

Full Length Research Paper

Climate characterization and calculation of thermal solar energy for a greenhouse in Aramberri, Nuevo León, México

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The cost of maintaining the suitable climatic conditions for cultivation in a greenhouse depends of the climate zone where it is located. For profitability reasons, in the State of Nuevo Leon the structures commonly used is lightweight such as galvanized steel pipe or wood and as a cover material, the plastic is the most common, resulting in a low insulation from the outside atmosphere. Thus, the expense that has to be done in maintenance, equipment and modifications to the elements on the greenhouse to ensure a climate suitable for the crop, will directly depend of the existing difference between environmental conditions of the outside and those that the crop requires for its correct development inside of the greenhouse. Due to the importance of climate for cultivation, it is necessary to determine the thermal dynamic characteristics for each zone where the greenhouse is located in order to define its climatic attributes. In this work we discuss the climatic characterization of the external environment year-round, as well as in the internal environment for a sampled period, for a greenhouse located in Aramberri, Nuevo Leon, México, under the completely open and completely closed window conditions. As well as the calculation of the energy needed for heat in the winter nights and the calculation of the solar energy that could be used for heating. In addition, the definition of the climate problem in-situ for the critical period of winter is presented. We also include the conclusions and recommendations from the information analysis, marking the importance of determining these kinds of studies.

Key words: Greenhouse, characterization, solar energy, climate zone, Nuevo León, México.

INTRODUCTION

The greenhouses or protected crops are structures that try to obtain an independent climate from the outside which also is suitable for the development of crops. In most of the cases its use is with commercial purposes and the equipment and investments made to build and maintain its operation must be financially profitable. Thus, depending totally of the difference between the desired

internal climate and the existing external climate, the structural form and the use of equipment to control the climate within these structures is limited to mechanisms that do not represent a greater investment in its initial acquisition, as well as in its operational maintenance. Each geographic area has its own climatic features, sometimes changing drastically in a few kilometers. This

can be clearly seen in several areas of the state of Nuevo Leon, where extreme climate predominates (INEGI, 2012; INEGI, 1981), having mainly subtropical climates, where 3 are dry (68.35%) and 3 semi-arid (9.31%) and within them, warm, semi-warm and temperate. We can also find the temperate arid cold environment (Medina et al., 1998; West and Wauchope, 1964).

Thus, in the state of Nuevo Leon, for the municipality of Aramberri the problem is to warm up the greenhouses in the months of winter, opposed as what happens at the municipality of Marin where the problem is to cool them in the months of summer (Leal, 2008). This can be verified when observing Figure 1 obtained from INIFAP (2010), if we consider that the optimal temperature range of some vegetables species is between 15 and 32°C (Monke, 2013; Boote et al., 2012; Kipp, 2009; Muñoz and Castellanos, 2004; Hussey, 1965).

For the abovementioned, it is necessary to carry out a climatic study for the greenhouse, as well as for the geographic zone where it will be located or where is in operation, based in the information of the environmental components that may be collected. Then, a situation analysis will be able to be carried out, determining the requirements and the problems in the current climatic conditions, making a diagnosis of the most appropriate solutions for the zone climatic-greenhouse system. This is only possible when numerical values of the measurements are provided by specialized sensors, which give an accurate scene of the climatic system.

In the month of November of 2010 this type of measurements were made in a greenhouse of the Faculty of Agronomy of the Universidad Autónoma de Nuevo Leon (U.A.N.L.), in the Asención extension, located at the municipality of Aramberri, Nuevo León, México. This sampling was used to analyze the thermal climatic situation of the greenhouse and the location zone. Furthermore, in the sampled period, it was also used to calculate the amount of thermal energy needed to warm up the greenhouse at night, as well as calculating the amount of thermal energy contributed by the sun feasible to be used for heating. With the results, recommendations were established for providing solutions to the climate control inside the greenhouse and avoiding crop loss in adverse climate seasons.

