The mass flow can be increased to greater heat production system.

T_{resmax} is the maximum stored temperature; it is determined by the thermal energy transferred by the PV/T collectors and can be given as follows:

$$T_{\text{resmax}} = T_{\text{eres}} - \left(\frac{Q_{\text{PVTmax}}}{\dot{m}_{\text{max}} \cdot C_p} \right), \tag{3}$$

where Q_{PVTmax} is the total thermal energy available at the output of the hybrid PV/T collector per hour and m_{max} is the maximum mass flow rate max.

A heat balance around the thermal storage tank provides

$$Q_u - Q_{es} - Q_p = m_{res} \cdot C_p \cdot \left(\frac{dT_{res}}{dt}\right), \quad (4)$$

where Q_p is the heat flux which represents the heat loss of tank to the surroundings; Q_{es} is the heat flux transferred from the hot water tank; What is the heat flux transferred by the collectors PV/T; M_{RES} is the mass of water in the tank. C_p is the specific heat of water. The flow of heat transfer from the hot water tank is as follows:

$$\dot{Q}_{ES} = \dot{m}_C C_P \left(T_C - T_F\right), \quad (5)$$

where T_c is the temperature of hot water and T_F is the temperature of cold water.

The temperature at the input of the tank increases during the day as there is sunlight, and because the cell temperature increases. As for the temperature inside the tank T_{res}, it depends on the load, that is to say, the use of hot water. The temperature inside the tank during the day may be less compared to that of the night because there is a prolonged effect of thermal storage during the night.

4.2. Space Heating. The space is heated by the hot air produced by the collectors PV/T air. The fan AC supplied ensures the distribution of air in the house.

5. Electric Power Generated by the PV/T System

The total energy generated by the collectors PV/T to power various loads of the house is as follows:

$$\dot{E}_{PVT} = \dot{E}_E + \dot{E}_V + \dot{E}_{EA} + \dot{E}_{ES}, \quad (6)$$

where $\dot{E}_E$ is the electrical energy consumed by lighting lamps (DC current). $\dot{E}_V$ is the electrical energy consumed by the fans (for space heating). $\dot{E}_{EA}$ is the electrical energy consumed by the load (A current). $\dot{E}_{ES}$ is the electrical energy consumed for heating domestic water (the electric boost).

6. Generalisation of the Model

The hybrid PV/T collectors are systems cogeneration of electricity and heat. They generate electricity that is used for lighting the home and the fans needed to heat the interior in winter or cooling in summer. For general application, the energy system studied previously is applied. The space heating is provided by hot water produced by the collectors PV/T through radiators combined with low power fans fed from converters continuous alternative.

The system consists of photovoltaic cells to heat water and air collector's hybrid-type single crystal and storage tank water is heated by the collectors and a PV/T extra electric power storage system (batteries) and DC to AC fans and extra strength.

Energy needs of the house are the electrical (DC lamps and fans) and thermal loads (heating water and space).

7. Habitation Energy Needs

To calculate the energy needs of a habitation, we must have two types of information, the first on climate data from the site of habitation's implantation (room temperature, solar irradiance, humidity, etc.) and data of profile of electrical and thermal load, that is to say, the type of load to power and level of comfort you choose. It should be understood that the reference temperatures allow the calculation of heating power for the worst case (winter in general). We will take the average temperatures recorded to ensure that our facility is not oversized and therefore not profitable.

7.1. Dimensioning of the Electrical System. The design follows a phased approach that can be summarized as follows.

(i) Step 1: determination of user requirements: voltage, power equipment, and service life.

(ii) Step 2: encryption of solar energy recoverable by location.

(iii) Step 3: setting the battery capacity.

(iv) Step 4: design of hybrid solar photovoltaic thermal collectors: operating voltage, total power to be installed, and number of branches.

(v) Step 5: selecting the controller and the inverter.

