EXPERIMENTAL STUDY OF THE THERMAL AND HYDROUS BEHAVIORS OF A SOIL HEATED BY A SYSTEM OF BURIED CAPILLARY PLAITS. STORAGE OF ENERGY IN THE UNDERGROUND OF THE AGRICULTURAL GREENHOUSES.

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Abstract
An experimental study of the thermal and hydrous behaviors of a soil heated by buried capillary plaits (in polypropylene) was done. This study was carried out on a prototype similar to an agricultural tunnel greenhouse. An acquisition system was used to measure the soil temperature, the soil water content at various depths, the soil surface heat flow, the relative humidity of the air, the solar radiation, the air temperature under the prototype of greenhouse as well as the surrounding climatic parameters. Conclusions relative to the storage and restoration of heat in the under ground of the agricultural greenhouses were drawn and some operational recommendations were given. A comparison between the behavior of the wet and dry soil was also carried out.

1. Introduction

The soil heating is used in agriculture (case of the greenhouses) to store energy and to restore it when the weather is cold. This would afford a microclimate favorable to the plants growth. It is also used to ensure temperatures required by species of seeds for germination and growth, (for example, case of seedbeds). A significant soil temperature fluctuation can influence the plants and the insects biological processes, pesticides and fertilizers decomposition, nutriments mineralisation, micro-organisms breathing, as well as the water infiltration rate in the ground. Thus, it would be of a great interest to study the effect of a buried system of heating on the soil thermal and hydrous profiles. In fact, many researchers were interested by the transfer of heat and mass in the porous media and in particular in soil. De Vrie. D.A (De Vrie, D.A.,1987) in 1987, has reviewed the theory of the coupled transfer of heat and moisture in the porous media developed by himself and Philip.J.R in the mid-1950s. He presented the limits of this theory and the assumptions that it contains, analyzed the problem of the definition and use of a thermal apparent conductivity and suggested same remarks on the phenomenon of hysteresis and its possible influence. In addition, he discussed some works concerning this theory and the laboratory and field experiment which were done by other researchers during thirty years and noticed that there are situations where some researchers found a good matching between the theory and the experience and others not. According to the author, disagreement is due to the operational limits of this theory and to considerations and adjustments, which are necessary to take for each situation. For field experiments, he noticed that the researchers found a good agreement between the theory and the experiment during the night but not during the day, when the solar radiations were intense.

Other researchers studied the phenomenon of water evaporation from the ground. Sifaoui M.S (Sifaoui, M.S.,1978) studied the surface evaporation and the deep evaporation from the soil by analyzing the balance of energy utilizing the neat solar radiation, the sensible heat flow, the heat flow absorbed by the soil and the latent heat flow. He noticed that if the soil surface is exposed to an intense flow of neat solar radiation, a superficial dry layer will be formed, thus constituting a heat insulator which reduces the heat penetration in the ground and consequently delay the water vapor diffusion in the atmosphere. Anandakumar, K.et al. (Anandakumar, K.et al., 2001) took measurements on sites of dry and wet soil (after rain) during the same period of the year. They measured temperatures for various depths, neat radiation, heat flow in the ground, air temperature and the wind speed. They also calculated thermal conductivity, heat-storage capacity and the soil thermal diffusivity. Thus, they noticed that these parameters values increase when the soil become wetter. They also noticed that the wet soil temperature is lower than that of the dry soil for only 20 cm of depth and for the other depths the temperatures are almost the same. Others studied the heat transfer in the ground under the microclimate of agricultural greenhouses. Grozdanov et al.(Grozdanov et al., 1987) suggested a model on the impact of radiation conditions on the temperature distributions inside the greenhouse. They noticed that when the solar radiation is intense, the greenhouse surface ground temperatures and the superficial layers temperatures can reach high temperatures (about 70°C). Boulard.T et al.(Boulard.T et al., 1986) studied the soil use for energy storage and restoring.