The relationship between heat transfer and thermal dynamic characteristic with growing plant in a greenhouse are expressed through a dynamic model, that including the solar energetic charge in to the greenhouse, its dynamic flux, and the effects on the plants through of crop transpiration and CO₂ used for photosynthesis and respiration. This is considered in the models developed for Leal (2008) and Tap (2000), which are used in this present paper. Moreover, the measurements made in the present research can be used in the future for more accurate decision making about the investment made for acquiring structure and equipment, make modifications

and the use of automated systems, based on the dynamic modeling of the climate within the greenhouse (Rytter et al., 2012; Rodríguez, 2002; Straten et al., 2000; Henten, 1994; Tap, 2000; Udink, 1983).

The price of decision making without a previous study which defines the real needs and the reach of these equipment and systems would represent a useless expense, which in the worst case scenario could lead to the loss of economic resources that are critical in times of low profits during the natural fluctuations of the price of sale of the crop in the market.

MATERIALS AND METHODS

Climate characterization of the Greenhouse in Aramberri, Nuevo León

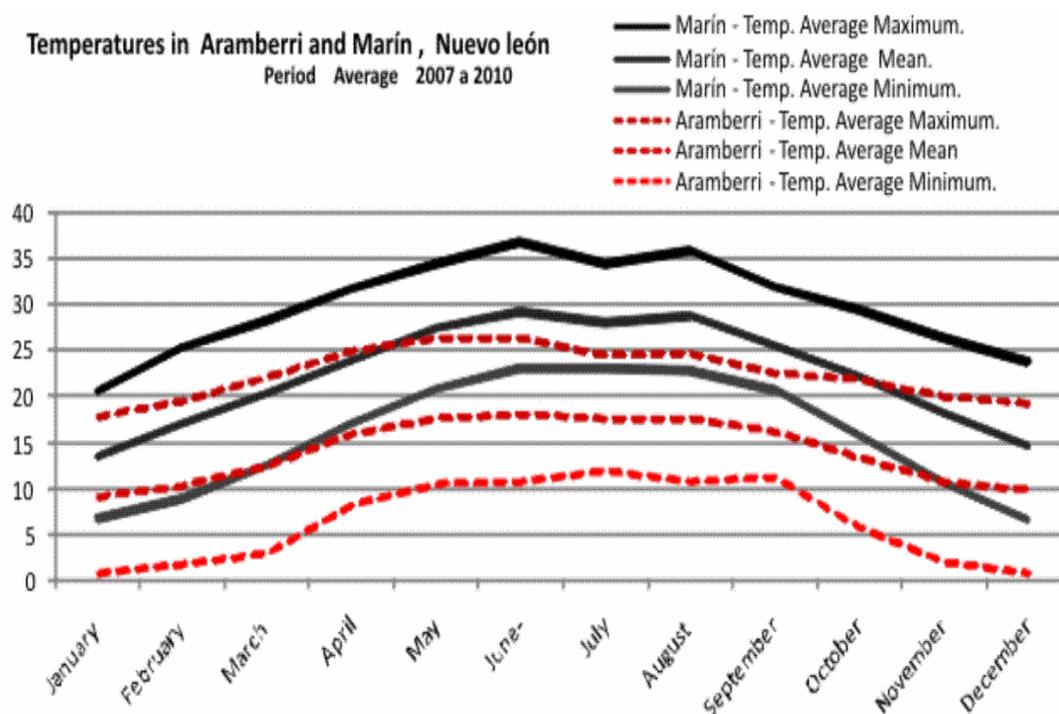
Climate description of the Asención Zone, in the municipality of Aramberri, Nuevo León, México

Asención is geographically located at 24° 19.5' North Latitude and 99° 56.5' West longitude, at an altitude of 2003 meters over the sea level, where the climate is classified as dry, semi-dry, with rainfall throughout the year (INEGI, 2012; INEGI, 1981). Figures 1, 2, 3 and 4 show the statistical averages of meteorological parameters for the area in the period 2007 to 2010.