7.2. Needs Assessment. Since the system provides energy during the day, it is natural to take the 24-hour period as time unit. The load profile for an habitation in Ghardaïa, witch is composed by: 2 litles rooms, 1 big room, 1 kitchen and 1bathroom (see Table 1). The power requirements are those necessary for the internal lighting and feeding of some appliances (TV, refrigerator). Electrical energy is required to supply the extra electrical hot water tank and the fans that are attached to the wall heat exchangers (radiators) for heat removal in the space of home. Hybrid air collectors for the preheating of the space can be used to reduce dependence on heating water radiators (Figure 6).

The position of the hybrid collectors relative to the sun affects their production aggressively. It is very important to place them for maximum use.

(i) Orientation to the south in the northern hemisphere.

(ii) Orientation to the north in the southern hemisphere.

Electrical energy needs of the home are estimated at 5262 Wh/day.

These needs are determined for the winter season for the heating of domestic water and space. For the summer season, the power of the electric boost will be added to meet fans for ventilation that creates the cold housing. So the calculated energy is constant all along the year.

7.3. Battery Capacity. Electrical energy needs of the habitation are estimated at 5262 Wh/day.

In terms of Ah, the consumption becomes

C = 5262/48 = 109 625 (if it works under 48 V),

Table 1: Electrical load profile for a habitation in Ghardaïa.

Device	Number	Tension (V)	Power (W)	Usage time/day (hour)	Daily consumption (Wh/j)
Lamps	05	12	18	05	450
Lamp	02	12	18	02	72
Television	01	12	75	04	300
Refrigerator	01	12	60	24	1440
Extra power (for heating water)	01	220 (AC)	1000	02	2000
Fan (for space heating)	02	220 (AC)	100	05	1000

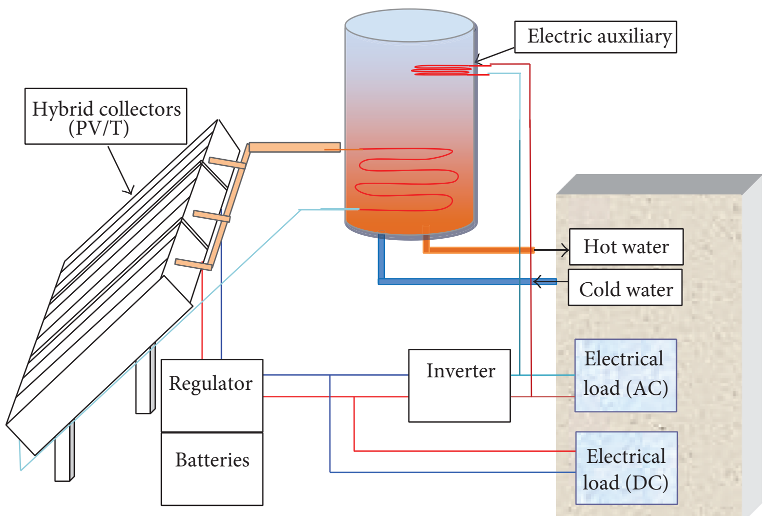

Figure 6: Diagram of the energy system based on collectors PV/T applied to habitation.

$$C = 5262/24 = 219.25 \text{ (if it works at 24 V)},$$

$$C = 5262/12 = 438.5\text{ Ah (if it works at 12 V)}.$$

Knowing that the hybrid collector is used that has been studied previously [12], it delivers 175 Wh/day. In terms of power, it must be less than 30 collectors to meet the needs of the habitation application studied. Depending on the voltage we want to use, one calculates the capacity of the battery and according to the autonomy of the system determines the exact number of batteries to be installed. Once the number of batteries is determined, one determines the number of branches of hybrid PV/T collectors installed and the number of PV/T collectors in series in each branch.

For the purpose of hot water, we found that a family of 4 people needs a thermal storage tank of 250 L.

8. Conclusion

We have proposed a cogeneration system based on hybrid solar photovoltaic thermal collectors for supplying electric power and heat, particularly the water heating and space and the electric charge needed for a comfortable habitation located in Ghardaïa. The results suggest that the cogeneration system based on the hybrid collectors PV/T is a complete energy system to supply electricity and heat a home.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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