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Analysis of thermal performance of an agricultural greenhouse heated by a storage system

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ABSTRACT

This work consists to study the storage system effect on thermal performance of an agricultural greenhouse in semi-arid climate case Ghardaia. The data climate is used for predict the energy needs as comparison with another without storage system. The obtained results indicate that the outside needs are less than the not heated with 3 to 5°C during winter night. Were the product rate being 2kg/day. The thermal behavior of the greenhouse was study numerically and the results are corroborating with the literature.

1. INTRODUCTION

As can be supposed an essential captor of solar energy, greenhouse at Algeria has achieved great success with using in agricultural. It can increase outputs of corps and prolong growth period [1].

Greenhouse is usually structured with steel skeletons, walls and roof covered by transparent material, and its covering area is about 50–200m^2. In south Algeria, the polyethylene greenhouse is mostly of tunnel or mono chapel type without walls. Energy inside it (greenhouse) mainly comes from solar radiation [2].

In the daytime, the temperatures of soil and the air inside greenhouse increase as the energy from solar radiation accumulated and stored [3].

With thermal curtain storage system helps greenhouse is able to maintain proper temperature at night. Through insulation and ventilation conditions greenhouse can keep favorable growing in autumn, springer and summer [4].

The temperature inside greenhouse can reach over 50 °C in high temperature season during day, therefore it be required the proper ventilation [5-6]. It's (ventilation) also needed to evacuate harmful gas in cold season. The temperature inside greenhouse is too low for corps to grow in winter. To maintain favorable growing conditions; some heating measures are used such as oil (gasoil) furnace.

Many researchers have developed different mathematical models descripting the mass and heat transfer process in greenhouse and including exterior parameters like as solar radiation, temperature and wind speed and so on Boulard et al.

Some researchers have investigated to develop the mathematical models descripting the mass and heat transfer process in greenhouse [7-8].

Greenhouse combined with earth tube heating, movable thermal curtain, phase change and solar collector is the min few researches found at now [9-10].

In the present work, a new idea that can store excess temperature in the daytime and provide heat by earth tube field with stones at night was proposed and applied in a tunnel polyethylene greenhouse.

In this work, greenhouse integrated with energy storage, for heating the greenhouse at night and in winter was investigate. We used storage tubes filled with stones to store energy absorbed by greenhouse at a semi-arid climate case Ghardaïa.

2. DESCRIPTION OF THE EXPERIMENTAL GREENHOUSE

The experimental greenhouse has a 176m^2 surface area. It locates at the Applied Research Unit on Renewable energy Ghardaia 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
- Longitude 3°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.

The geographic situation of the Ghardaïa province area colored with red in the map of the Figure 1.

Figure 1. Geographic situation of Ghardaïa

The two tunnel greenhouse test bench complete occupied and without storage system are shown in the Figure 2. 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].

Figure 2. The two greenhouses test facility in URAER

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 and 140°C.

3. DESCRIPTION OF THE STORAGE SYSTEM

The thermal storage system with design steps presented in the Fig.3. 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.

Figure 3. Storage system and its design steps

4. OUTSIDE GREENHOUSE MEASUREMENTS

The outside climatic parameters, global radiation, temperature, relative humidity, pressure and air velocities measured by metrological installation.

4.1. Radiation components

In Fig. 4, we plotted the global, direct and diffuse solar radiation at horizontal surface in a clear day. We can see that the luminous power increases from sunrise until reaching a maximum value of 1000 W / m^2 at about 13h. After this, as the sun continues its trajectory by lowering on the horizon, the angle of incidence increases, which is accompanied by a decrease in the intensity of the luminous flux received at ground level.

The direct irradiation decreases progressively until a zero value and is reached at about 17:50 local time. The evolution of diffuse radiation uniformly distributed around the 130W/m^2, or 18% of the global radiation. The superposition of the direct and diffuse components at the horizontal surface of the flux solar radiation gives the global radiation.