Figure 1 shows that the temperatures are low compared with other zones in the state because of the altitude. Moreover, taking into account that the optimal temperature range of some of the vegetable species are between 15 and 32°C (Monke, 2013; Boote et al., 2012; Kipp, 2009; Muñoz and Castellanos, 2004), it is possible to establish that the air temperature is suitable for growing tomatoes in the period from late March until early October and being not suitable in the winter period for the months of January to March and from October to December. During these winter months, the minimum temperature is regularly found on 5°C on average, and one single event of low temperatures would be lethal for growing tomato. Figure 2 shows that the relative humidity is suitable for the crop, staying between 60 and 80% which is the recommended for tomato (Kipp, 2009; Muñoz and Castellanos, 2004). From Figure 3, it is possible to verify that although there are rains all the year, it generally is limited to less than 60 mm per month, resulting in a dry ground with vegetation of scrubs in the plain and pine trees in hills and slopes of the hills (INEGI, 1981). In Figure 4, it is possible to determine that strong ventilation is present, with consistent wind speeds averaging of 10 km/h year round, with gusts of 30 to 60 km/h. So, with this information we can determine that the principal thermal climatic problem for the operation of the greenhouses in the Asención area in Aramberri, Nuevo León, is to heat them during winter nights.

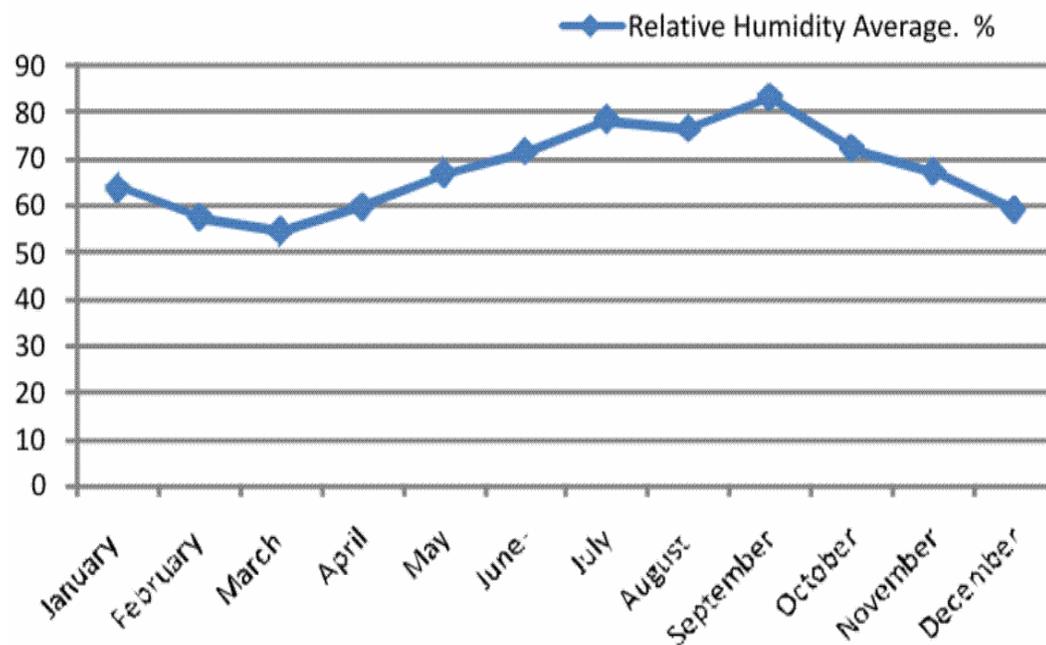
Description of the Asención greenhouse in Aramberri, Nuevo León, México

The greenhouse is 40 m long, 30 m wide and 5 m high at the ridge. It has a rectangular shape with semi-cylindrical cover. With zenithal vents and plastic rolling curtains of 2 m manipulated with motors in the 4 lateral walls, all of them with mesh to avoid insects. The orientation of the greenhouse is southeast-northwest and its structure is galvanized steel in 3 spans, with a polypropylene cover (Figure 5).