Santamouris, M. et al. (Santamouris, M. et al., 1994) constructed and tested a prototype of passive solar agricultural greenhouse, designed in order to reduce heat losses and increase useful solar gains on a daily and seasonal basis. The passive elements of the greenhouse were a mass storage wall located on the north side and a network of earth-to-air heat exchangers buried in the greenhouse. Monitoring of the greenhouse for a 2-year period has shown that the passive systems have offered energy equal to 35% of the heating requirements of an identical conventional greenhouse.

This paper deals with the experimental study of the thermal and hydrous behaviors of a soil heated by buried capillary plaits (in polypropylene). In this work, we aim to study soil behavior in order to facilitate soil storage energy and acquire the techniques relative to the storage and restoration of heat in the under ground agricultural greenhouses heated by geothermal sources, factories and power stations thermal discharges or passive solar energies.

2. Description of the experimental installation

This study is carried out on a prototype which simulates an agricultural tunnel greenhouse formed essentially by a parallelepiped box with the following dimensions (2x1,5x1 m), filled of soil (fine sand) and a stainless steel structure of 1,2 m height with a semi-cylindrical form assembled on the box and used as support for the plastic cover. The box is divided into two compartments; one filled with wet soil, irrigated on its surface by a dropper and the second filled by a relatively dry soil (not irrigated).

The heating system consists of two capillary plaits placed respectively at depths of 40 and 70 cm in the soil and including a system, feeding separately or simultaneously the two plaits of water at constant temperature that may reach 90°C.

The capillary plait has the characteristic to be flexible, easily usable and with low costs. It is formed by capillary tubes of 2mm internal diameter, spaced each other of 10mm and connected to two 20mm diameter collectors (figure1b). This form allows a heat flow uniform distribution in soil around the plaits similar to a heating plane plate.

Two temperatures of heating (feeding of the plaits) are used: water at 70°C to simulate the very abundant geothermal sources in the Tunisian South and water at 40°C to simulate the thermal discharges of the factories and power stations.

An acquisition system (Campbell scientific data acquisition systems) is used to measure the soil temperature, the soil water content at various depths, the soil surface heat flow, the relative humidity of the air, the solar radiation, the air temperature under the prototype of greenhouse, as well as the surrounding climatic parameters.