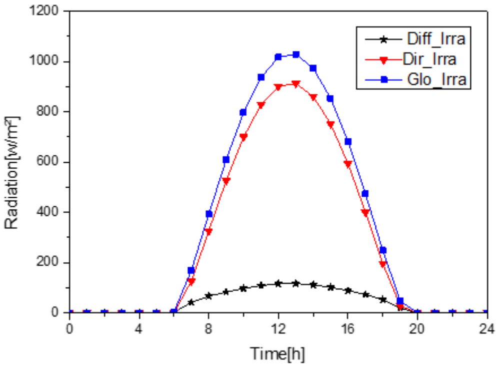

Figure 4. Evolution of different components of horizontal radiation

4.2. Temperature, pressure and relative humidity

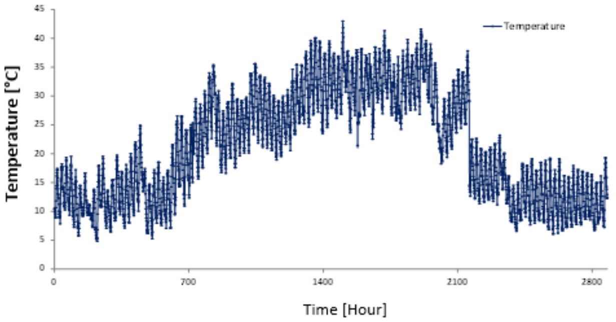

Figure 5. Instantaneous temperature Evolution measured at Ghardaïa at four seasons

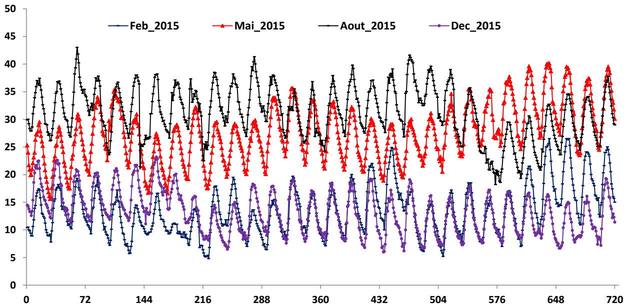

Figure 6. Evolution of Instantaneous temperature measured at Ghardaïa at different months

In this section, we presented the temperature evolution outside greenhouse in four periodic seasons of year. Figure 5. shows the instantaneous temperature evolution during 2800 hours equivalence of four periodic consideration seasons. We can see that the maximum values may have passed 40 °C. In Fig. 5, we present the detail of the temperature evolution in February, May, August and December 2015. It can be seen that the temperature can be attains 45°c in august.

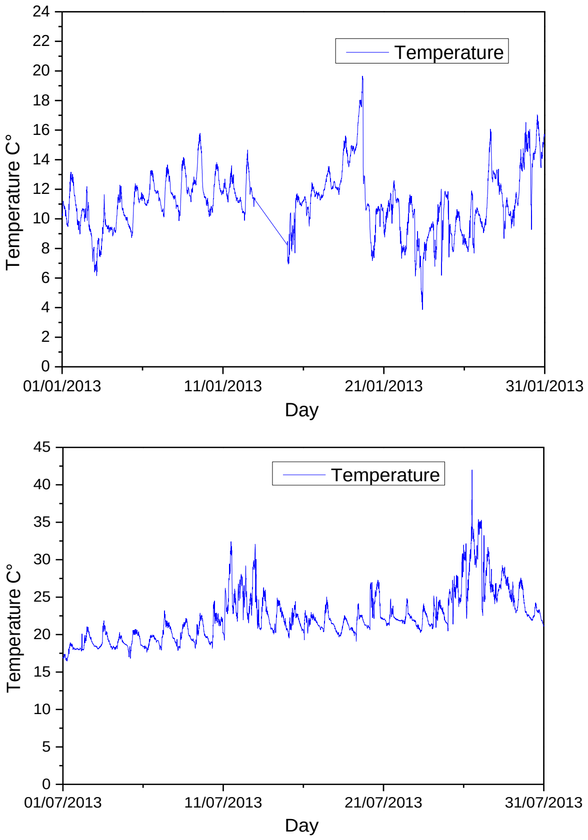

Figure 7. Instantaneous temperature evolution at Ghardaïa measured at January and July

