Investigation note

Study of strategies for climate management in low-tech greenhouses in hot climates

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Abstract

In the present work, the study of the effect of shading and ventilation as strategies for microclimate management in low technology greenhouses in the Irapuato region of Guanajuato is exposed. By means of the measurements of the climatic variables of global solar radiation, temperature and humidity of the air, the transmittance of the greenhouses was determined, which were of τ= 0.56 for the greenhouse without liming and τ= 0.26 and τ= 0.14 for the shaded greenhouse by liming and thermal meshes. The rate of air renewal was determined and it turned out that an exchange of N= 59.4 h^{-1} is adequate for the regulation of temperature. It was concluded that shading has little influence on the behavior of the temperature and humidity of the air inside, while the overhead and lateral ventilation is decisive for the regulation of the microclimate.

Keywords: protected agriculture, liming, shade, ventilation rate.

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Introduction

A greenhouse is a closed structure, covered by a transparent material, capable of modifying the external environmental conditions and creating artificial microclimate conditions in the interior where a crop is usually found, so that it can develop its maximum productive potential, even out of season (Baile and González, 2001; Castilla, 2007). However, these conditions are not achieved naturally, there are many factors that intervene directly and indirectly, among those that most influence are: the natural climate of the place (external environment), the constructive characteristics (design of the structure), the type of crop and its degree of development and other variables, which in their interaction provide the thermal and humidity behavior of the air and together with the new techniques of climate control to act and in time on the elements of the climate that have the greatest influence on the development of the vegetables, the optimum conditions that the crops require to obtain good yields will be reached (García and Martínez, 2015).

In the case of low-tech greenhouses, heating systems and air humidification are not available, so, during the day, the thermal behavior and humidity of the air depend completely on the solar radiation, on the crop evapotranspiration and of air renewal by natural ventilation (Wang and Boulard, 2000; Baille and González, 2001; Boulard *et al*., 2002). For climatic conditions of the sub-humid semi-warm type of the Irapuato region (INEGI, 2000), the greenhouses present problems such as high solar radiation, high temperatures, low relative humidity during the day and high relative humidity at night and at dawn and for course, limited carbon dioxide concentrations, which makes the microclimate conditions are not the most appropriate for crops.

High-level technology is still out of reach for most producers, as it involves high investment costs and technical know-how, which, with the modest capacity of farmers, is limited. A simplified thermodynamic model, which helps to understand the behavior of a greenhouse, is shown by a pair of equations:

$$V{}^{\circ}c_p \frac{dT_i}{dt} = {}^{2}A_s R_e - UA_c\left(T_i - T_e\right) - {}^{\circ}c_p VN\left(T_i - T_e\right) - {}^{a}ET \qquad 1$$

$${}^{\circ}V \frac{dw_i}{dt} = -{}^{\circ}VN\left(w_i - w_e\right) + ET \qquad 2$$

Where:

V- greenhouse volume, m^3
ρ- average air density, kg/m^3
N- rate of air renewal in the greenhouse due to ventilation, 1/s
ET- evapotranspiration inside the greenhouse, kg_w/s
T_i- temperature of the air inside the greenhouse, C
T_e- air temperature outside, C
A_s- floor area covered by the greenhouse, m^2

τ- greenhouse transmittance
R_e- global radiation abroad; W/m^2
U- overall coefficient of energy loss per roof, W/m^2 C
A_c- roof area, m^2
C_p- specific heat of the air, J/(kg °C)
W_i- humidity ratio of the air inside the greenhouse, kg_w/kg
W_e- humidity ratio of the air outside the greenhouse, kg_w/kg
λ- latent heat of water vaporization, J/kg.

It is observed that, to modify the temperature and humidity of the interior air of a passive greenhouse, ventilation can be actuated, which allows the renewal of interior hot air by cooler air from the outside. This is achieved by means of permanent or temporary openings in the roof, in the lateral or frontal walls (Boulard *et al*., 2002; Castilla, 2007), but when the climatic conditions of the region are not favorable, these actions do not help much. Several studies have also shown that another option to control high temperatures is to reduce the intensity of solar radiation that enters the greenhouse by shading with thermal screens, shading meshes or liming (Caldari, 2007; Meca *et al*., 2007), that along with ventilation, you can improve the microclimate conditions.