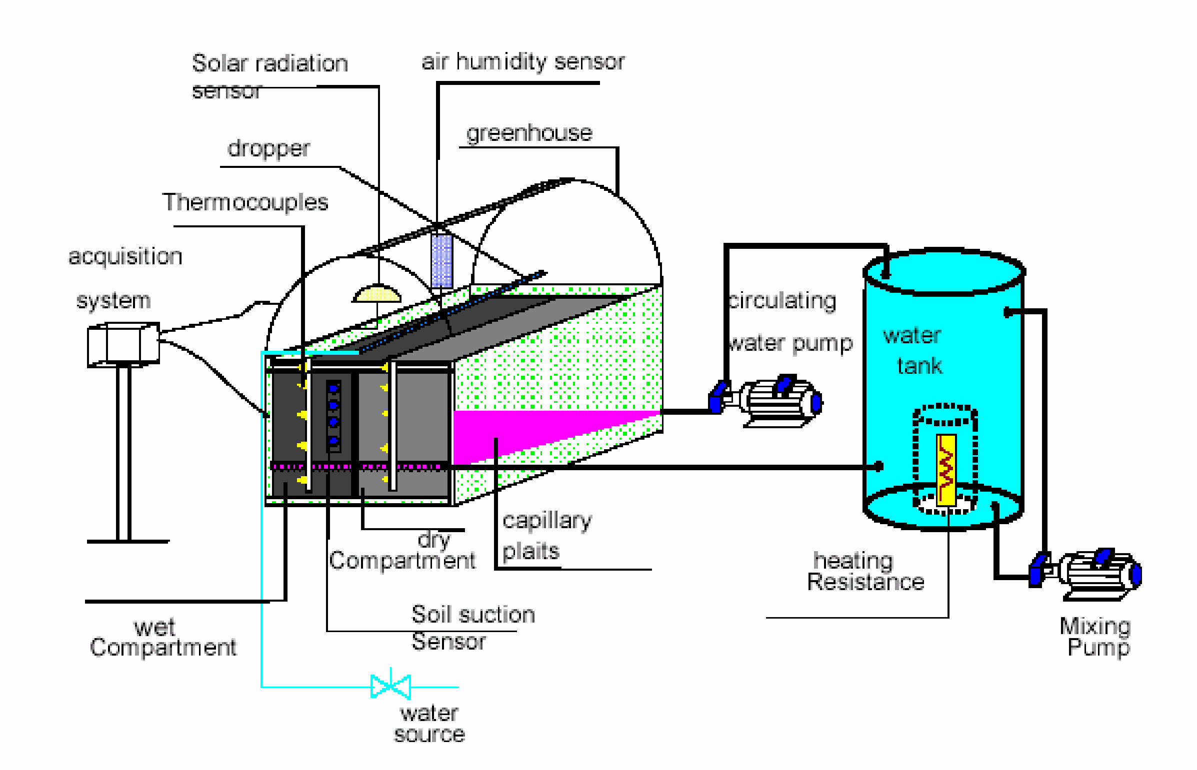

Figure 1a. Experimental installation

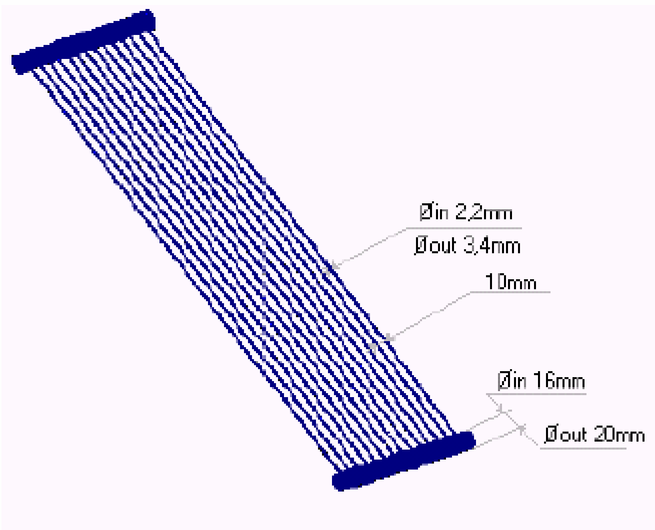

Figure 1b. Capillary plait

3. Operations and results:

During ground heating, the inside and the outside air temperature fluctuate between day and night while following the sunning and the inside air temperature still greater than the outside one also at night (figure 2). we notice the absence of the greenhouse inside air temperature inversion phenomenon which occur usually at night. The relative inside air humidity decreases when the temperature of the air increases. The value of the lowest moisture is obtained at nearly midday (when the solar radiation is maximum). During the night, the air is saturated, thus evaporation is null (figure 3).

The soil surface temperature fluctuates between day and night following the sunning. In fact, during the night, the dry soil surface temperature is higher than that of the wet soil. However, during the day, the temperature of the wet soil surface becomes greater . Under the influence of an intense solar flow, a superficial soil layer dry rabidly and constitute then a heat insulator which reduces the heat penetration in the soil and consequently delay water vapor diffusion in the atmosphere. The wet soil temperature variation amplitude is higher than that of the dry soil. The temperature fluctuations amplitudes decrease according to the soil depth (figures 4 and 5).

