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Development of a New Solar System for Heating and Cooling an Agricultural Greenhouse †

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Abstract: In order to increase the quality and quantity of agricultural products from greenhouse cultivation, and to cope with a very competitive market, it is necessary to have an optimal climate inside the greenhouse. To achieve this, the farmer uses expensive and very power-consuming heating and cooling systems. In order to solve this problem, a new system has been developed with a solar thermal collector and a specific heat transfer fluid. The experimental study of this new system has shown that this new system was able to keep the temperature inside the greenhouse in an optimal range for the development of the plants.

Keywords: solar system; greenhouse; solar radiation

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1. Introduction

The agricultural greenhouse is a small space where one tries to accommodate as many plants as possible. Originally conceived as a simple shelter or enclosure for growing or protecting plants by exploiting solar radiation, the greenhouse has become an industrial plant production facility where attempts are made to adapt the immediate environment of the plant to improve its productivity and quality, freeing it from the external climate, the local soil and even the seasons. Plant growth is strongly dependent on the external conditions; wind speed, temperature and humidity and on the internal means of action of the greenhouse such as heating, ventilation ... etc. In addition to the function of the plant such as transpiration. Temperature is one of the most important parameters for climate management in the greenhouse, although it is difficult to control. In fact, its optimal value differs from one crop to another and according to the crop stage. Its importance lies in the fact that it influences photosynthesis, respiration and intervenes in the speed of growth, budding, size and firmness of the product. The difference in temperature between day and night is also an important factor. Thus, to maintain a climate control strategy, heating is necessary during winter periods when the temperature is below the set temperature required by the plant and ventilation is necessary during hot periods.

In Europe, greenhouses cover over 60,000 hectares and consume about 1.5% of the total European energy budget for heating and cooling [1–5]. In southern Europe, greenhouses equipped with heating systems consume on average 7.5 L of fuel oil per square meter per year [6]. In Morocco, there are hundreds of hectares of greenhouses equipped with heating systems (especially floriculture greenhouses) which represent only 1% of the total greenhouse area and require the equivalent of US$450 per hectare per day throughout the winter period [7–10]. Thus, worldwide, heating costs for agricultural greenhouses represent about 30% to 35% of total operating costs [11]. This prohibitive cost of energy has prompted several countries to develop new heating techniques using renewable energy.

The aim of this paper is to study the thermal performance of a new solar heating system. This system is based on the selective absorption of solar radiation by a collector, with circulation of a heat transfer fluid, installed inside the greenhouse. The energy stored during the day by the heat transfer fluid will be used to heat the greenhouse at night.

2. Materials and Method

2.1. Acquisition Box

The CR10X (Figure 1) has become a standard in many industrial and research measurement applications. Renowned for its unrivalled reliability and exceptional energy efficiency, it is widely used in operations requiring high autonomy in the field, and complex applications such as meteorology, hydrology, geotechnics, structural monitoring. This datalogger is equally capable of operating on a test bench device or as a networked industrial control system [12].

Figure 1. Acquisition box.

This durable and flexible datalogger offers extensive measurement and control functionality, with a wide range of communication options, peripheral expansion systems and software.

2.2. Type K Thermocouple

The Type K thermocouple, usually referred to as the Chromel/Alumel, is the most widely used thermocouple today. Type K thermocouples are designed primarily for general temperature measurement in the most common atmospheres with a sensitivity of 4uv for 0.1 °C [13]. The maximum continuous operating temperature is about 1100 °C, although above 800 °C oxidation causes the sensor to drift and it gradually moves out of its tolerance class. However, it can be used in the short term up to 1200 °C. In our case we used these thermocouples to measure the temperatures at the inlet and outlet of the solar collector.

2.3. The Eppley Pyranometer

The Eppley pyranometer (Figure 2) measures the global radiation (direct + diffuse) [16] of an entire hemisphere in the wavelength range 0.3 to 3 μm. It has a receiving surface formed by two concentric silver rings; the inner ring is coated with black, the outer ring with white. The temperature difference between the two rings is measured by thermocouples in thermal contact with the inner surfaces of the rings, but electrically isolated. This instrument is used to measure the solar radiation incident on the greenhouse. Its sensitivity is 30 $\mu V \cdot W^{-1} \cdot m^2$ and its lapse of response is 3.8 s [14].

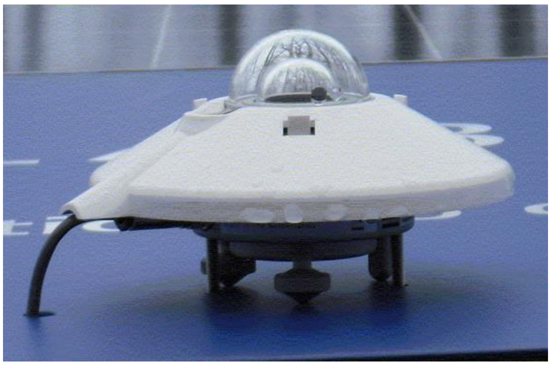


Figure 2. Eppley pyranometer.