In view of this situation, the interest to study the effectiveness of shade and ventilation as strategies for the management of the climate of the most common greenhouses in the region of Irapuato, Guanajuato arises. This will allow decision making regarding its management, to select the air conditioning equipment and adapt the most appropriate technologies for each type of greenhouse and each crop, generating a microclimate with the minimum investment in energy.

Materials and methods

The study was carried out in two typical greenhouses of warm regions, located in the region of Irapuato, Guanajuato (20º 40' 27" north latitude, 101º 20' 51" west longitude, 1 720 m), which are curved roof with height to the gutter of 3.5 and the maximum height of 6.0 m (Figures 1 and 2). The cover is 720 gauge white milky polyethylene. Both have zenithal and lateral ventilation of the type of roller blind protected with anti-aphid mesh and manually operated, cataloged as low-tech greenhouses.

Figure 1. Exterior view of the greenhouse without shade.

Figure 2. Whitewashed greenhouse with thermal mesh inside.

The effect of the shading was verified in a whitewashed greenhouse and also with thermal meshes in the interior with different degree of shade. Liming consisted of opaque coating material by adding a lime-based mixture, commercially known as white Spain, whose opacity depends on the dose applied. The greenhouse has a semicircular roof with overhead and lateral ventilation, covered with milky white polyethylene of 70% transmissivity. The microclimate was monitored every 10 min, measuring global radiation, relative humidity and air temperature during the warm months of March to May.

For the measurement of the climatological variables, the historical records of an automatic meteorological station of the Foundation Guanajuato Produce, AC., it was considered with information at intervals of every 15 minutes of the climatological variables of the region: temperature and relative air humidity, global solar radiation, wind speed and direction, atmospheric pressure, precipitation and potential evapotranspiration. The meteorological station is equipped with a CM3 pyranometer of 300 nm at 1 100 nm and a capacity of 1 200 W/m^2. Two portable meteorological stations of the Davis brand model Vantage pro2 Plus were used equipped with a pyranometer with measurement in a bandwidth of 300 nm to 1 100 nm and capacity for 1 200 W/m^2. One station was installed inside the greenhouse and another outside, collecting the data every 10 minutes.

Additionally, temperature and humidity humidity sensors were installed inside and outside the greenhouse, adapted to a Vernier brand data acquisition system with an interface to a PC, with measurement intervals every minute, to later consider an average each 10 minutes. For the determination of transmittance, the definition adopted by the majority of researchers (Montero *et al*., 2000; Baile and González-Real, 2001; Hernández *et al*., 2001), which is the fraction of the radiation, was used. Global solar transmitted into the greenhouse (R_i) in relation to the global solar radiation that hits the surface of the earth (R_e).

$$\tau = \frac{R_i}{R_e} \qquad 3$$

To determine the rate of air renewal due to natural ventilation, the change in water vapor content was considered through a material balance (equation 4), whose solution is given by equation (5) (Baptista *et al*., 1999).

$$\frac{d}{dt}\left(\circ V w\right) = \circ_e V_e w_e - \circ V_s w \qquad 4$$

$$\ln\left(w_e - w\right) = -\frac{V_e}{V} t + c \qquad 5$$

Where:

V_e/V is the ratio of the volumetric flow that enters the total volume of the greenhouse, representing the rate of air renewal, N.

w, w_e- is the concentration of water vapor in a kilogram of dry air (kg_w/kg) that exists in the greenhouse and outside, respectively, in a given time *t*.

When doing the linear regression on a semi-logarithmic graph with the measurements taken, the slope of the line will represent the relation N= V_e/V and then the airflow due to ventilation can be determined.

Results and discussion

Ventilation is one of the most important means available in a low-tech greenhouse for the regulation of the microclimate, since it favors the exchange of air with the external environment, with which the temperature and humidity of the air are regulated and as a consequence, the concentrations of carbon dioxide and oxygen. In Figures 3 and 4, the conditions of temperature and relative humidity of the air are shown in a completely closed empty greenhouse in relation to the conditions of the air outside. It is observed that the confined air reaches an average temperature of 46.34 °C, when outside, the average air temperature is 25.90 °C, an average temperature difference of 20.44 °C, while the relative humidity in the interior is lower 8%, which the greenhouse converts the external environment from dry warm to a desert type microclimate.