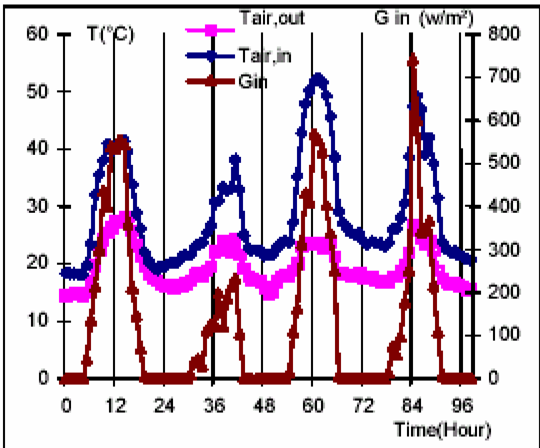

Figure 2. Variation of the outdoor and indoor air temperature and the indoor solar radiation under the prototype during the period of 01/05 to 08/05/2002 when the soil was heated at 70°C on the depth of 70 cm.

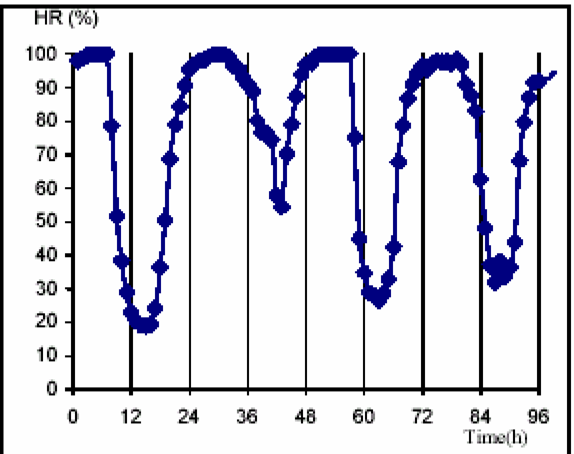

Figure 3. Variation of the relative air humidity

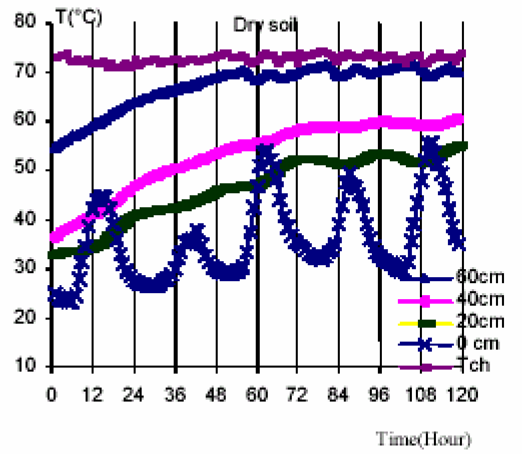

Figure 4. Variation of the dry soil temperature for various depths when the soil was heated at 70°C on the depth of 70cm.

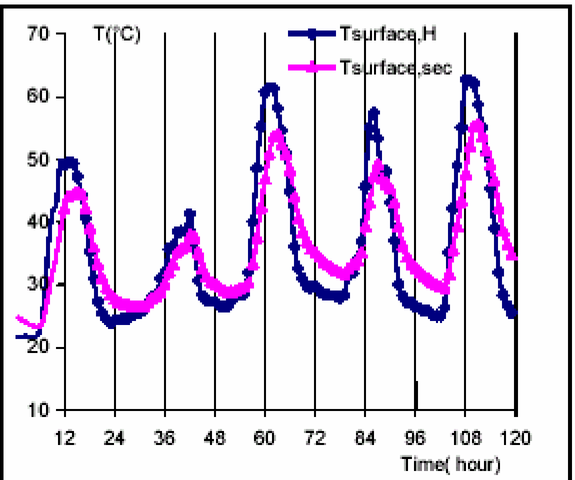

Figure 5. Variation of the wet and the dry soil surface temperatures when the soil was heated at 70°C on the depth of 70cm.

The ground can be divided into two zones (upper and lower). The thickness of the upper zone depends on the temperature of the heating water. It is about 20 cm for a heating temperature of 70°C, 30 cm for a heating of 40°C and 40 cm for a non-heated ground. The role of this zone is to store the solar energy collected during the day and to restore it at night. It is a storage section of short-term heat (daily). The lower zone stores heat provided by the heating system and heat which is not restored at night by the upper zone. The temperature fluctuations are reduced in this zone. Thus, this layer is said to be a long-term storage section.

