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Heating of an agricultural greenhouse by a reservoir filled with rocks

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Abstract
Agricultural greenhouses are structures that produce fruits and legumes with high yields, in off-season and in places where the development of the plantation is difficult, this by creating a favorable microclimate for the good development of the plantation. Heating is a necessity during winter periods, with the aim of increasing the temperature and decreasing the air humidity of the inside greenhouse. Heating by solar energy is very promising compared to traditional systems using fossil fuels which are very expensive and polluting. In this work we have studied a simple and economical heating system of a greenhouse with a cylindrical PVC tank filled with rocks. The results of this study showed that the rock-bed system allowed to increase the nighttime temperature inside the greenhouse by 1-2 °C and to decrease the relative humidity of the greenhouse by 3% compared to the reference greenhouse.

Nomenclature

T_{exp} Temperature inside experimental greenhouse (with heating system) (°C)
T_{-t} Temperature inside reference greenhouse (without heating system) (°C)
T_e Temperature outside the greenhouse (°C)
H_{exp} Humidity inside the experimental greenhouse (°C)
H_{-t} Humidity inside the reference greenhouse (°C)
H_{re} Humidity outside the greenhouse (°C)
U_i Wind speed inside the experimental greenhouse (m/s).
U_e Wind speed outside greenhouse (m/s).
D_{vi} Wind direction inside the experimental greenhouse (deg)
D_{ve} Wind direction outside the greenhouse (deg)
R_{net} Net radiation (W/m^2)
R_g Outside global radiation (W/m^2)
T_{soil} Soil Temperature of the experimental greenhouse (°C)
T_{rocks} Temperature of inside rock bed (°C)

1. Introduction
A greenhouse is a structure with transparent walls, allowing plants to be grown in a warmer or better controlled environment than outside [1]. Culture can be made in the original soil or soilless, hydroponics, in pots or rock wool bags. A greenhouse is intended to protect plants against climatic hazards and to promote the growth of crops (vegetables, flowers, etc.) by creating climatic conditions more favorable than the local climate or to produce "out-of-season". Heating is required during winter periods to maintain the air temperature and humidity inside greenhouse in the optimum range for the good growth of the plantation [2]. To heat the greenhouse we need to install heating systems that we will generate the heat required to increase the temperature of the greenhouses to the optimal temperature, These systems consume a lot of energy [3].
Increasing fossil fuel prices and their adverse effects on the environment and human health have forced farmers and researchers in this field to use alternative heating sources. Renewable energies are the most promising sources, especially solar energy [4-6].
The most economical and efficient process to heat the greenhouse is to store excess heat during the day to use it to heat the greenhouse overnight. Usually, this storage is done in water, air or rocks tanks distributed in the greenhouse. The use of rocks for thermal storage offers advantages such as non-toxic, non-flammable and inexpensive [7- 9]. Many heating systems has been studied and developed by many researchers in the world

namely Santamouris et al. [10], Jain and Tiwari [11], bargach et al [12] , Lazaar et al. [13], I. Attar et al. [14] and Zhang et al [15]; but the majority of these systems are too expensive and difficult to achieve.

In order to keep the optimum growing environment in greenhouse, two greenhouses are constructed and installed in the MELK Zhar, Experimental center of Regional Centre of Agricultural Research of Agadir (INRA). The first is equipped with rock-bed heating system, and the second one devoid of a heating system erected for control purposes.

In this work we have studied the effect of a greenhouse heating system by a tank filled rocks placed on the ground of the greenhouse, during the day these rocks store the heat coming from the air of the greenhouse and release it into the air inside the greenhouse overnight to increase its temperature.

2. Material and Methods

2.1. Description of the greenhouse

We installed two greenhouses of the same size to the experimental field MELK ZHAR of Regional Center for Agricultural Research of Agadir, located in Had Belfaa region (30°13 Latitude, 9°23 Longitude, 80m Altitude). One greenhouse was equipped with a rock-bed heating system (named experimental greenhouse), the other greenhouse did not contain any heating system, it served as a reference (named reference greenhouse). The surface of each one is 15m^2 (Length =5m, Width =3m) and a height of 2.5m at gutter level and 3m at span level. These greenhouses are covered with a plastic cover (polyethylene with 200µm of thickness), and the orientation of its spans was North-South, i.e., perpendicular to the prevailing wind direction (figure 1 and Figure 2).