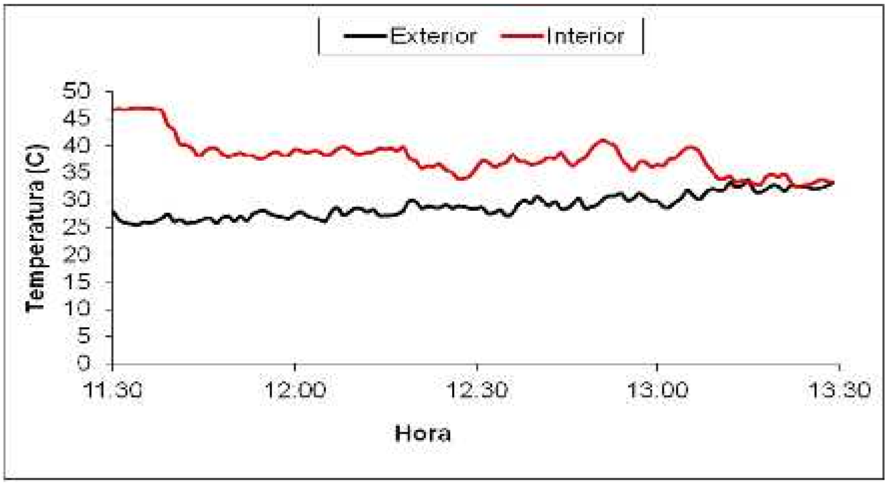

Figure 3. Change of temperature in a natural ventilation process.

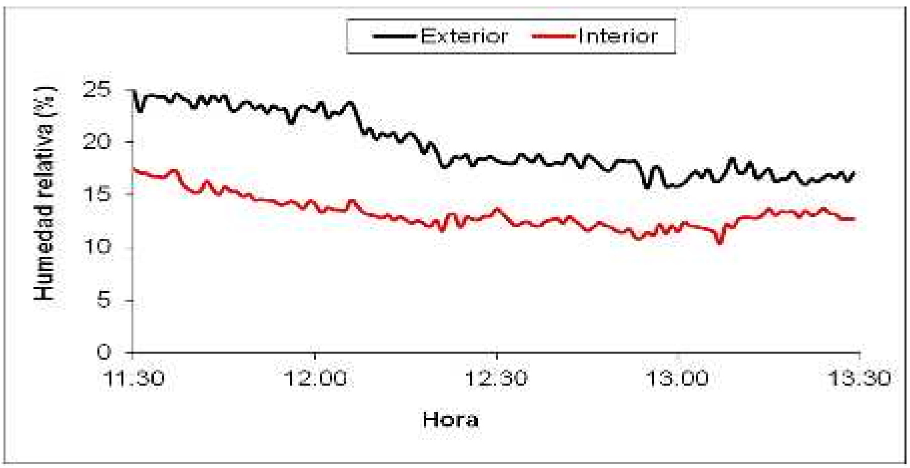

Figure 4. Relative humidity in a natural ventilation process.

Perhaps the absolute humidity (Figure 5) is the most visible parameter in the behavior of the greenhouse before the renewal of the air.

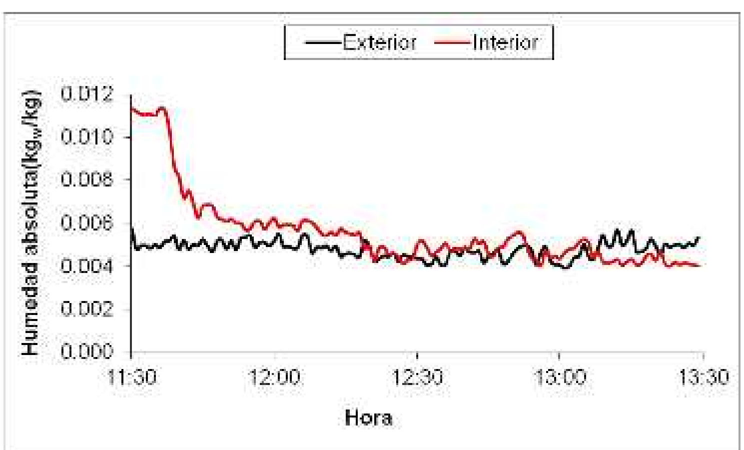

Figure 5. Absolute humidity of the air in a ventilation process.