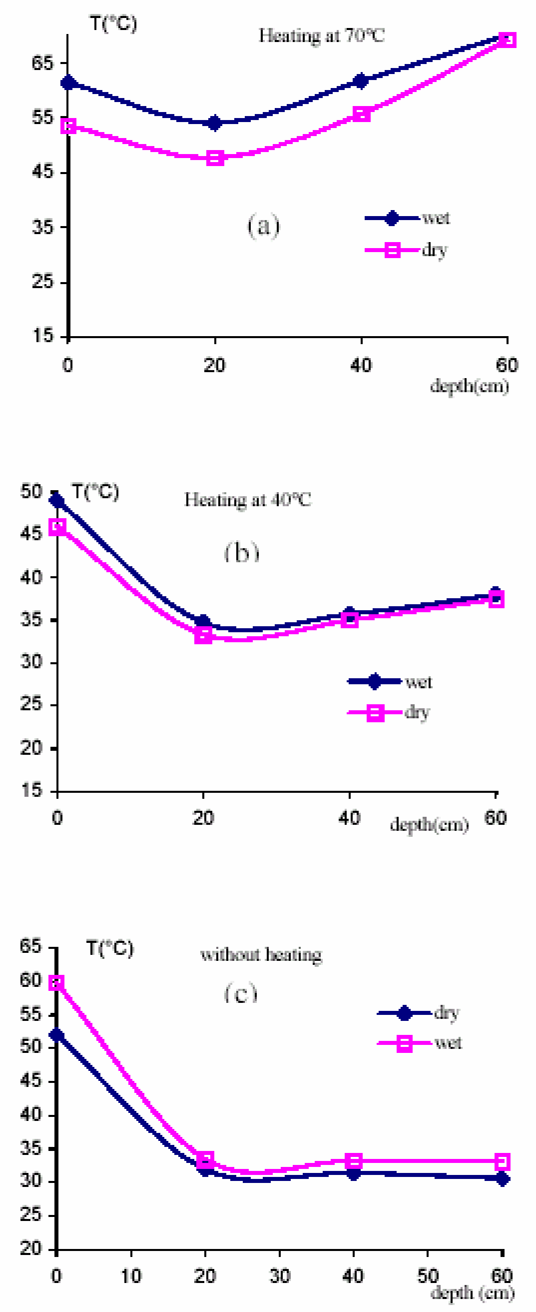

Figure 6. Profiles of soil temperature with depths in the wet and the dry compartment in daytime at (13:00)