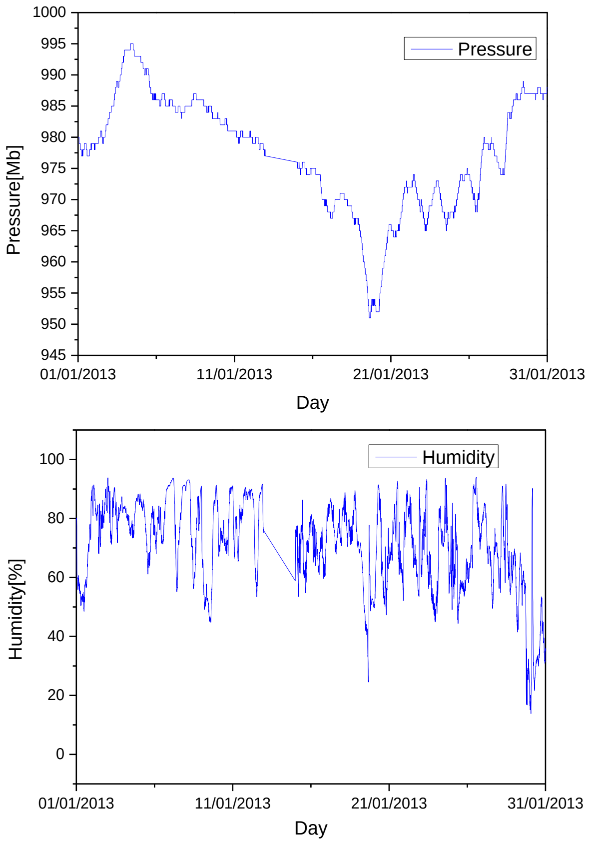

Figure 8. Instantaneous evolution pressure and relative humidity at Ghardaïa measured at January and July

As comparison with past years, we also plotted the temperature evolution during January and July 2013, Fig.7. The temperature in July can passed 42°C, when on the other hand in January does not exceed 20°C.

Fig. 8 shows the pressure and relative humidity evolution in low periodic temperature especially in January; they have large values.

5. INSIDE GREENHOUSE MEASUREMENTS

5.1. Global radiation

Fig. 9 shows the global at inside and outside the greenhouse radiation in a clear sky day. The transmission coefficient of the greenhouse cover can be calculated and deduced through the total energy flux transmitted to the measured outside the greenhouse. We can observe that the transmissivity coefficient is weak at the beginning of the day then progressively increase as day progresses to attain 0.75.

It observed that the transmissivity is weak at the beginning of the day and then progressively increases as the day progresses to reach a value of 0.75. This corresponds to an increase in overall illumination. The condensation phenomenon will therefore gradually diminish until it disappears.

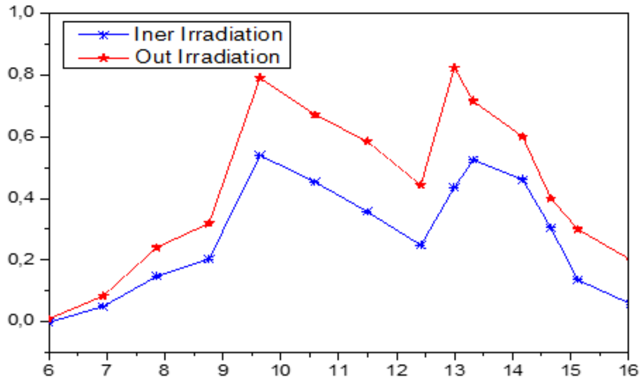

Figure 9. Measurement Irradiation iner and out greenhouse at time

5.2. Temperature and humidity

The main parameter measured in our study is the temperature inside the greenhouse for several solicitations. The thermocouples placed on the same vertical axis, at the soil, vegetal cover, and above Fig. 10. In this context, we propose to plot the temperature profiles correspond to the first two positions Fig.11.

The obtined results indicate that the curves follow the same trends whatever the height and with a generally low gap.