Source: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (inifap)

Figure 1. Maximum, mean and minimum air temperatures averages for the period of 2007 to 2010, in the zone of Ascensión in Aramberri and the zone of Marín on the state of Nuevo León, México.



Source: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (inifap)

Figure 2. Relative humidity average for the period of 2007 to 2010, in the zone of Ascensión, in Aramberri, Nuevo León, México.

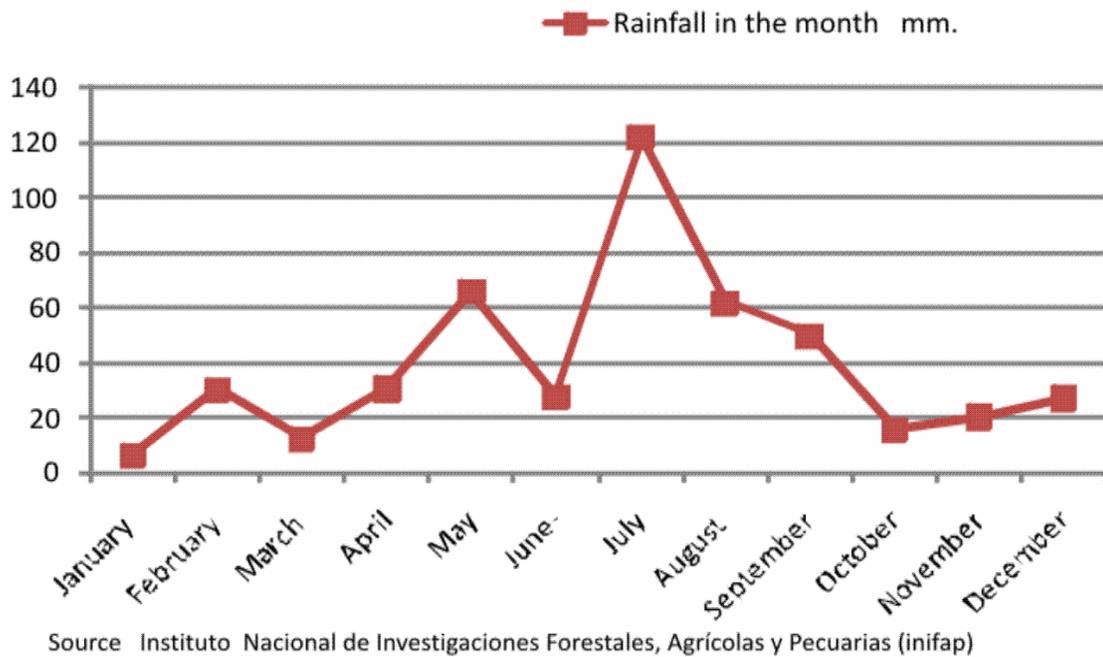


Figure 3. Average monthly rainfall for the period of 2007 to 2010, in the zone of Ascención, in Aramberri, Nuevo León, México.

