Comparative study of geometrical configuration at the thermal performances of an agricultural greenhouse

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Abstract. The aims objective of this work consists to study the storage system effects on the thermal performance of a tunnel agricultural greenhouse. The study focus on the use of the data climate analysis to predict the outside needs as comparison with another without storage system. The obtained results indicate that the outside needs are less than the no heated with 3 to 5°c during winter night. The thermal behavior of the greenhouse was study numerically and the results are corroborating with the literature. In addition, we conducted a comparative study designed to identify the optimal form of the greenhouse; two geometrical configuration are considered.

1 Introduction

The greenhouse is a production tool used to create artificially a microclimate to promote growth and development of culture. By its presence, it protects vegetation from blows due to changes in climate factors [1]. The main greenhouse environmental factors, which are different from the outside, are temperature, light and humidity. Each of these factors is conditioned in the greenhouse, by its level outside the enclosure, by the properties of the roofing material and by the characteristics specific to this greenhouse [2-3].

Tunnel-type plastic greenhouses are widely used around the world, especially in the Saharan countries because of their low investment cost [4].

These are efficient in winter and spring, where solar energy is useful and sufficient for greenhouse production. On the other hand, these greenhouses lose their effectiveness in summer where, the climate is very hot, which causes excessive overheating and strong hygrometries inside [5].

These extreme weather conditions affect the quality and quantity of the product and promote the development of certain diseases. On the physical plane, the greenhouse is a complex energy system in which all the different modes of thermal and mass exchange . If

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they are relatively simple and well known, their coupling causes difficulties in the modeling of the system [6-7].

In this system, natural convection is a particularly important mechanism for heat exchange between indoor air and all other solid surfaces (floor, walls, roof, culture, air conditioning and heating systems)[8].The aim objective of this study consists predict the storage system effect at the thermal behavior of an agricultural greenhouse in semi-arid climate . The study base on the use of the date climate to ameliorate the efficient of the production in this region with excess temperature. The outline of paper is: We start by an introduction; the potential solar is treated in the second parts. The third parts reserved to the description of the experiment. In fourth parts, we interpreted the results and discus and we finish by a conclusion and some perspectives.

2 Description of the experimental potential solar energy area study

In this study, experiments were carried out in two greenhouse at the Applied Research Unit on Renewable Energy at Ghardaïa from Algeria.Around of 77% of Algerian area presented arid and semi-arid regions. The characteristics of this region (Ghardaïa) are:

- Location 595Km south of the Mediterranean sea
- Latitude and 32°36 N
- Longitude3°80E
- Altitude of 469 m above the sea level
- Rate of sunny days per year: 77%
- Annual daily average of global solar irradiance about 7 kWh/m^{2}at horizontal surfaces.

Fig.1 show the variation of the average monthly global solar radiation in a period of 2016 [2-3].It can see that the global solar flux has the same trend of variation as the ambient temperature Fig.2 [1]. It is observed that the peak of average monthly radiation is registered in May, June, July and august (6000W/m^2) with a highest monthly ambient temperature surrounding 38°C. The least average monthly radiation is 2900W/m^2 with a monthly ambient temperature around 10° C in January and December. Figs.3and 4 gives the variation of the   instannious monthly ambient temperature and relative humidity in four season of period of 2016. We can see that the ambient temperature passed the 40°C in august where the relative humidity passed 85% in January. An experimental study has carried out during the month of January 2016, which is the winter season.
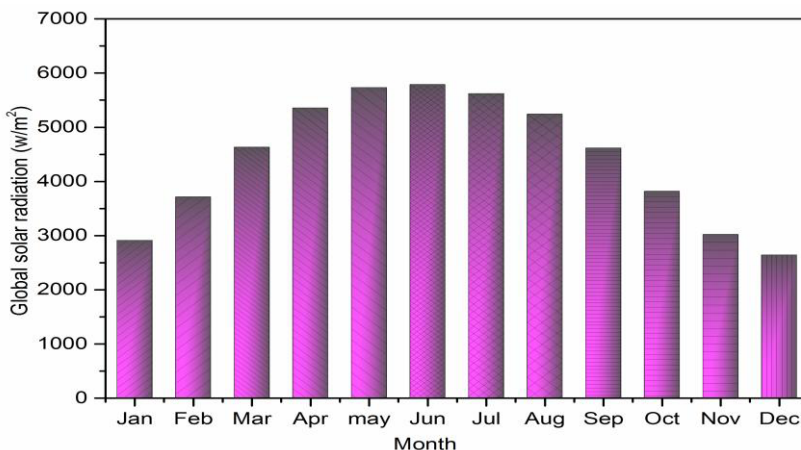
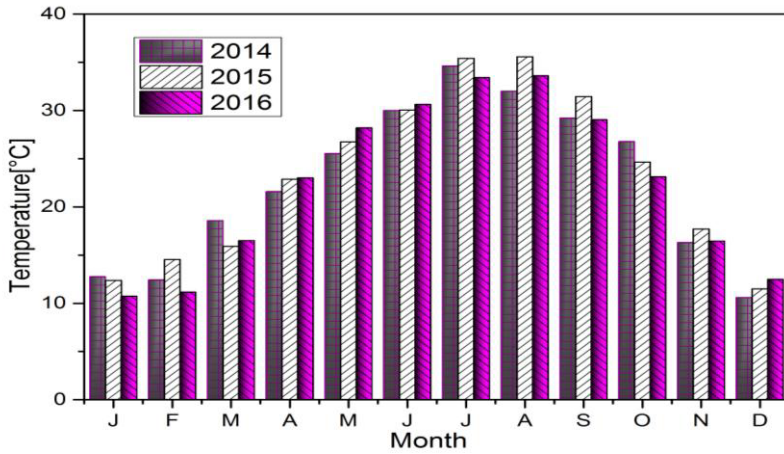**Fig. 1.** Monthly variation of the global solar radiation for the year 2016 in Algeria.