2.4. Temperature Sensor

The HygroVUE™10 offers a combined temperature and relative humidity element in an advanced digital sensor that is the ideal solution for weather networks [15]. The electronics inside the sensor provide accurate measurements and the sensor is easy to use. The SDI-12 digital output allows simple connection and measurement for many data logging systems. Another advantage is that this digital output avoids the additional errors associated with measuring analogue sensors. In our experimental study we used the HygroVUE™10 for the measurement of the ambient air temperature. the Measurement accuracy is ±0.1 °C (over the range 20 °C to 60 °C) [17] (Figure 3).

Figure 3. Temperature sensor**.**

3. Results and Discussions

In order to optimize the energetic balance of agricultural greenhouses, several works have been carried out whose principle is to limit the thermal exchanges between the internal climate of the greenhouse and the external environment. Most of the solutions propose to insert a screen between the greenhouse wall and the crop. There are two types of screens: static screens, which are generally placed at night to limit losses due to infrared radiation emitted by the ground, and dynamic screens based on a fluid circulating between two walls (double coverage) or inside a collector placed in the greenhouse. This second type of screen has a double role: to cool the greenhouse during the day by conveying the excess energy reaching the plant and to heat it during the night by restoring the energy stored during the day. With this objective in mind, a heating and cooling system for an agricultural greenhouse has been developed by the Solar Energy Laboratory of the Faculty of Sciences of Rabat (Figure 4). This system is centered on a polyethylene solar collector with methylene blue circulation acting as a heat transfer and selective fluid: introduced into the greenhouse, it transmits the part of the solar spectrum useful for photosynthesis and absorbs the rest.

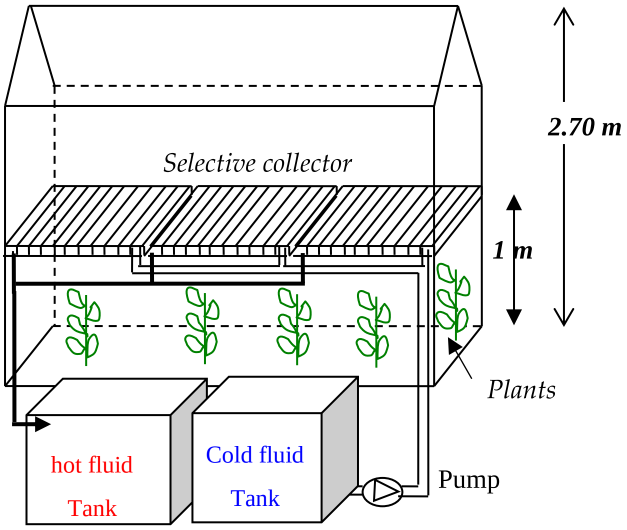
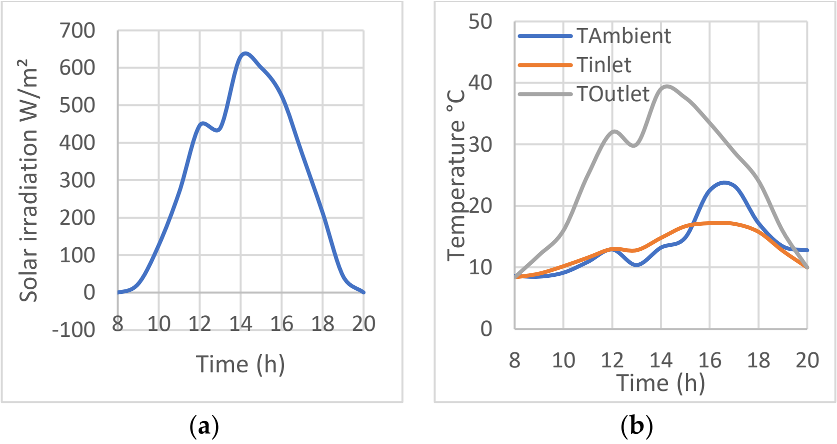


Figure 4. Experimental greenhouse with heating system**.**

During the day the fluid acts as a heat shield as it moderates the greenhouse climate by absorbing excess energy from the plant. This energy is then transported to the storage tanks to be released at night to heat the greenhouse by reversing the direction of flow.

In order to evaluate the performance of the polyethylene collector, the temperatures of the heat transfer fluid at the inlet and outlet of the collector, as well as the temperature of the ambient area outside the greenhouse and the incident solar radiation were measured. Figure 5 shows one day of these measurements.