With the opening of the zenith windows, the flow of air between the interior and the exterior begins, decreasing the temperature and humidity, tending to reach the conditions of the outside air. With an average wind speed of 3 km/h, the air renewal rate is N= 13.68 h^{-1} with a correlation coefficient of data R^2= 0.94. With this ventilation capacity, the difference in temperature between the inside and the outside is ΔT= 11.58 °C on average. For when the zenithal and lateral windows are opened, an average renovation rate of N= 59.4 h^{-1} is reached, with R^2= 0.97 and a thermal jump ΔT= 1.10 °C on average, the conditions of the exterior are practically reached. Ventilation has a great influence on the management of the microclimate of a greenhouse, along with it there will be a supply of carbon dioxide and oxygen with the confined environment.

When the tomato crop is in full production, with a height of 2 m and zenithal and lateral windows are opened, the air exchange is of N= 13.32 h^{-1}, with R^2= 0.96, practically the temperature of the interior reaches to equalize the external air temperature in a period of 4 to 5 min, while the indoor air humidity is higher due to the evapotranspiration of the plants (Figures 6, 7 and 8).

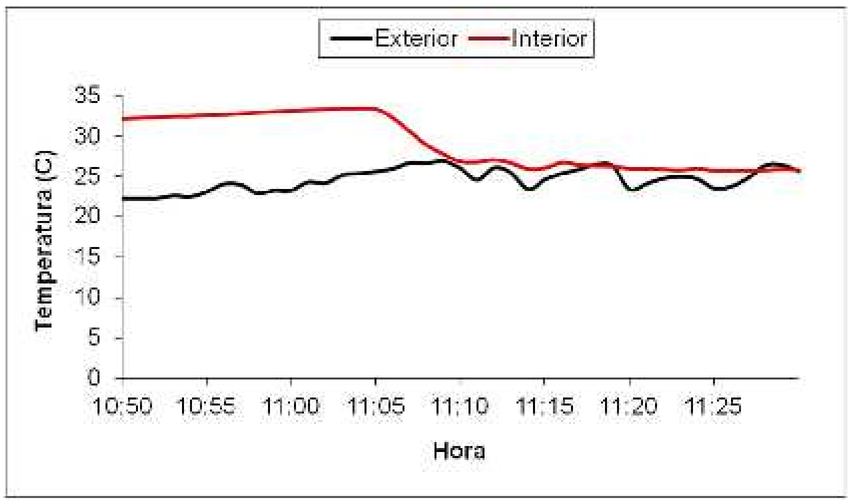

Figure 6. Temperature change with overhead and lateral ventilation.

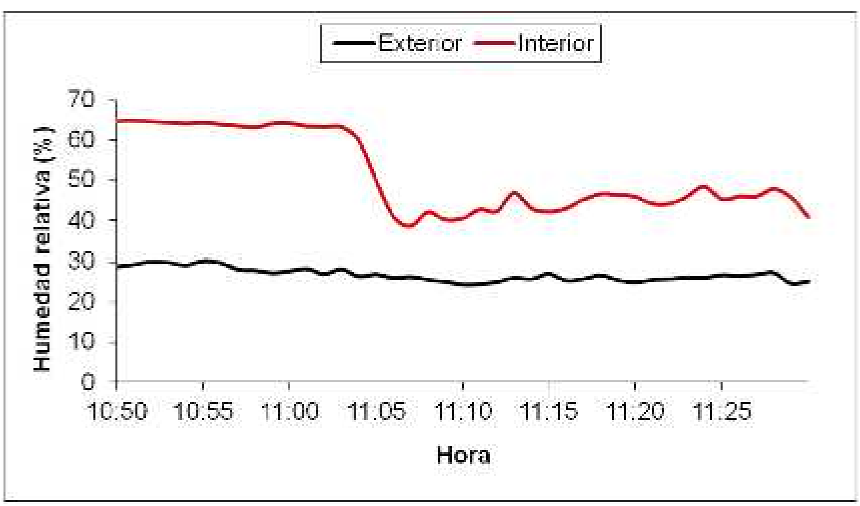

Figure 7. Change of relative humidity with overhead and lateral ventilation.