These two greenhouses were planted on 28 /10/ 2015 by Pristyla tomato; each greenhouse contains a row of 9 plants distant of 0.4m, orientated North-South, i.e., perpendicular to the prevailing wind direction.

Figure1: The experimental greenhouse

Figure 2: Inside view of the greenhouse

2.2. Sensors installed in greenhouses.

In order to study the microclimate of the two greenhouses (experimental and reference) and the effect of the heating system by rock-bed on the climate of the greenhouse, we installed the following sensors described in figure 3**.**

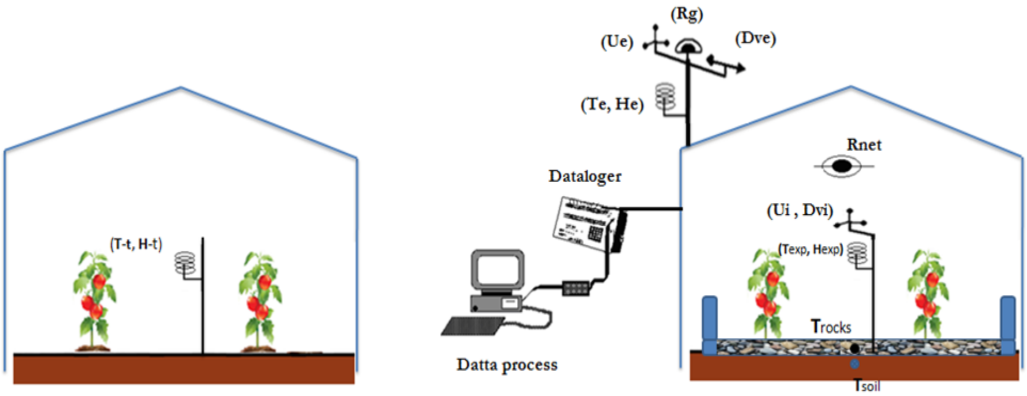

Figure 3: The sensors installed in the experimental greenhouse (A) and reference greenhouse (B).

For the experimental greenhouse the installed sensors are described in figure 3(A). In this greenhouse we measured the temperature and the relative humidity of the inside air of the greenhouse in its center with an HMP60 sensor (Figure 5) (which measures the temperature Between -40 to 60 ° C and relative humidity between 0 and 100%), Net radiation by the CNR4 sensor (Figure 4), the average soil temperature and rock-bed temperature by probes PT-108 (Figure 6). In parallel, in the reference greenhouse (figure 3.(B)) we measured with the same types of sensors, the temperature and relative humidity of the air inside the greenhouse in its center, the soil temperature and the temperatures leaf. A weather station was installed outside the greenhouse to measure wind speed and direction, the air temperature and relative humidity and the global solar radiation (Figure 9). All these sensors are connected to two CR3000 Micrologger (Figure 8) which instantly acquire every 5 seconds and record the averaged values in 10-minute time steps. Via a computer, the data stored by these stations are collected and processed. In the following table (Table 1), we described the sensors used in the experimental greenhouse, in reference greenhouse and in outside of the greenhouse, their name, unit of measure and the precision.

Figure 4: CNR4 Net Radiometer

Figure 5: HMP60,Temperature and Relative Humidity Sensor

Figure 6: PT-108 Temperature Probe

Figure 7: Two Dimensional Ultrasonic Wind Sensor

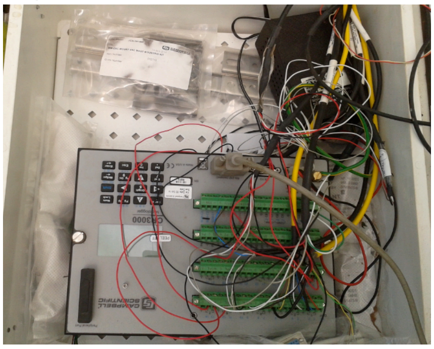

Figure 8: Campbell Scientific CR3000 Micrologger

Figure 9:Weather station

Table 1: List of sensors.