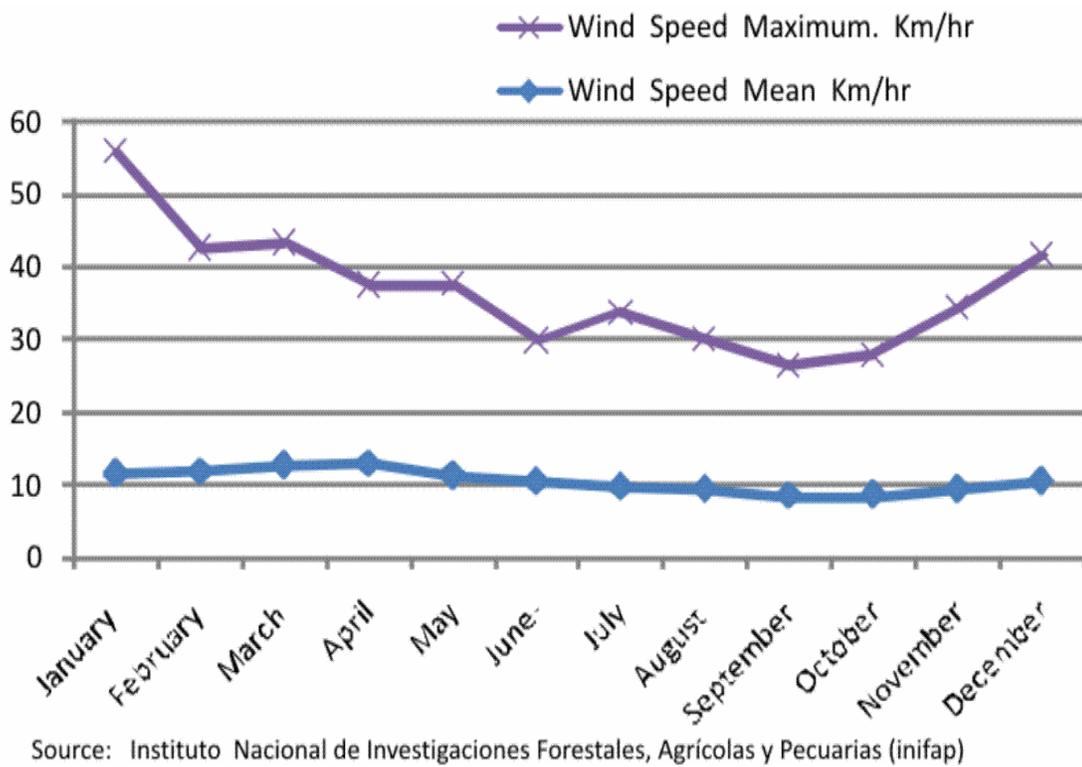


Figure 4. Average wind speed maximum and mean for the period of 2007 to 2010, in the zone of Ascención, in Aramberri, Nuevo León, México.



Figure 5. Studied greenhouse in Aramberri, Nuevo León, México.

Climatic data measured in the greenhouse of the ascension in Aramberri, Nuevo León, Mexico

The sampling was done using 2 Davis weather stations, model Vantage- Pro2. One was installed inside the greenhouse and the other outside. With the outdoor station the taken measurements were temperature, relative humidity, solar radiation and wind speed. The inside station was placed in the center of the greenhouse and the taken measurements were air temperature and relative humidity. During testing, the greenhouse was uncultivated. Sampling was done in winter, taking data every 10 min in 2 phases:

Phase (a): With open vents from 18:00 h of November 12, 2010 until 21:00 h of November 13.

Phase (b): With closed vents from 21:00 h of November 13, 2010 until 13:00 h of November 15.

The values of the measured data are presented in Figures 6 and 7. Figure 8 shows in a single graph the data of solar radiation, as well as air temperature in the outside and inside, and can see the thermal effect of the solar radiation over the greenhouse in the sampled days for the typical winter period.

Analysis of the measurements

In winter, during the day, with closed vents the temperature inside the greenhouse rises up to 40°C, about twice the temperature registered at the outside. While with the vents open, the inside temperature tries to be equalized with the outside temperature due to ventilation. The contribution of heat load from the sun during the day can be appreciated and it can be exploited to reduce energy consumption during the night.

Thus for days sampled, we will calculate the energy needed for heating and energy provided by the sun during the day feasible to be used for heating.

Calculation of the thermal energy needed for heating the Aramberri greenhouse in a typical winter period

The sampling in the Aramberri greenhouse was done during a typical winter period and calculations were made using the data in Fig.6 to determine the energy required to heat the greenhouse at

night under the winter conditions in the sampled days. We will consider that the windows will be closed in the night. Thus, the heat loss would occur only across the cover.