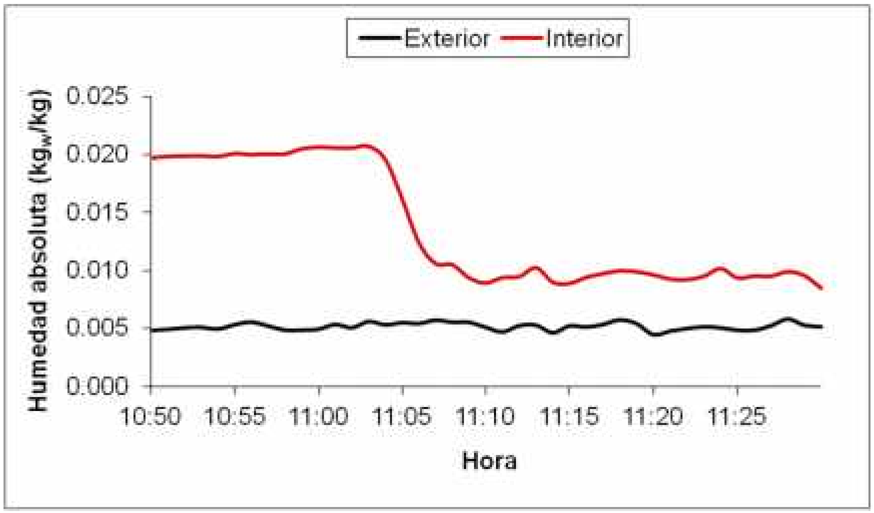

Figure 8. Change of absolute humidity with overhead and lateral ventilation.

In the case of the shaded greenhouse, Figure 9 shows the global solar radiation inside and outside. In the area covered with thermal mesh the average transmittance is τ = 0.26, with a standard deviation of 0.03, while when shading is not applied, the transmittance with the same covering material is τ= 0.56 Flores *et al*. (2012). Support with zenithal and lateral ventilation, a temperature difference between indoor and outdoor air is achieved is ΔT= 2.8 °C with a standard deviation of 1.1 °C. The difference of the temperature of the air between the interior and the exterior is not very significant compared to greenhouse without shade and as it is observed in the relative humidity of the air, the thermal conditions depend more on the ventilation than on the shade.

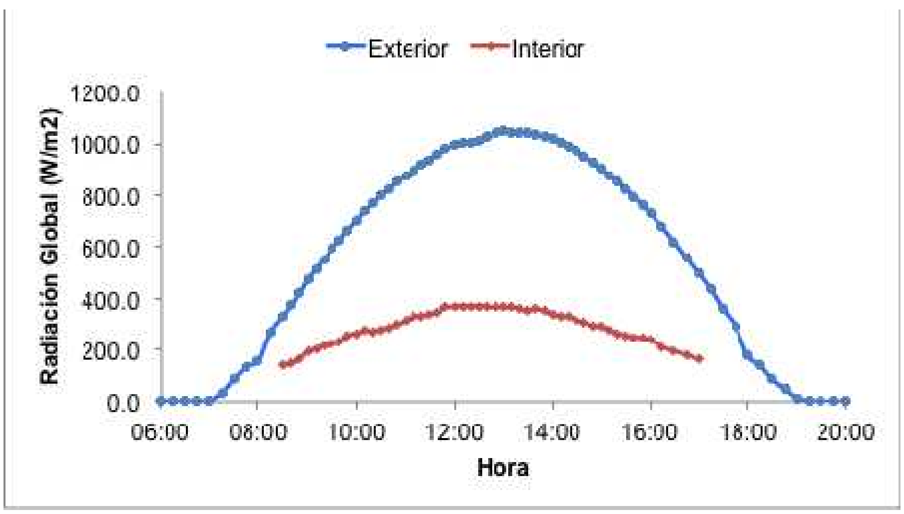

Figure 9. Solar radiation in a whitewashed greenhouse with a thin thermal screen.