Fig. 2. Monthly variation of the mean ambient temperature in three years at Ghardaïa.
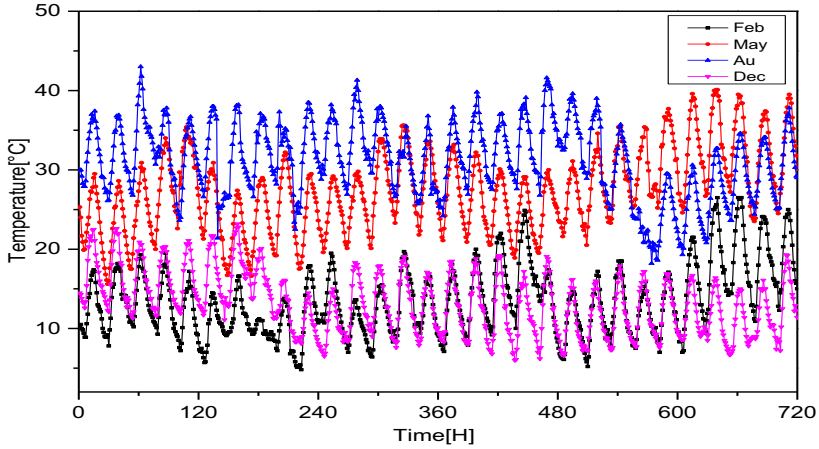
Fig. 3. Instannious temperature evolution in four month Feb, May, Aug and December2016.
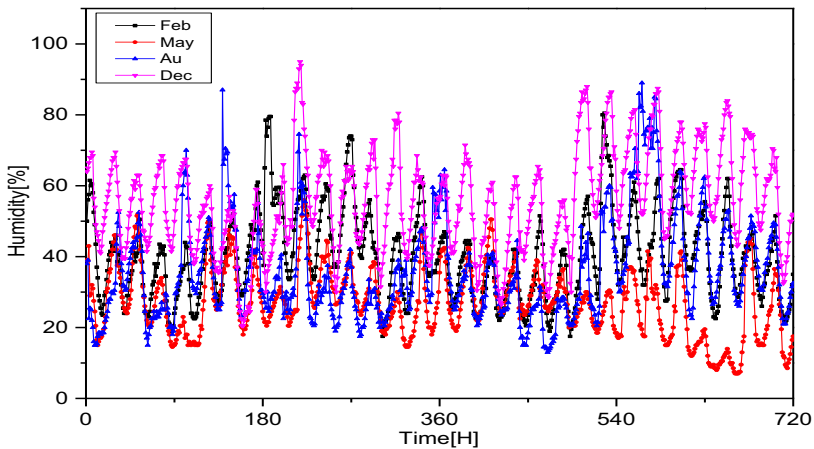
Fig. 4. Instannious relative humidity evolution in four month Feb, May, Aug and December 2016.

2.1 Experimental investigation

The two tunnel greenhouse test bench complete occupied and without storage system are shown in the Fig.5. It has a height of 3m, 25m of length and 8m of width, which leads to a volumetric of 528m^3.The greenhouse has a north-south direction, with optimal deviation angle of 32° to the West. It has doors (opening) at the side walls create for ventilation [11-12]. The polyethylene covers the experimental greenhouse with a low density, extensible and a 0.18 mm thickness. Polyethylene had a low and diffusion temperature respectively about -110°C   and140°C.