The Stratification phenomena of air temperature are not as important. For this reason, we assumed that the temperature distribution in greenhouse is almost uniform. It noted that the curves have almost the same shape with smaller deviations according to the surface states (absorptivity, reflexivity and emissivity) the temperatures at soil are generally greater than the plants. The maximum deviation can reach 5.5 ° C. It should be noted that sometimes the temperature of the soil becomes lower compared to the plant temperature of the; this is certainly due to irrigation. This operation carried out on the day itself between 7:00 and 11:00.

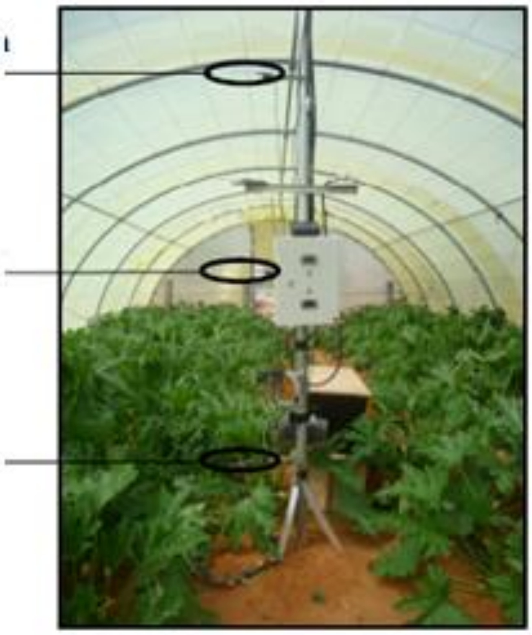

Figure 10. Selected measurement positions

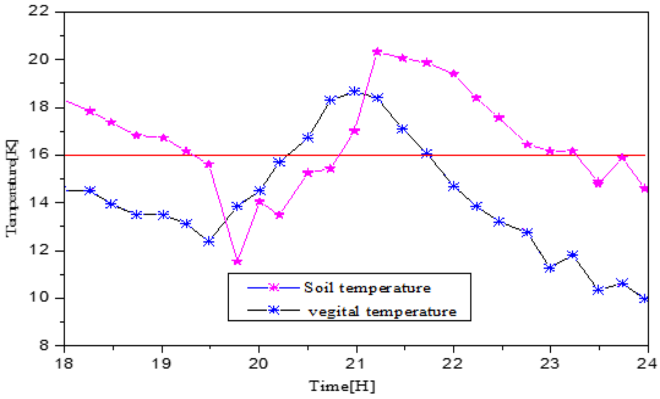

Figure 11. Temperature evolution at different position

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.

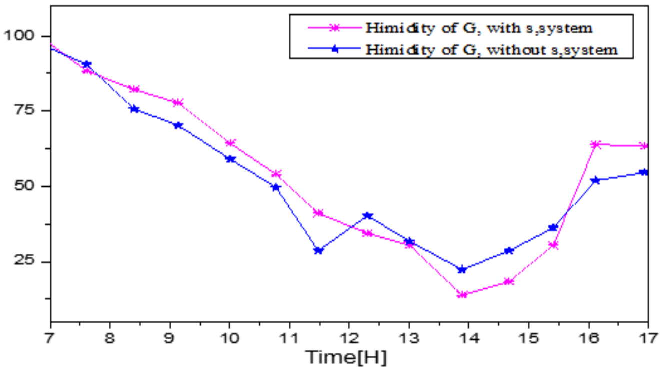

Figure 12. Measurement humidity in both greenhouses [%]

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.

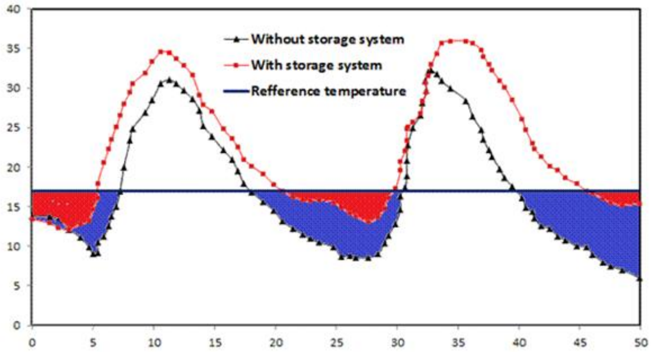

Figure 13. Heating needs of both greenhouses

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.