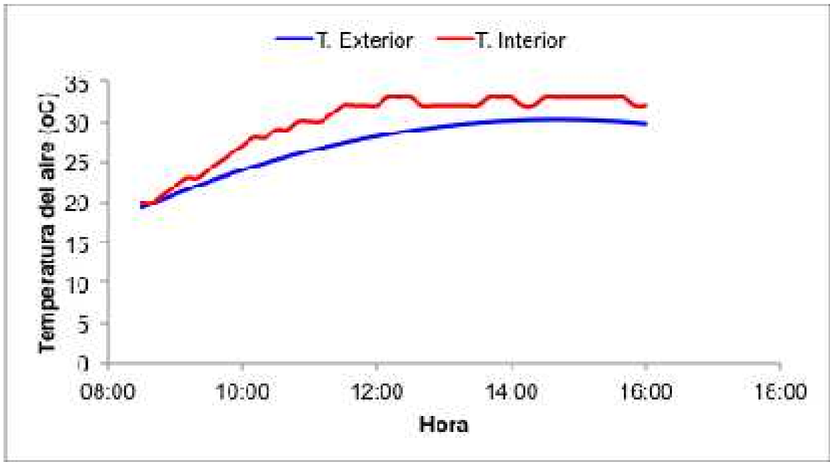

Figure 10. Air temperature in a whitewashed greenhouse with a thin thermal screen.

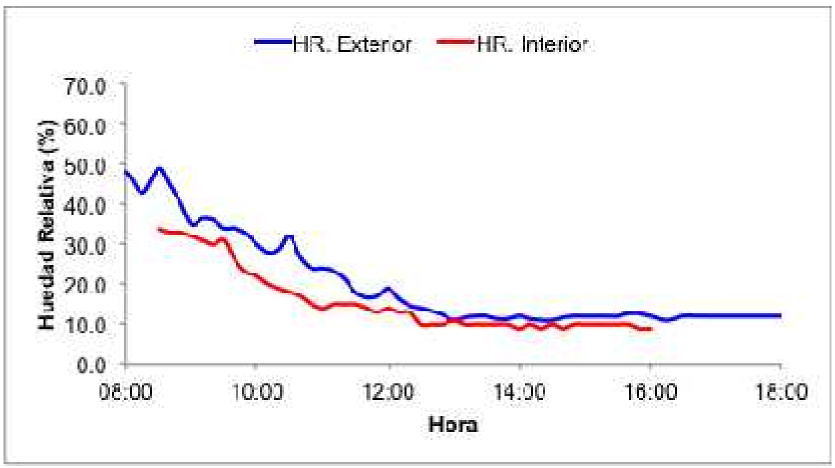

Figure 11. Relative humidity in a whitewashed greenhouse with a thin thermal screen.

In Figure 12, the global radiation in the exterior and interior of the greenhouse is shown in the area with liming and shading with a denser thermal screen with which an average transmittance of τ= 0.14 with a standard deviation of 0.03 is reached.

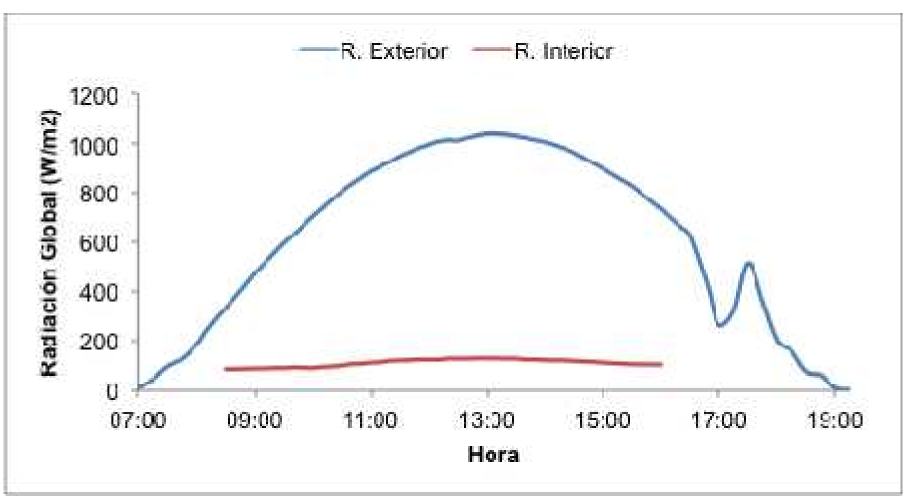

Figure 12. Solar radiation in a whitewashed greenhouse with a thick thermal screen.