Thus, to calculate the energy required for heating we will use the equation shown in (1), proposed by Sainato et al. (1999) applied in Medina et al. (1998), which is also proposed by Tap (2000) and Leal (2008) as part of the equation to modeling the greenhouse climate. The night periods were from 18 : 00 to 06 : 00 for the days sampled, corresponding to the condition of the outside air temperature T_e in Figure 6, in the periods of 18 to 30 h, 42 to 54 h and 66 to 78 h respectively. The inside temperature required T_i was set at 15°C, which is the minimum optimal for cultivation. Therefore, for each time interval, the values calculated of q_c would correspond to the amount of energy lost through the cover that should be compensated to continue maintaining the 15°C inside.

$$q_{ci} = \frac{K \cdot A_r \cdot (T_i - T_e)}{A_g} \quad (1)$$

Where:

q_c = Loss of heat through the cover $\frac{\text{Joules}}{\text{Seg} \cdot \text{m}^2}$

K = 5. Heat transmission coefficient for the cover. $\frac{W}{\text{m}^2 \cdot ^\circ\text{C}}$ (Henten, 1994)

A_r = 1,821.8 Area of the cover (m^2)

A_g = 1,200 Surface area of the greenhouse (m^2)

T_i = 12 Inside temperature ($^\circ\text{C}$)

T_e = (Figure 6) Outside temperature ($^\circ\text{C}$)

The energy needed for heating in each period is calculated with (2):

$$E_c = \int_{t_i}^{t_f} q_{ci} \cdot dt \quad (2)$$

Where: E_c = Energy needed for heating $\frac{\text{Joules}}{\text{m}^2}$

t_i = Start time period in min.

t_f = End of time period (min).

dt = 10 Time interval between measurements (min).

The results of the calculations are shown in Table 1.

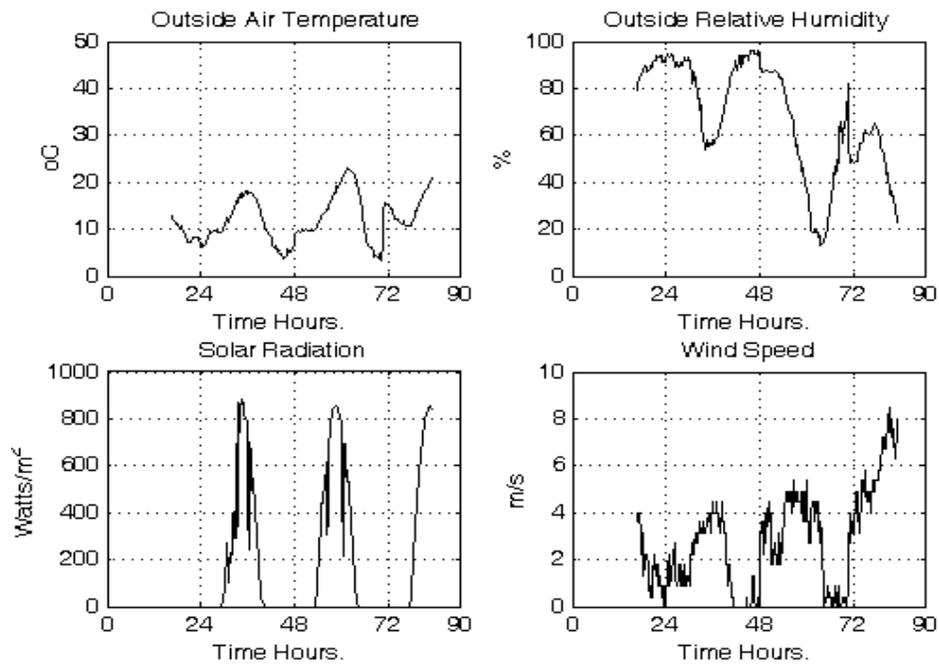


Figure 6. Measured data outside the greenhouse of Asención, in Aramberri, Nuevo Leon, México. From 12 to 15 of November of 2010.