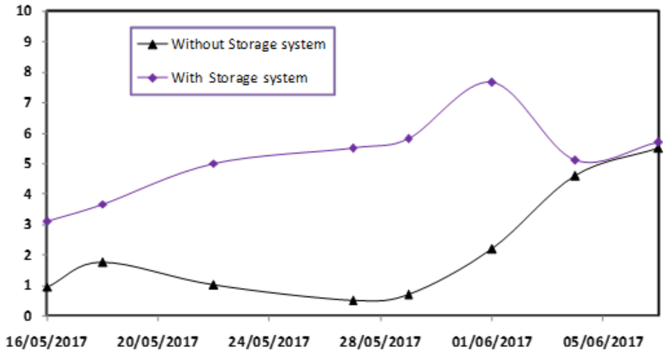

Figure 14. Production in both greenhouses

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.

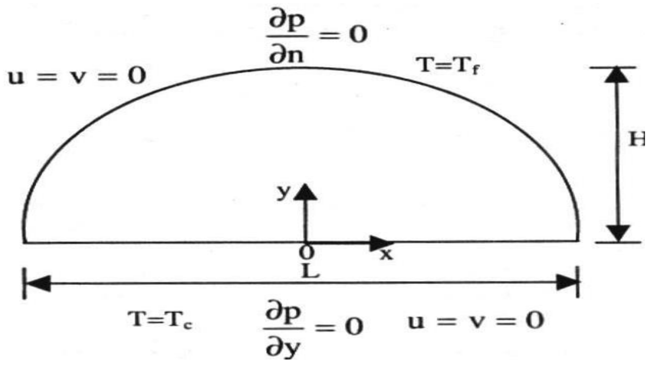

Figure 15. Geometrical configuration

6.2. Numerical results

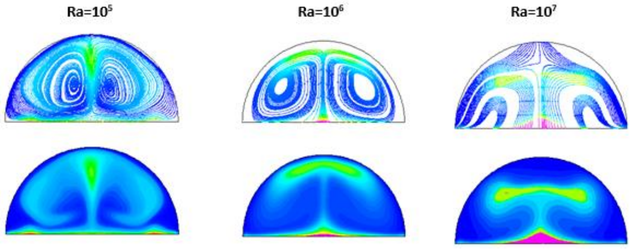

Figure 16. Isolines and isothermal of heated greenehouse

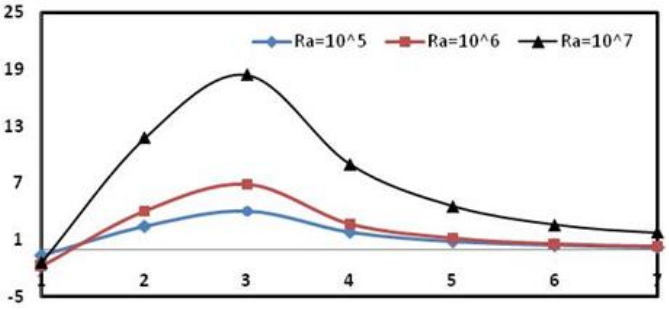

Figure 17. Local Nusselt number for different Rayleigh number

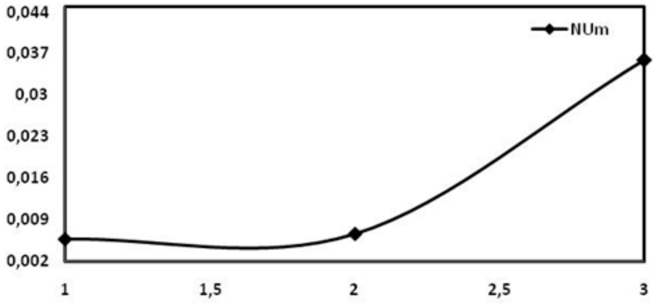

Figure 18. Mean Nusselt number

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*