Fig. 5. The two greenhouses test facility in URAER

2.2 Description of the storage system

Design steps of thermal storage system are presented in the Fig.6 and 7.It consists of the following parts:

- Four (4) PVC cylindrical pipes of 200 mm of diameter, implemented on the H position form.
- These pipe fields by stones
- Stones having 50 to 100 mm of approximate diameter.
- The storage system implemented about 0,70m away from the depth.

Fig. 6. PVC pipe rumpled with stones

Fig. 7. PVC Emplacement

3 Experimentation and results

In the two greenhouses with and without storage system, courgettes plants are transplanted on the 27 th of December 2017 and the harvesting started on the 14 th of March 2018. The major environmental factors that affect the growth and the precocity of the production of greenhouse plants are temperature, light and humidity. The courgettes plants have two optimum temperatures, one during the day; which varied between 24 and 32 °C, and the other nocturnal temperature that is the most crucial temperature varied between 16 and 19 ^{0}C. A courgettes crop (local variety) was planted in both greenhouses, planted at 20 plants in the row, and arranged in (8) eight rows with 30 cm between the rows and 20 cm between the plants. During the growing period, the January has the least average monthly radiation is $2600W/m^2$ with a monthly ambient temperature around 10°C (Fig.2 and 3).

The heating requirements of both greenhouses with and without storage system at night, are shown in Fig.8 with a set temperature point of 17 ° C (required temperature for plants at night our case courgettes).

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.
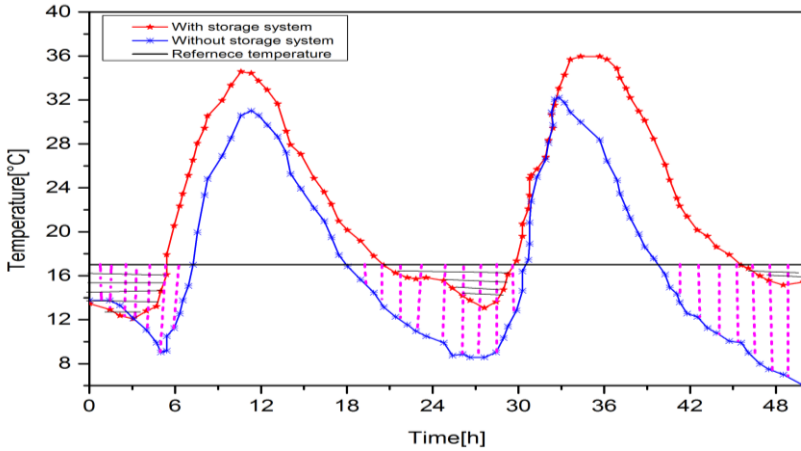
Fig. 8. Temperature evolution at night of both greenhouses (heating requirement).

4 Numerical study

The aim objective of this investigation is to study the air behavior evolution inside the heated greenhouse without vegetal cover by comparison with an author chapel greenhouse. The Ansys software 16.0 code used. Flow considered laminar in two-dimensional along x and y, where the Physical properties of air supposed constant, except its density (ρ) whose variation was given by the Boussinesq approximation [13-14-15-16]:

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

4.1 Geometrical configuration

Geometrical configuration with all boundaries condition considered in this study showed in the Fig.9.
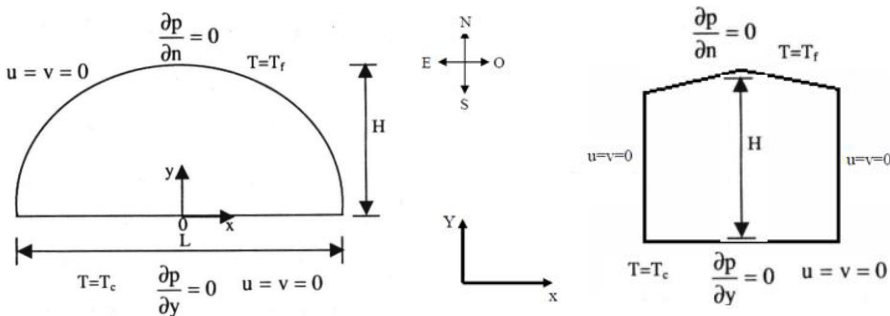

Fig. 9. Problem Position and boundary condition for tunnel greenhouse

4.2 Simulation results

Streamlines and isotherms for different Rayleigh numbers (Ra) are shown in Fig.10 and 11. Fluid flow intensifies and natural convection increases and predominates on conduction.