In the Figure 13 shows the temperature of the air inside and outside, obtaining a difference ΔT= 3.0 °C on average, with a standard deviation of 1.1 °C and in Figure 14, the relative air humidity conditions are shown in both media, where it is observed that ventilation has more influence on the characteristics of the microclimate compared to shading.

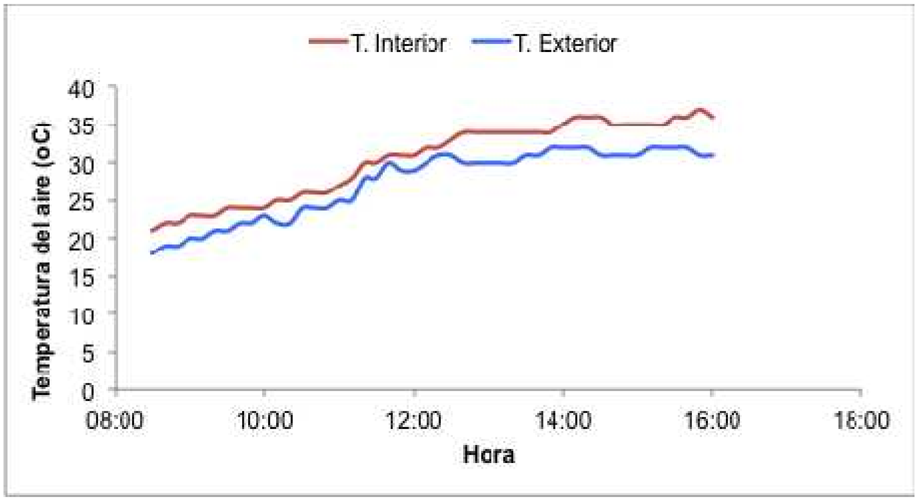

Figure 13. Air temperature in a whitewashed greenhouse with a dense thermal screen.

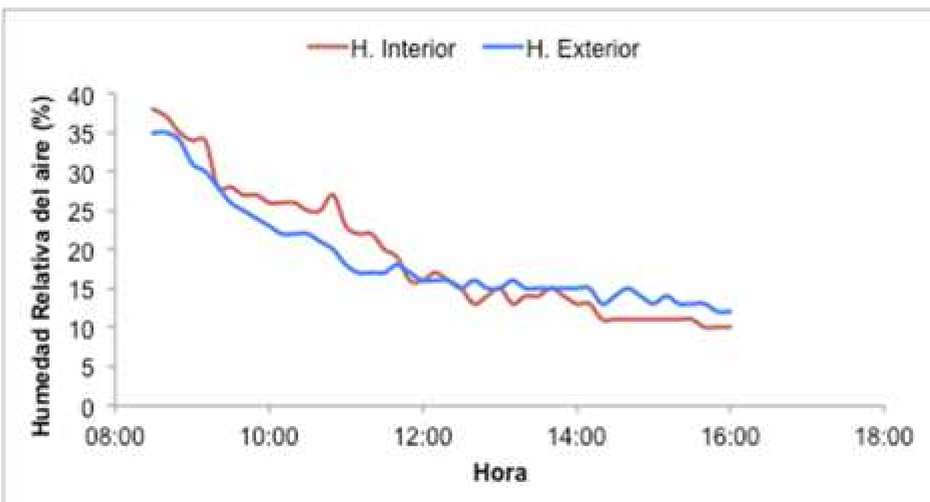

Figure 14. Relative humidity of the air in a whitewashed greenhouse with a dense thermal screen.