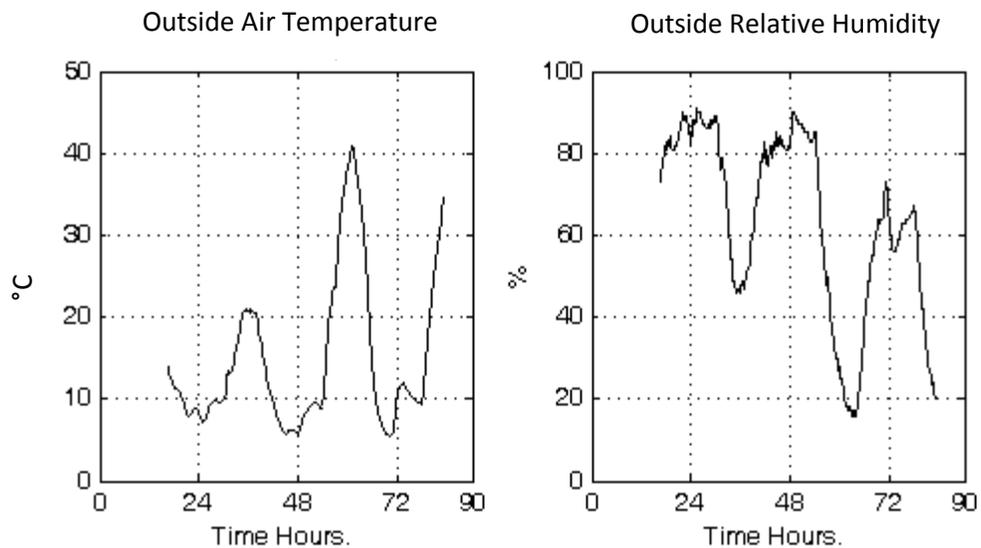


Figure 7. Measured data Inside the greenhouse of Asención, in Aramberri, Nuevo Leon, México. From 12 to 15 of November of 2010.

Calculation of the energy provided by the sun during the day, feasible to be used for heating in the greenhouse of Aramberri, in a typical period of winter

The graph in Figure 6 of solar radiation that was measured outside of the Aramberri greenhouse in a typical winter period shows the

energy provided by the sun during the days sampled in $\frac{\text{Watts}}{\text{m}^2}$.

These data were taken for calculating the energy supplied by the sun feasible for heating, by means of Equation (3). This Equation (3) is the fragment of the dynamic model proposed by Tap (2000) and applied by Leal (2008), that models the sun energy that crosses the

