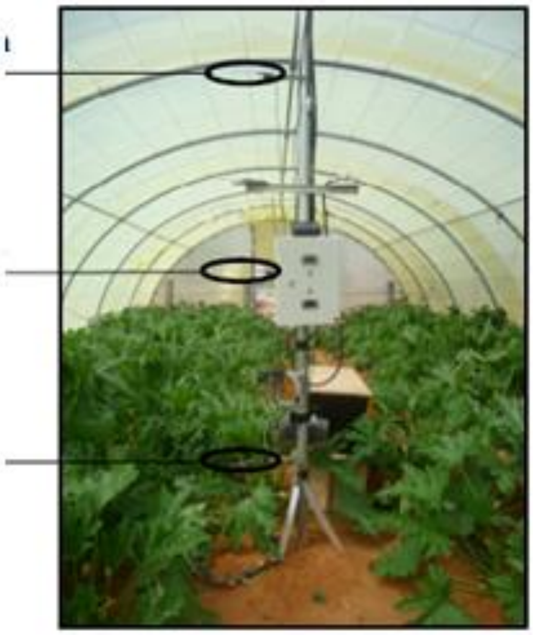

Figure 10. Selected measurement positions

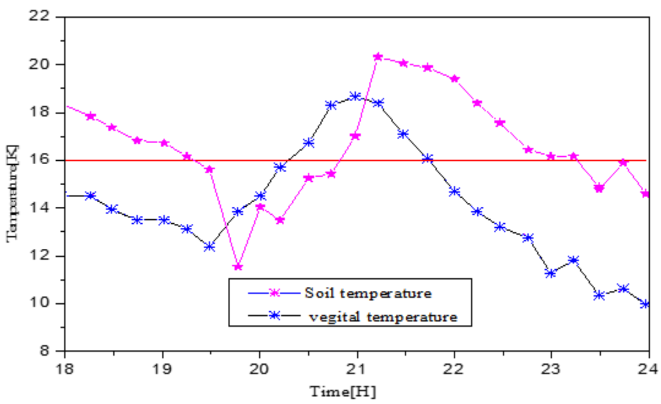

Figure 11. Temperature evolution at different position

Fig. 12 shows the relative humidity in the two experimental greenhouses with and without thermal storage system. The humidification degree required in the greenhouse directly related to its temperature. The sudden increase of the temperature of the in the greenhouse indeed a rapid drop in its relative humidity and reaches its minimum of 18% at 13h where the temperature is at its maximum corresponding to a maximum solar radiation.

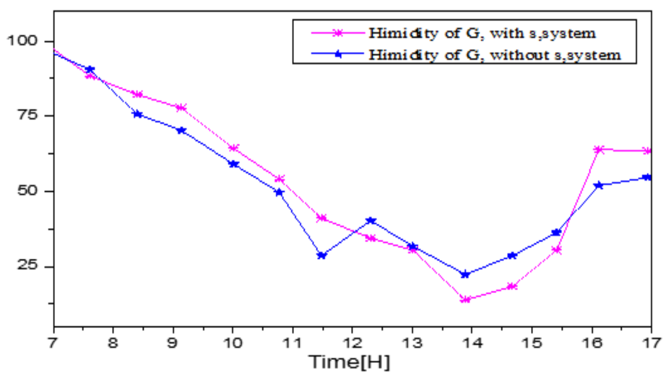

Figure 12. Measurement humidity in both greenhouses [%]

The heating requirements of both greenhouses with and without storage system at night, with a temperature of set point of 16 °C (required temperature for plants at night our case Courgettes) are shown in Fig.13. The curves show that the needs of the experimental greenhouse occupied with the storage system are lower than the without storage system with difference between 3 to 5°C per night. These results show that the storage system thermal is effective and satisfactory.

