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Hybrid PV/T water solar collector for net zero energy building and fresh water production: A theoretical approach

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HIGHLIGHTS

- We studied the possibility of obtaining an nZEB and producing fresh water.
- A hybrid PV/T water solar collector is used.
- A solar prototype is studied under the climate of Ouargla city.
- A numerical simulation is carried out for 1 year with the TRNSYS 17 software.
- A program is coupled with TRNSYS for the simulation of the solar still.

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ABSTRACT

The purpose of this work is to study the possibility of obtaining a net zero energy building and producing fresh water via a solar still by using a hybrid PV/T water solar collector. A solar prototype built in the city of Boussaâda is studied under the climate of Ouargla city to show the importance of the use of passive solar architecture. The results highlight the importance of using passive solar techniques to reduce heating energy needs. Energy savings are realized with passive techniques even before the use of active solar systems. It is possible to cover the energy requirements with the use of hybrid PV/T water solar collectors. High solar thermal fractions for domestic hot water are achieved during the year. Solar electricity produced is high and can cover the annual needs of domestic hot water, air conditioning and heating, lighting and household equipment of the prototype. A part of the difference in area between that used to cover the thermal requirements of domestic hot water and the total area of the PV/T collectors is used for supplying a solar still. An increase in the annual production of 2.97 times is obtained compared to passive solar still.

1. Introduction

Renewable energy has known a huge development in recent years, this clean technology ensures the energy security of non-oil countries on one hand and environmental protection on the other hand. It should be noted that even the countries producing energy products will face the depletion of these resources since the worldwide consumption continues to increase.

Solar energy is considered as the most abundant on earth. Indeed, the energy of 84 min of solar radiation on the earth can cover the energy demand around the world for one year [1].

Due to its geographical location, Algeria has one of the highest solar fields in the world. The sunshine duration of almost all the national territory exceeds 2000 h annually and reaches 3900 h (high plateaus and Sahara).The daily solar energy received on a horizontal surface of 1 m^2 is about 5 kWh over the major part of the national territory, almost 1700 kWh/m^2/year in the North and 2263 kWh/m^2/year in the south of the country [2]. It seems interesting to consider the use of solar energy not as an ecological factor, but as a real alternative to energy resources.

The building sector is the most responsible of the energy consumption in Algeria. According to statistics from the Department of Energy in 2005, the building sector consumes over 42% of the domestic primary energy, which makes it the most energy consumer sector [3].These statistics tend to increase due to the enormous development of the building stock as well as the increase of comfort requirements in recent years. Power breaks are observed in summer period due to the increased use of air conditioners.

On the other hand, Algeria is still facing feedstock difficulties in drinking water and sanitation especially in areas of high population density despite the investments made. The critical situation of Algeria in terms of drinking water is expressed by the established ratio between

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renewable resources and consumption (500 m^3/capita/year). Experts estimate that if the natural water resources fall below 1000 m^3/capita/year, it becomes a scarce resource. Experts predict that this ratio would be 430 m^3/capita/year in 2020 [4] and dangerously reach 300 m^3/capita/year in 2025 or 200 m^3/capita/year, if only surface water is considered. This tendency results from the fact that Algeria is a semi-arid country, it is also based on data related to population growth as well as economic and social development.

It is more advisable to integrate and use solar energy for residential applications and for desalination of salt water.

In Algeria, the problem of salt water in the region of Sahara is often found. The considerable evaporation of surface water caused by the intensity of solar radiation and the high ambient temperature effects the degree of salinity and the presence of minerals in groundwater. The use of solar energy through solar stills to purify this water is an economic and a simple solution.

Therefore, the aim of our work is to study the possibility of using a hybrid solar PV/T water collector for supplying a house with thermal energy for domestic hot water and a solar still with preheated brine and with electricity for lighting, air conditioning, heating and household appliances. The high intensity of the solar radiation and ambient temperature has an effect on the dimensioning of the hybrid PV/T solar collector. It is clear that the area needed to meet the thermal domestic hot water is smaller than the area of the PV modules due to high electricity needs. Part of the difference between the two areas will be designed to supply a solar still with preheated brine.

2. Literature review of hybrid PV/T collectors and solar still

The major applications of the solar energy can be classified into two categories: solar thermal systems that convert solar energy into thermal energy and solar photovoltaic systems that convert solar energy into electrical energy [5].

Today, the efficiency of conversion to electricity of commercialized photovoltaic panels is between 12 to 18%. Over 80% of incoming solar radiation is reflected or converted into heat [6]. Increasing photovoltaic cell temperature decreases the performance of the latter. The increase of 10 °C of the PV cell temperature leads to a reduction of the electrical energy produced by the cell of 5% [7].