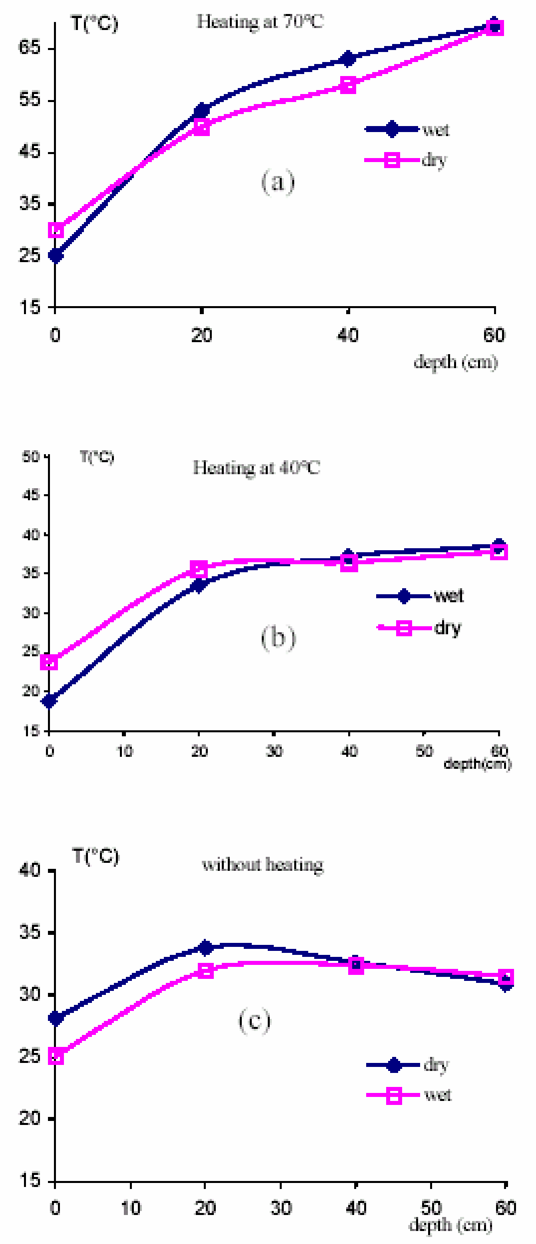

Figure 7. Profiles of soil temperatures with depths in the two compartments at night at (04 :00)

During the day, although heat-storage capacity of the wet soil is more important than that of the dry soil, the temperature in the wet soil is higher than that of the dry one for all depths, (figures 6-a, 6-b and 6-c). The wet soil, with thermal conductivity more significant than that of the dry soil, acquires a quantity of energy, by conduction through its surface and the capillary plaits, more significant than that received by the dry ground. Consequently, the wet soil can store more significant energy than the dry one.

On the other hand, during the night, the wet soil superficial layers temperature is lower than that of the dry soil (figures 7-a, 7-b and 7-c). The wet soil yields more heat than the dry soil, because of its higher thermal conductivity. However, the wet soil deep layers temperature still more significant. Figures 6 and 7 show that beyond a certain depth, the ground temperature does not vary between the day and the night. Only the superficial layer is influenced by temperature fluctuations throughout the day and the night. This surface constitutes the ultimate layer of heat transfer by convection with the ambient air, radiation through its upper surface and conduction through its lower surface.

At a heating exposure of 70°C, the soil temperature becomes relatively high. The heat flow on rface is always negative. The soil yields heat to the greenhouse ambient air. The yielded heat quantity increases during the night and decreases during the day (figure 8a). during the cooling of the soil after a heating with 70°C, when its temperature drops, the heat flow on the surface, which were always negative, becomes positive the day and negative the night. At the equilibrium, when the soil temperature is stabilized, the heat stored in the day will be restored at night (figure 8b). Whereas, for a heating of 40°C, the yielded heat during the night is more significant than that received during the day. It is the phenomenon of long-term restoring (figure 8c). Without heating in summer, the quantity of heat received during the day is more significant than that yielded during the night. It is the phenomenon of long-term storage (figure 8d).