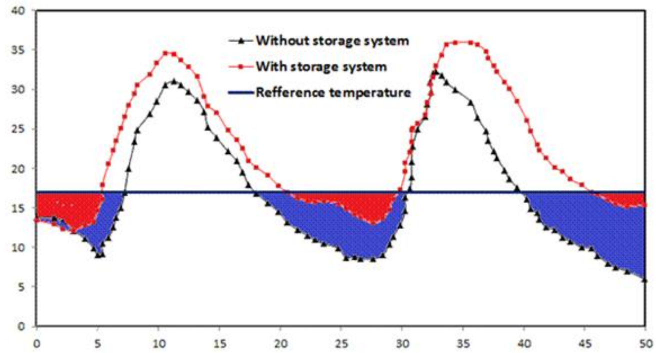

Figure 13. Heating needs of both greenhouses

Fig. 14 shows the production evolution in both greenhouses with and without storage system in two weeks. The results show that the production quantity in the experimental greenhouse with storage system is more than those of the greenhouse without a storage system with a difference rate about 2kg per day.

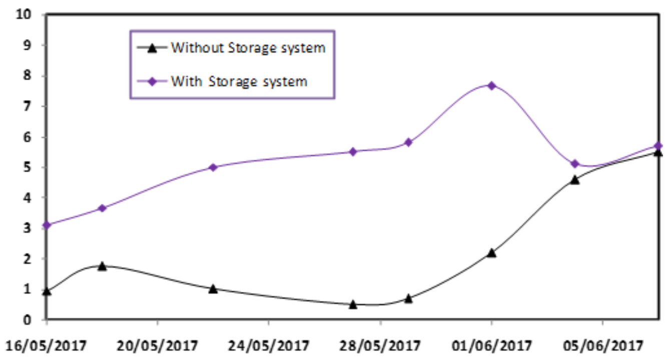

Figure 14. Production in both greenhouses

6. NUMERICAL SIMULATION

The aim of this investigation is to study the natural convection in laminar regime of the air of a tunnel greenhouse devoid of vegetal cover. The Ansys software 14.0 code used.

Flow is considered to be in two-dimensional along x and y.

Physical properties of the air confined within the greenhouse assumed constant, except its density ρ whose variation given by the Boussinesq approximation.

$$\rho = \rho_0(1-\beta(T-T_0))$$

Velocities considered Low (negligible) and the flow is laminar.

6.1. Geometrical configuration

The geometrical configuration with all boundaries condition considered in this study shown in the Fig. 15.