Description	Sensors	Denomination	Unite	Precision
Global Solar Radiation	Pyranometer Kipp&zonen CMP11	R_g	W /m^2	± 0.2%
Air Temperature and Relative Humidity	Vaisala HMP60	T_e H_e	°C %	±0.6°C ±3%
Rock-bed Temperature	PT-108	T_{rocks}	°C	±0.2°C
Soil Temperature	PT-108	T_{soil}	°C	±0.2°C
Wind Speed	WINDSONIC1-L	U_v	m/s	±0.001m/s
Wind direction	WINDSONIC1-L	D_v	Degree	±1°
Net Radiation	CNR4	R_{net}	W/m^2	< 1 %

3. Description of the heating system.

As it is shown in figure 10, the storage system consists of a cylindrical tube of PVC 200 mm in diameter filled with gravel diameter between 4 and 8 cm placed on the floor of the greenhouse.

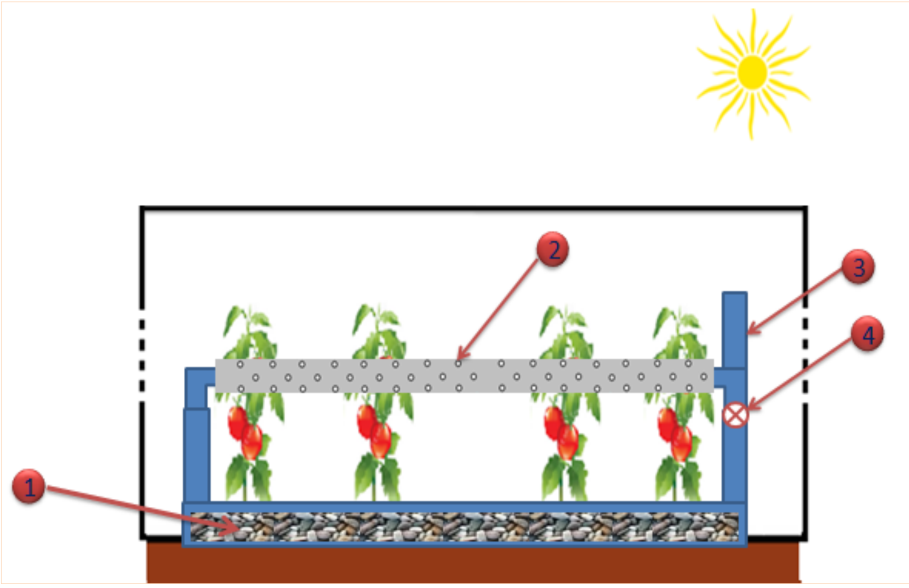

Figure 10: Schematic of the greenhouse with rock-bed system

1-Rock-bed
2- Sheath with holes
3- Tube to enter hot air from the top of the greenhouse
4- Fan.

The day when the air inside greenhouse is hot (greater than 25°C), the air of the greenhouse is forced to circulate in the reservoir of rock-bed by means of a fan connected to the inlet of the reservoir, the hot air transmits its heat to the rock-bed.

At night when the air inside the greenhouse is cold (less than 12°C), the heat stored in the rock-bed is recovered to heat the greenhouse. A plastic sheath is installed near the plantation to distribute the heat homogeneously in the greenhouse.

4. Results and discussion

Air temperature, air relative humidity and solar radiation are one of the most important variables of the greenhouse climate that can be controlled; because it affects the quality and yield of the plantation. The average monthly values of temperature and solar radiation are represented in Figure 11, this figure shows that heating a greenhouse in the Agadir region (In south of Morocco) is necessary during the months of December, January and February.

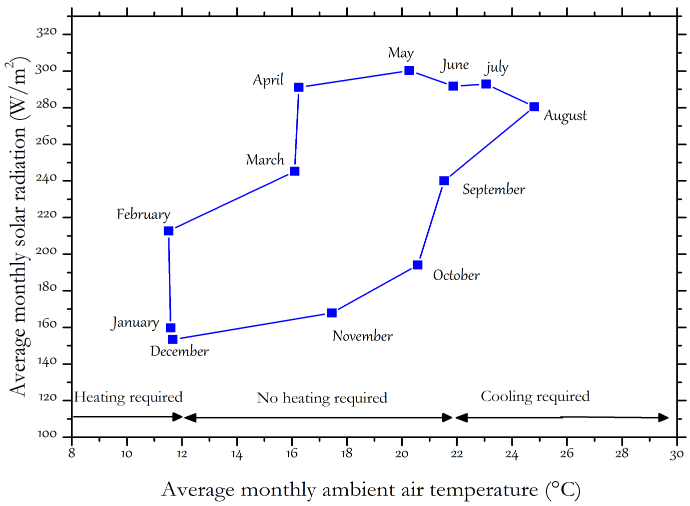

Figure 11: Monthly average values of ambient temperature and solar radiation

4.1. Air temperature.

Figure 12 shows the variation of the air temperatures, inside the experimental greenhouse, inside the reference greenhouse and outside greenhouse. In order to show the effect of heating clearly, two days were chosen. It is found that the outside air temperature is always lower than the temperature of the air inside the greenhouse.