(**a**) (**b**)

Figure 5. (**a**) Collector inlet and outlet temperature variation. (**b**) Global solar radiation variation**.**

From Figure 5 the temperature of the heat transfer fluid increases as it passes through the collector, since the temperature at the outlet is higher than the temperature at the inlet. This rise is proportional to the increase in solar radiation. Thus, the heat transfer fluid can gain up to 20 °C when the solar radiation is around 600 W/m². This shows that the collector we have developed perfectly converts solar radiation into thermal energy and transmits it to the heat transfer fluid. In order to evaluate the performance of this collector, we determined its thermal efficiency during the day by calculating the useful energy divided by the received energy (Equation (1)). Figure 6 shows the result of this study.

$$\eta = \frac{\text{useful energy}}{\text{received energy}} = \frac{\dot{m}\, C_p (T_{outlet} - T_{inlet})}{S_c H_G} \quad (1)$$

$\dot{m}$: Overall flow rate of the heat transfer fluid during the storage phase 0.0251 L/s

C_p: Specific heat of the fluid; due to its low concentration, the specific heat of the fluid will be taken equal to that of water C_p = 4182 J/Kg/°C = 1.16 Wh/Kg/°C
S_c: Surface of the cover S_c = 7.2 m^2
H_G: Global irradiation.

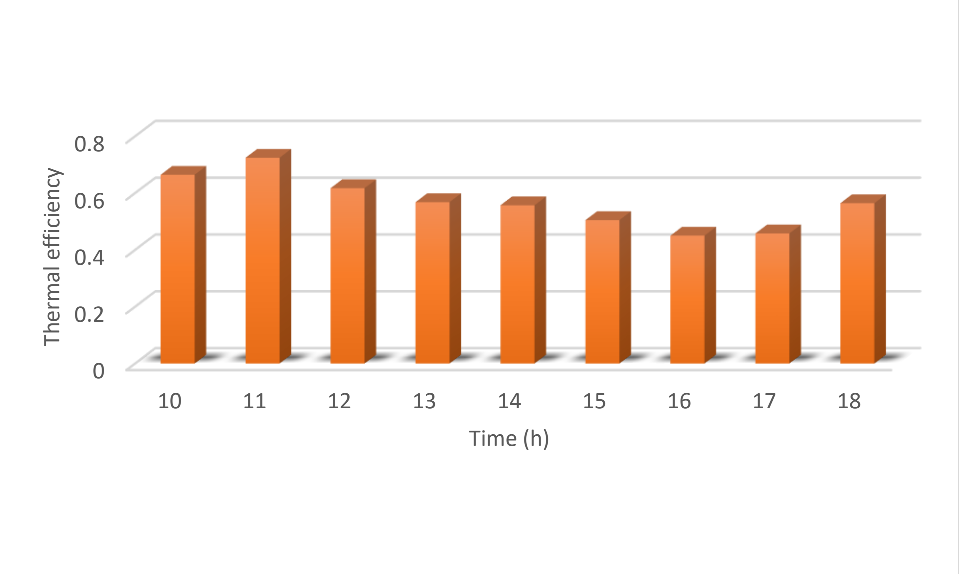


Figure 6. Solar collector thermal efficiency.

Figure 6 shows that the thermal efficiency can vary between 72% and 45%, which indicates that the collector was able to convert 72% of the solar energy received. However, as the solar radiation increases above 400 W/m^2, the efficiency decreases to 42%. This is mainly due to the absorption of Mytilene blue, which is saturated above this radiation value. The part not absorbed by the heat transfer fluid is used by the plantation in the photosynthesis process. The rest of the solar radiation is received by the soil and transformed into heat, which explains the increase in the internal temperature of the greenhouse during the day. On the other hand, the average energy stored by the system is 13.9 Kwh/day and represents 56% of the incident solar radiation. This energy, when dissipated in the greenhouse during the night, maintains the temperature at the desired

4. Conclusions

In this paper, we have presented the working principle of a new solar heating system used for heating and cooling of agricultural greenhouses. The system consists of a polyethylene collector, two tanks, a pump for the circulation of the heat transfer fluid and methylene blue as the heat transfer fluid. The experimental study of this system showed that the heat transfer fluid can gain up to 20 °C when the solar radiation is about 600 W/m^2. This shows that the collector we have developed converts solar radiation into thermal energy and transfers it to the heat transfer fluid. The thermal efficiency varies between 72% and 45%, which means that the collector was able to convert 72% of the solar energy received. This energy stored during the day by the heat transfer fluid will be used to heat the greenhouse at night. This will save more than 30% of the plantation's total costs.

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