The heated air particles at ground level rise along the wall then, cooled particles in contact with roof goes approximately to the author walls. The influence of Rayleigh number on the streamline (top the fig.10 and bottom the fig.11) and the isotherms (bottom of the Fig.10and top of the Fig.11) is illustrated. With different Rayleigh numbers the flow characterized by two air circulation loops in both cases. For small Rayleigh numbers (between Ra = 104 to 105), the isotherms are parallel. This representation indicate that the heat transfer dominated by conduction.

When the Rayleigh number increases, isotherms becomes more and more wavy and transfer heat exchange was more pronounced in the two cases, tunnel and chappel greenhouse. As this obtained result, fluid flow intensifies and natural convection increases and dominates conduction. The heated air particles at ground level rise along the wall. Then, the cooled particles in contact with the roof flow approximately a median plane.
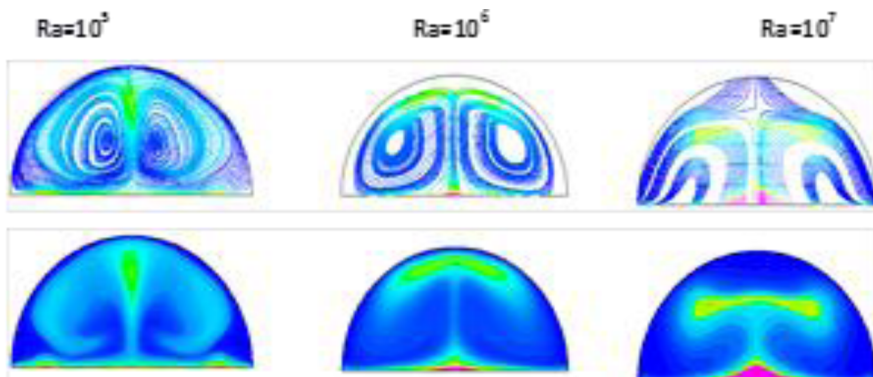

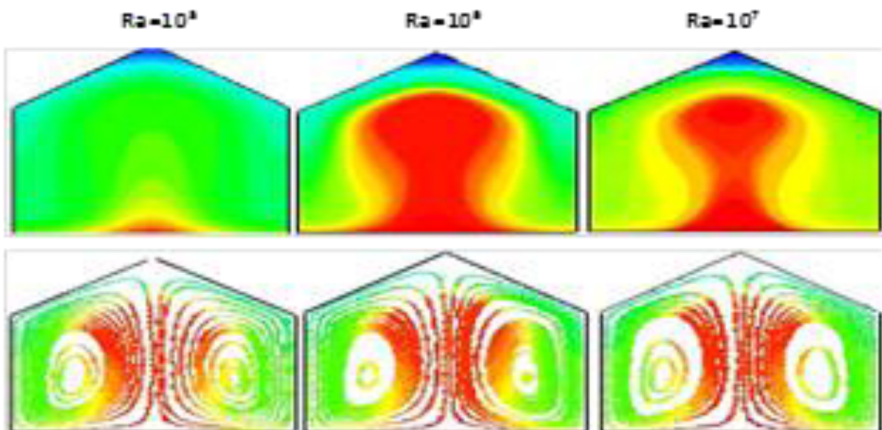**Fig. 10**. Isolignes and isothermal evolution in tunnel greenhouse

Fig. 11. Isolignes and isothermal evolution in Chappel greenhouse

5 Rayleigh number Effect's at the heat transfer exchange

The exchange heat transfer evolution in the both proposed geometrical configuration of greenhouse for different Rayleigh numbers represented by the local Nusselt number in Fig.12 and (13).Therefore, the logic was respected as long as there is a concentration of isotherms at the corners (ground), which explains a large number of Nusselt. It was found

that for a small Rayleigh number varying between 10^4 to 10^5, the Nusselt number of is small and it is the conduction that dominates. With increase of Rayleigh number, the exchange rate increases and the local Nusselt number becomes important in the tunnel compared with the chappel greenhouse. The rate transfer represented according to the mean Nusselt number Fig.14. It can be see that the tunnel is higher losses compared to the chappel. Finally, from these results; we can observe the good according between the literature and the present work for different Rayleigh numbers.