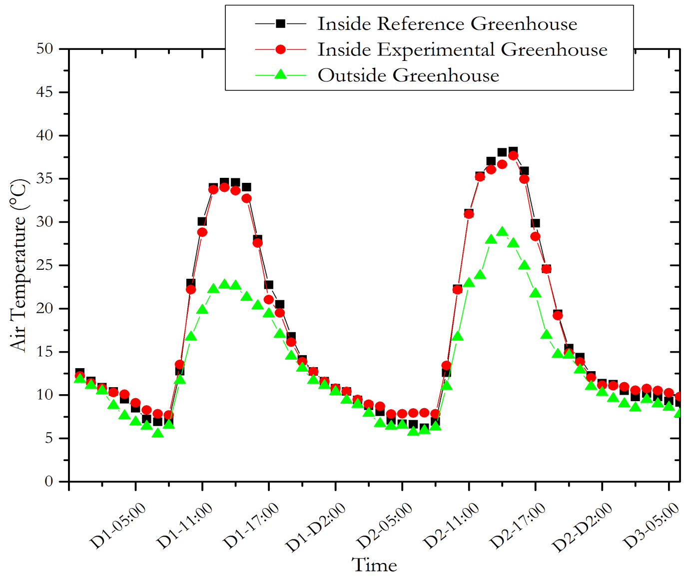

Figure 12: Variation of air temperatures inside the experimental greenhouse, inside the reference greenhouse and outside.

At night, the air temperature of the experimental greenhouse is higher than that of the reference greenhouse, the difference can reach 1-2°C, but at the day the air temperature of the experimental greenhouse is lower than that of the reference greenhouse, the difference can reach 1°C

4.2 Air Relative Humidity

Figure 13 shows the time course of the inside air relative humidity of the experimental greenhouse, the inside air relative humidity of the reference greenhouse and the air relative humidity of the outside. It is observed that the outside air relative humidity is always higher than the inside air relative humidity, the difference in relative humidity during the day can reach 4%, and 10% at night.

During the day the air relative humidity of the experimental greenhouse is higher than that of the reference greenhouse, the difference is 1%, but during the night the air relative humidity of the experimental greenhouse is lower than that of the reference greenhouse, the difference of relative humidity can reach 3%.

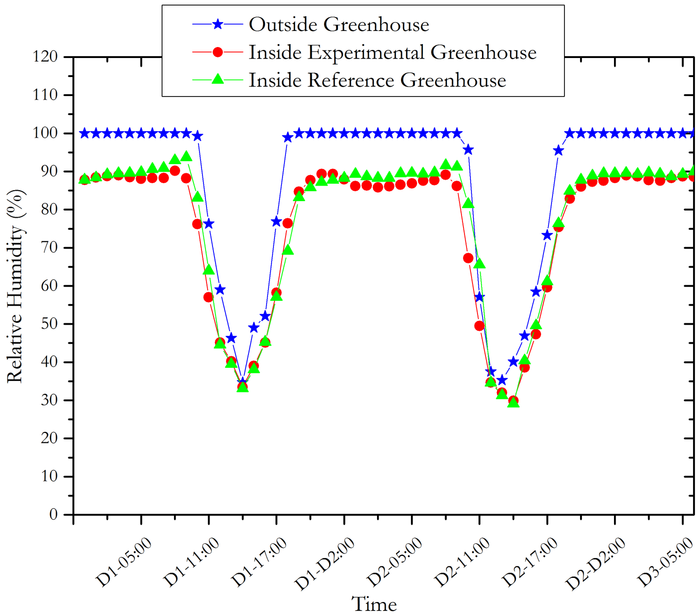

Figure 13: Evolution of the inside relative humidity of the experimental greenhouse, the inside relative humidity of the reference greenhouse and the air humidity outside greenhouse.

4.3. Solar Radiation

Solar radiation is also an important parameter in greenhouse because it influences the inside air temperature and photosynthesis. Figure 14, shows the evolution of the external global solar radiation and the Net radiation inside the greenhouse.