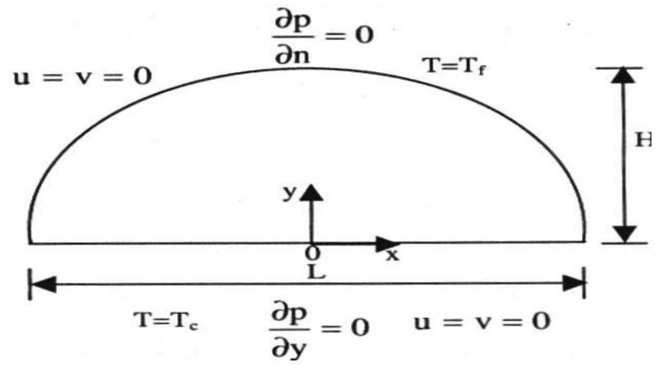

Figure 15. Geometrical configuration

6.2. Numerical results

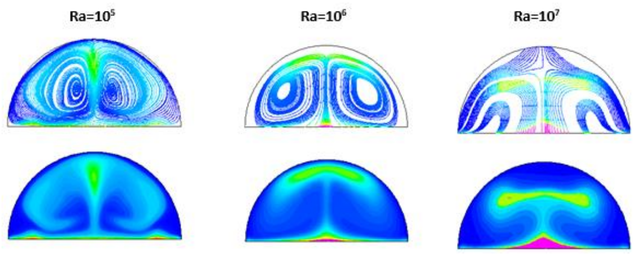

Figure 16. Isolines and isothermal of heated greenehouse

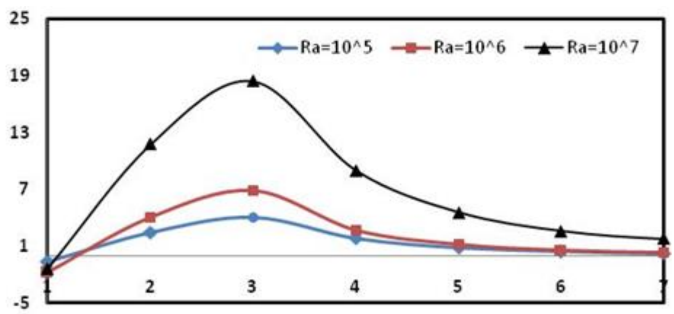

Figure 17. Local Nusselt number for different Rayleigh number

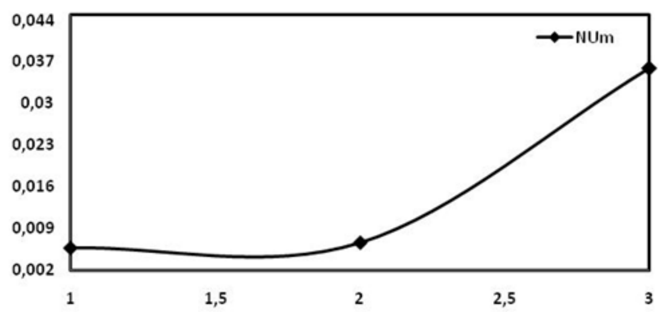

Figure 18. Mean Nusselt number

The stream function and isotherms for different Rayleigh R_a numbers shown in Fig.16. The flow of the fluid intensifies and the natural convection increases and predominates over the conduction. The air particles heated at ground level rise along the wall, then, they cooled in contact with roof flow near the other wall. The influence of the Rayleigh number on the traces of the stream function (top of the figure) and the isotherms (bottom the figure) is illustrated. For different Rayleigh numbers the flow characterized by two air circulation loops.

For small Rayleigh numbers (R_a = 10^5), isotherms are parallel, and this representation is characteristic of heat transfer dominated by conduction. As the Rayleigh number increases, the isotherms become increasingly undulating and the heat transfer becomes more pronounced. Thus, the flow of the fluid intensifies and the natural convection increases and predominates over the conduction. The air particles heated at ground level rise along the wall. Then, the particles cooled in contact with the roof flow near a median plane.

The exchange of heat transfer in the greenhouse with different Rayleigh numbers, represented by the Nusselt number is given in Fig. 17 and 18. Therefore, the logic is respected as long as there is a concentration of isotherms at (Ground), which explains a large number of Nusselt. In order to analyze the influence of the Rayleigh number on the exchange rate, the variation of the local and mean Nusselt number as a function of the Rayleigh number are presented. It can be seen that for a Rayleigh number ranging from 105 to 106, the Nusselt number is small and conduction dominates. With the increase of the Rayleigh number, the exchange rate increases indicated by the important values of the Nusselt Number. From these results, the good connection between the literature and the present work is observed for different Rayleigh numbers. Our objective was to study the behavior of the air inside the greenhouse.

We used a code that allowed us to determine the spatiotemporal distributions of isolignes and isothermal in the entire field of study. We have also shown that for flow conditions imposed on the (heating of the rollers) and for low differences temperature between floor and roof, the air circulation is characterized by two recirculation cells rotating in the opposite direction. Therefore, this study should make it possible to improve the thermal design of greenhouse as well as the positioning of heating systems with thermal storage.

7. CONCLUSION

In conclusion, careful measurements and a detailed study, over a growing total complete cycle, of two horticultural greenhouses subjected to the same agronomic program, one with thermal storage system and an anther without system makes the following conclusions: The Storage efficiency improved if a practical solution to air circulation not found the same order of stratification. The external needs of the experimental greenhouse with storage system are lower than without storage system. The study shows that temperatures and solar irradiations are parameters significantly affect agricultural production in general. The thermal storage system has no negative influence on crops, which have consistently yielded similar crops in both the control greenhouse. The numerical simulation makes possible to improve the thermal design of greenhouse as well as the positioning of the storage system for heating.

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NOMENCLATURE

Ra	*Rayleigh number*
Re	*Reynolds number*
Nux	*Local Nusselt Number*
Num	*Mean Nusselt Number*
Pr	*Prandtl number*
Pvc	*Plastic pipe*
I_t	*total solar radiation* (W/m^2)
A	*surface area* (m^2)
P	*Pressure (pas)*
T	*Temperature (°C)*

Subscript

Max	*maximum*
Min	*minimum*
H	*heat gain*
Am	*ambient*
co	*cover of greenhouse*

Greek symbols

ε	*emissivity*
Δ	*difference in time*
λ	*Thermal conductivity (W/mK)*
α	*thermal diffusivity*