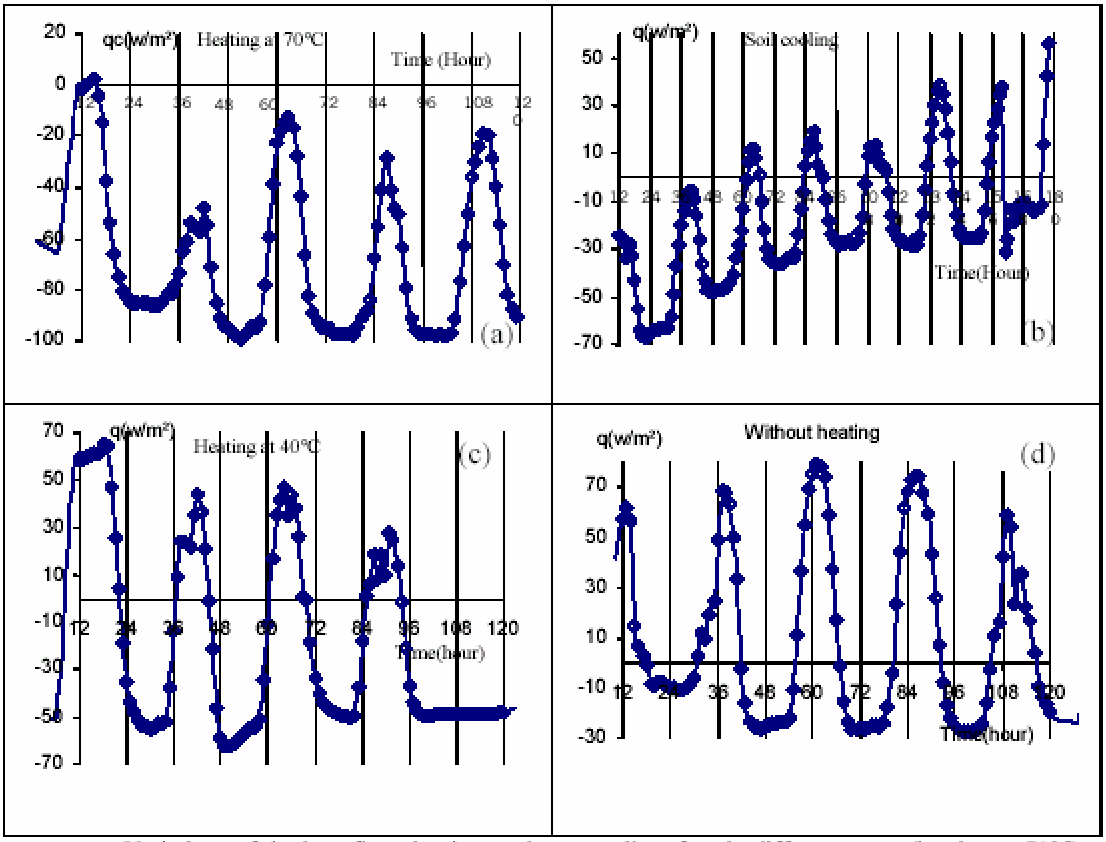

Figure 8. Variations of the heat flow density at the wet soil surface in different cases (heating at 70°C and at 40°C, without heating , relaxation)

Figures 9 and 10 exhibit the evolution of the soil water content and the inside relative air humidity during the heating of 70°C and 40 °C. The curves of the water content are deduced from the curves of suctions (expressed in bar) by using the retention curve of Gardner (Gardner, 1964).

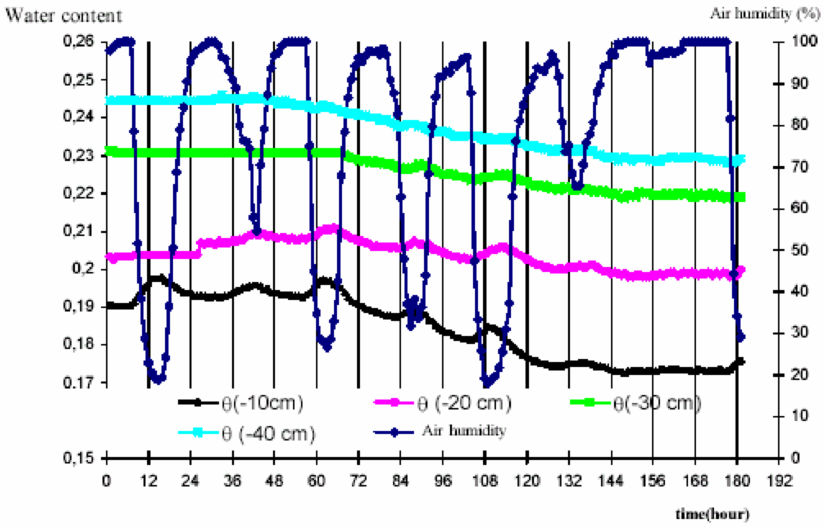

Figure 10. Evolution of the soil water content at various depths and the relative indoor air humidity when the wet soil was heated at 70 °C at the depth of 70 cm.