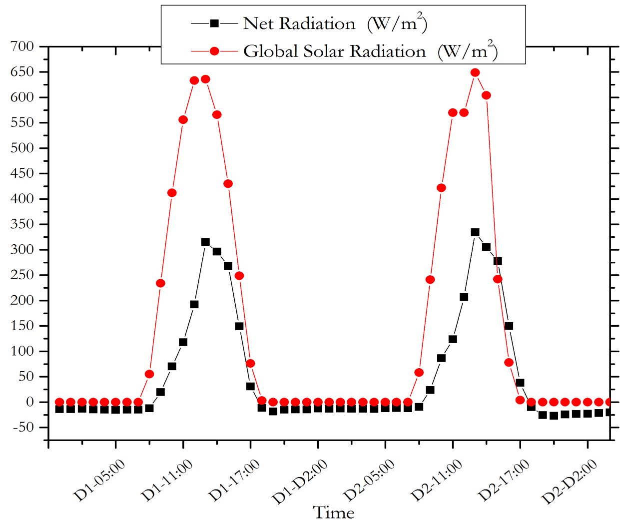

Figure 14: Variation of global solar radiation and net radiation inside the greenhouse

Global solar radiation during this period reaches a maximum value of 670 W/m^2. The Net radiation in the greenhouse is highest during the day (340 W/m^2) and minimum at night (-15 W/m^2).

4.4. *Soil and rock-bed temperature*

Figure 15 shows the variation of temperature inside the rock-bed, air temperature inside the experimental greenhouse and soil temperature, we observe that:

- On the day the temperature of the air inside the experimental greenhouse is higher than that of the rock-bed.
- At night the temperature of rock-bed is higher than that of the air inside the greenhouse, this because of the heat that has been stored by the rocks during the day. This energy will be released into the air inside the greenhouse to increase its temperature overnight. It is found that the temperature difference between the rock-bed and the air inside the greenhouse up to 5 °C at night, (discharge period of rock-bed), and day the difference can reach -8 °C (charging period of rock-bed).

The rocks lose part of their heat at the beginning at night, because of the location of the rock-bed that is placed on the ground of the greenhouse; it exchanges heat with the air inside the greenhouse.

In order to reduce heat losses, it is proposed in the next study to place our reservoir under the soil of the greenhouse, at the depth where the temperature of the ground is not influenced by the greenhouse air.

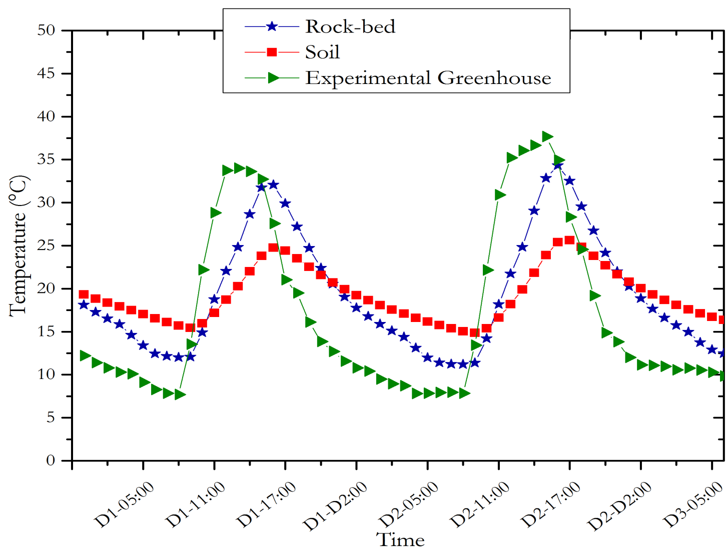

Figure 15: Variation of the temperatures of rock-bed, air inside the experimental greenhouse and soil of the greenhouse.

Conclusion

For greenhouse horticulture, climate control is important to obtain both a high quality product and a high yield. Developing efficient and economical heat storage systems and related devices is as important as developing new energy sources from the point of view of energy conservation.

The rock-bed system studied in this work can increase the greenhouse air temperature by 1 to 2 °C during the night and reduce it by 0.5 to 1 °C compared to the reference greenhouse (without heating system).

For the relative humidity of the air, this system made it possible to increase the air relative humidity of the experimental greenhouse by 1% during the day and to reduce it by 3% during the night compared to the reference greenhouse.

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