Conclusions

For the climatic characteristics of the Irapuato region, Guanajuato, it was observed that the greenhouses with passive climate management with zenith and lateral ventilation, perform adequately. However, when in a natural way, for certain hours and certain seasons, the local climate is not the most suitable for crops, the greenhouse affects this situation a little more, registering higher temperatures and lower humidity contents in the air. which gives the impression that the greenhouse only comes to put the most unfavorable climatic conditions, unless more complex systems are available for the modification of the microclimate, such as evaporation of water by means of nebulization or humid panels and heating, but that already implies expenses additional that the producer is not willing to invest, especially if the destination of production will be directed to local markets.

For this type of greenhouses, the shading does not show many advantages to lower the temperature, the thermal behavior is more influenced by ventilation and evapotranspiration. A suitable roofing material, with a transmissivity of $\tau = 0.70$ and an adequate dimensioning of the lateral and zenith windows, would be sufficient for its operation. For the region under study, low-tech greenhouses perform well during part of spring and autumn, but not for summer.

Cited literature

Baille, A. y González, R. M. 2001. Utilización de modelos para el control y la ayuda a la decisión en invernaderos. situación actual y perspectivas, incorporación de tecnología al invernadero mediterráneo. Estación Experimental “Las Palmerillas” de Cajamar, España.

Baptista, F. J.; Bailey, B, J.; Randall, J. M. and Meneses, J. F. 1999. Greenhouse ventilation rate: theory and measurement with tracer gas techniques. J. Agric. Eng. Res. 72:363-374.

Boulard, T.; Kittas, C.; Roy, J. C. and Wang, S. 2002. Convective and ventilation transfers in greenhoses Part II: Determination of the Distributed Greenhouse Climate, Biosystems Engineering. 83(2):129-147.

Caldari, J. P. 2007. Manejo de la luz en invernaderos. Los beneficios de la luz de calidad en el cultivo de hortalizas. I Simposio Internacional de Invernaderos. México, DF. 1-5.

Castilla, N. 2007. Invernaderos de plástico: tecnología y manejo. 2ª Edición, A. Madrid Vicente, Ediciones.

Flores, O. A.; Martínez, S. G. y Quiroz, R. J. C. 2012. Predicción de la transmitancia de un invernadero con techo removible. Rev. Mex. Cienc. Agríc. 4:743-746.

García, G. F. J. and Martínez, T. J. F. 2015. Control climático en invernaderos y las nuevas aplicaciones. Rev. Agricolae No. 7:52-59.

Hernández, J.; Hernández, G.; Soriano, T.; Morales, M. I.; Escobar J. y Castilla N. 2003. La orientación de un invernadero y la geometría de su cubierta determinan la transmisividad global a la radiación solar. Actas de Horticultura. 39:379-

Meca, D.; López, J. C.; Gázquez, J. C.; Pérez, P. J. y Baeza, E. 2007. Efecto de dos dosis de blanqueo sobre la productividad y el microclima de un cultivo de pimiento en invernadero. Acta de Horticultura. Sociedad Española de Ciencias Hortícolas. 68:884-887.

Montero, J. I.; Antón, A.; Hernández, J. and Castilla, N. 2001. Direct and diffuse light transmission of insect proof screens and plastic films for cladding greenhouses. Acta Hort. (ISHS). (559):203-210.

Wang, S. and Boulard, T. 2000. Measurement and prediction of solar radiation distribution in full-scale greenhouse tunnels. Agronomie. 20(34):41-50

Wu, G. W. and Song, J. N. 2010. Design and experiment on vibration spacing scarifier for meadow. Transactions of the Chinese Society for Agricultural Machinery. 41(2):42-46.

Xin, L.; Liang, J. and Qiu, L. 2013. Dinamic analysis and experimental research of vibratory subsoiler system. J. Theoritical Appl. Inf. Technol. 48(2):1195-1201.

Zhao, D. W. 2010. Research and design of vibrating subsoiler. Agric. Sci. Technol. Equipment. 190(4):29-30.

Zhou, Y. 2009. Ploughing resistance and kinematics analysis of vibration fertilizer discharging mechanism. Modern Agric. Machinery. 10:74-76.