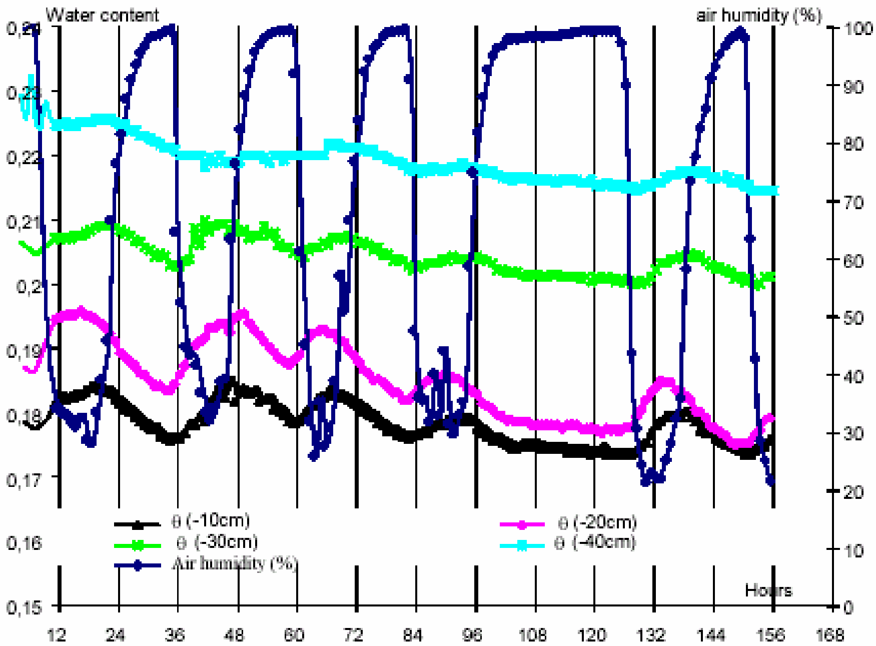

Figure 11. Evolution of the soil water content at various depths and the relative indoor air humidity when the wet soil was heated at 70 °C at the depth of 70 cm.

Like the temperature, water content in the superficial layers fluctuates between the day and the night. The amplitudes of these fluctuations decrease according to the depth. However, there is a phase difference between soil water content evolution and sunning. When the solar radiation increase, the inside relative air humidity decreases which increases the soil evaporating capacity, soil suction decreases and soil water content increases. These fluctuations are due to the redistribution of the water content when the temperature field changes and during evaporation starting from the ground. This result is in agreement with De

Vrie. D.A (De Vrie, D.A., 1963) point of view such that in moist soils (not saturated in water), heat transport is complicated by the fact that temperature gradients cause moisture movement, so that the moisture will tend to redistribute itself when temperature field changes. Evaporation causes moisture movement, occurring both in the liquid and in the vapor phases and giving rise to a transport of sensible and latent heat, which influences again the temperature distribution.

4. Conclusions

According to the results obtained, we notify the following:
The ground can be divided into two zones. The thickness of the upper zone depends on the temperature of the heating water. It is about 20 cm for a heating with 72°C, 30 cm for a heating with 40°C and 40 cm for a ground not heated. The role of this zone is to store the solar energy collected during the day and to restore it in the night. It is a storage section of short-term heat (daily). The lower zone stores the heat provided by the heating system and the heat not restored in the night by the upper zone. The fluctuations of the temperature are reduced in this zone so we can call it a long-term storage section. Soil moisture increases the heat storage capacity in the long-term storage zone and facilitates the heat extraction from court-term storage zone to the greenhouse inside air at night. However at daytime soil moisture in the court-term storage zone increases the evaporation which is harmful to plants and greenhouse microclimate. An irrigation during the night is a first approach of solution. But it remains interesting to study the capillary plaits position effect on the upper zone and to give models for the various noted phenomena in order to give operational recommendations in the case of these buried heating systems uses.

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