Researchers propose to remove this heat by introducing a coolant (water and air) that extracts heat and which can be used in thermal applications. This type of solar collector is called hybrid PV/T solar collector. More than the generated electricity, hybrid PV/T solar collector has three possible applications: heating air [8], heating water [9], or heating the water and the air at the same time, this type is called Bi fluid [10].

Research has been conducted since 1970 to model and improve the design of hybrid PV/T solar collectors [11–14] as well as improving their integration and evaluating their impact on the energy behavior and the economy of buildings [15].

Basant Agrawal and G.N Tiwari [16] show that the use of BiPVT collectors (building integrated photovoltaic thermal) is more suitable from an energy and economic point of view than the BiPV collectors (building integrated photovoltaic). The overall energy efficiency of BiPVT collector is almost 17 to 20% higher and the exergy yield is about 1.5 to 2% higher than those of a similar BiPV collector. All researches concluded that hybrid PV/T collectors represent the adequate solution to reduce the energy impact of buildings.

Another interesting application of solar energy is solar desalination. Several types of solar stills were made. The most used are those of greenhouse type. They have the advantage of being simple, easy to perform, with rustic design, and inexpensive. However they have a major disadvantage of low production (about 2 to 3 l per square meter per day) [17].

Considerable studies have therefore been done in recent years to improve the production of solar stills. Different techniques are developed; some researchers have studied the influence of the shape, the type and the operating parameters on the production of the solar still [18–23].

The improvement of the solar still production can be achieved by preheating the brine before being introduced into the latter. Increasing the temperature of the brine leads to an increase in the temperature difference between the water to be distilled and the glazing (condensing surface), thereby increasing production. For this purpose a coupling with a solar thermal collector will allow it to warm up. Different researches were carried out in this way [24–37].

It is certain that the economic factor plays a role in choosing the type of active or passive solar still. This study aims to use a PV/T solar plant to meet the energy needs of a building on one hand, and to feed a solar desalination plant with preheated brine on the other hand.

Ouargla city, situated in south of Algeria, has a groundwater salinization problem due to the intense evaporation of surface water. Studies done before on this region [20] show the importance of using solar energy for desalination of brackish water. Therefore and based on these studies, we will explore the possibility of supplying a solar still and a solar prototype building with a hybrid PV/T solar collector. The solar still chosen is a single sloped type that is characterized by simplicity and relatively acceptable efficiency. During the day, the solar still is supplied with preheated brine from hybrid PV/T collector without the use of a storage tank. During the night, it is disconnected from the collectors to eliminate reverse circulation.

3. Description of the solar system and the studied prototype

3.1. Weather data

Ouargla city is characterized by extreme climatic conditions. It is located at a latitude of 31.91°, a longitude of 5.4° and an altitude of 141 m. This city ranks in the climate zone D1 (according to the Algerian thermal regulation, Algeria is divided into seven climatic zones for estimating air conditioning requirements), with a basic temperature estimated at 5 °C in winter and 44 °C in summer [38]. Figs. 1 and 2 shows the various metrological characteristics of the city of Ouargla.

3.2. Solar circuit

The solar circuit shown in Fig. 3 is composed of several solar PV/T connected in series and providing thermal energy to a solar storage tank via a heat exchanger in the lower part of the tank on the one

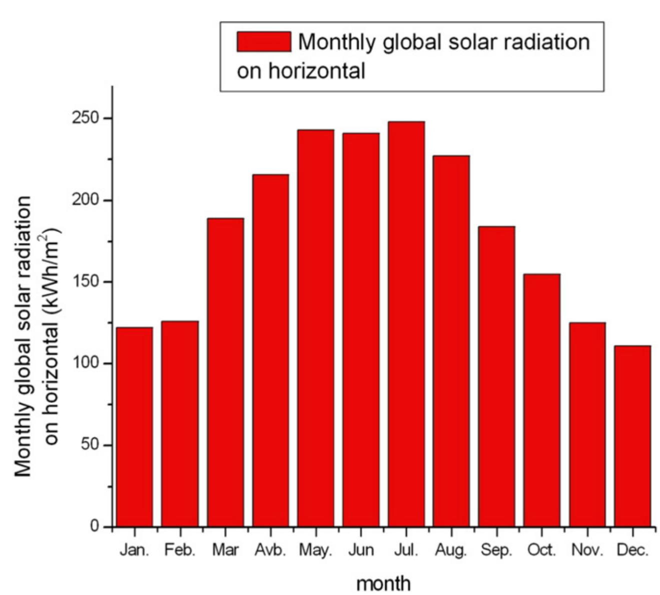

Fig. 1. Monthly average of global solar radiation on horizontal surface.