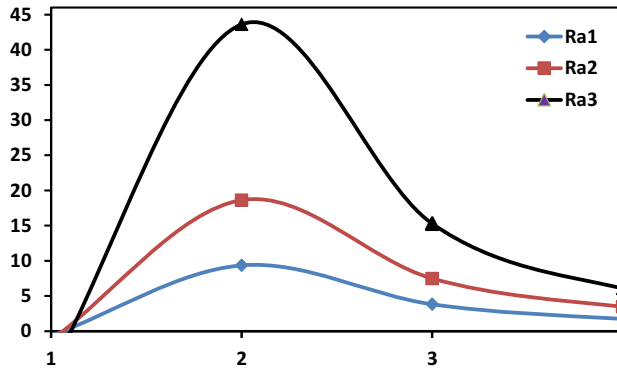**Fig. 12**. Local Nusselt Number evolution in tunnel greenhouse at three values of Rayleigh number Ra=10^5, $10^6$and 10^7
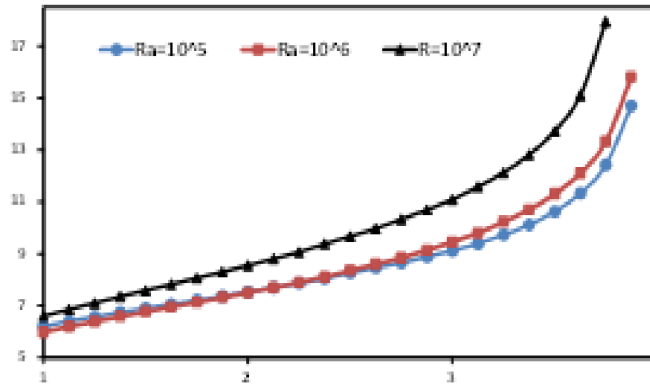

Fig.13. local Nusselt Number evolution in Chapel greenhouse at three values of Rayleigh number Ra=10^5, $10^6$and 10^7
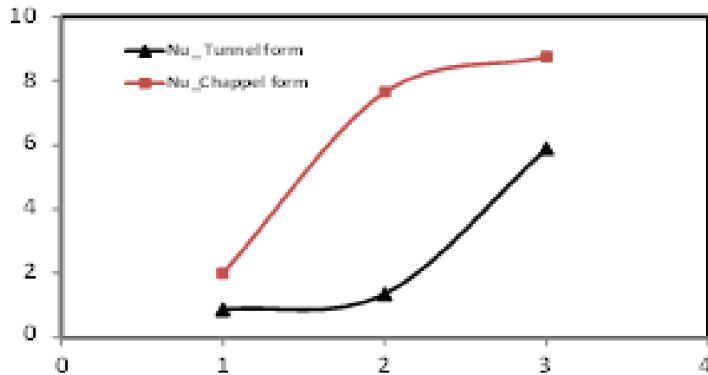
Fig.14. Mean Nusselt number evolution in tunnel and Chappell greenhouse

Conclusion

Our objective was to study the storage system effects and the air behavior inside the greenhouse.The thermal performences of the heated grenhouse are ameliorated with outsit needs between 3 to 5 °C.Numerical similation was conducted to predict the air behvior inside the grenhouse by the spatiotemporal distributions of isolignes and isothermal.We have also shown that for the conditions imposed on the 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 storageand geometrical configuration.

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Nomenclature

Ra   *Rayleigh number*
Ra   *Reynolds number*
Nux *Local Nusselt Number*
Num Mean Nusselt Number
Pr   *Prandtl number*
Re   *Reynolds number*
Pvc   *Plastic pipe*
I_t *total solar radiation (W=m2)*
A   *surface area (m²)*
m   *mass(kg)*
Q   *heat rate (W)*
t   *time (s)*
hi   *Convective heat transfer*
coefficient between liquid and
P   *Pressure (pas)*
Cp   *specific heat of air at constant*
pressure (J/kgK)
T   *Temperature*
U   *velocity (m=s)*
V   *volume (m^3)*
Y   *depth of soil (m)*
M   *mass flow rate (kg/s^{-1})*
D_0 *Diameter (m)*
D   *diffusion coefficient*

Exposants

Cd   *conductive heat*
Cv   *convective heat*
L   *latent heat*
R   *radiation heat*

Subscript

Max   *maximum*
Min   *minimum*
H   *heat gain*
A   *absorbed*
a   *ambient*
co   *cover of greenhouse*
b   *bottom*
e   *edge*
to   *top*
pol   *polyethylene*
av   *average*
inl   *inlet greenhouse*
in   *inside greenhouse*
out   *outside greenhouse*
so   *soil*
sts   *storeg system*

Greek Symbols

ε   *emissivity*
Δ   *difference in time*
λ   *Thermal conductivity (W/mK)*
α   *thermal diffusivity*
μ   *dynamic viscosity (Ns/m^2)*