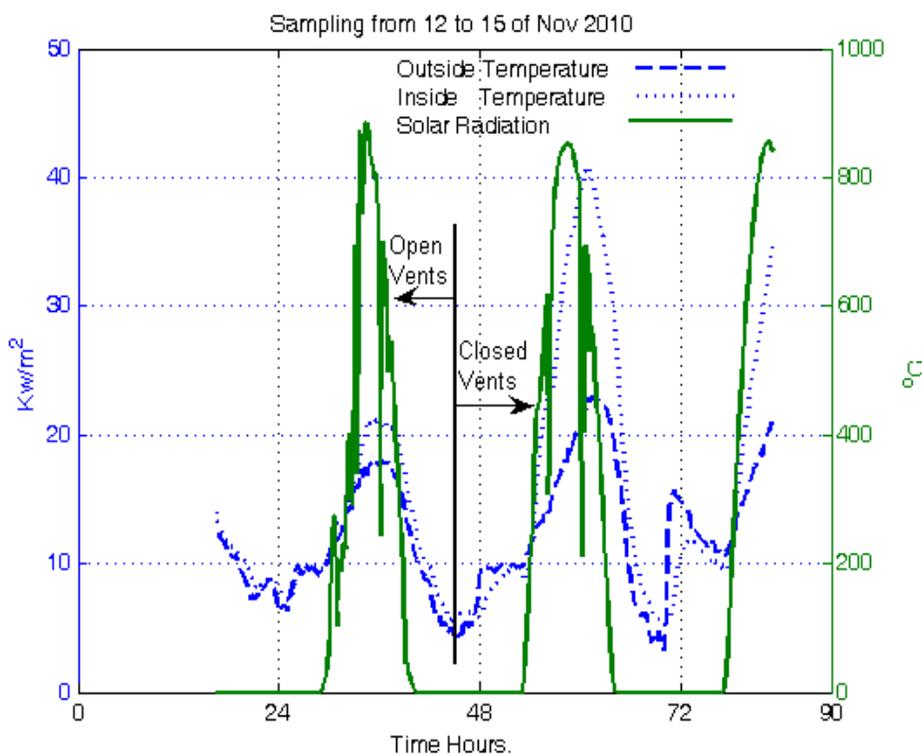


Figure 8. Inside temperature, outside temperature and solar radiation measured in the greenhouse of Asención, in Aramberri, Nuevo León, México.

plastic cover of the greenhouse, providing heat inside the structure. The calculation of the energy provided by the sun took place with the data of Figure 6 in the periods of 30 : 00 to 40 : 20 h and 54 : 00 h to 64 : 20 of the days sampled.

$$Es = \int_{t_i}^{t_f} \eta G_i \cdot dt \quad (3)$$

Donde:

Es = Energy supplied by the sun $\frac{\text{Joules}}{\text{m}^2}$

η = 0.7 Conversion Factor de, adim. (Tap, 2000)

G_i = Solar Radiation $\frac{\text{Watts}}{\text{m}^2}$

t_i = Start time period (min)

t_f = End of time period (min).

dt = 10 Time interval between measurements, in min.

Table 2 shows the results of using Equation (3) with the data of the graph of solar radiation in Figure 6.

RESULTS

The climate characterization was performed in a greenhouse located in Aramberri, Nuevo León, México. It consisted of defining the outside climate characteristics year - round in the 2007 to 2010 period, and inside for the sampled period.

From the study, based on the presented climate data, the results shown that:

1. The average relative humidity is maintained on the appropriate values for tomato crop (Figure 2).
2. Rainfall is uniform throughout the year but low in intensity (Figure 3), representing a limitation and a problem to solve.
3. The intensity of the dominant winds is 10 km/h, (Figure 4), which is very favorable to renew CO_2 rates on the greenhouse and also contribute to the pollination of flowers of some crops such as tomato and pepper. Winds exceeding 30 km/h make it mandatory to close the vents to safeguard the integrity of the structure (Kipp, 2009; Muñoz and Castellanos, 2004).

DISCUSSION

Based on the results, it can be established that the critical air temperature for crop development in the greenhouses of Aramberri is given only in winter, (Figure 1.) requiring energy investment in this period for heating at the night. During daytime, due to the altitude, the sun energy is enough to raise the temperature inside the greenhouse in appropriate values to ensure the satisfactorily development for cultivation (Figure 8). It was also established that

Table 1. Thermal energy needed for heating the Aramberri greenhouse in a typical winter period (Ec).

Period (12 h)	Total energy joules/m ²	Energy joules/m ² h
18 to 30 H	1,100,800	91,733
42 to 54 H	1,425,100	118,758
66 to 78 H	800,300	66,692

Table 2. Energy provided by the Sun during the day, feasible to be used for heating in the greenhouse of Aramberri, in a typical period of winter (Es).

Period (10 : 20 h)	Total energy joules/m ²	Energy joules/m ² h
30 to 40 : 20 h	10,994,340	1,064,003
54 to 64 : 20 h	13,669,320	1,322,880

the energy required for heating during the night in the 3 sampled periods presented in Table 1, resulting in 1,108,733.33 joules/m² on average. And the estimated energy supplied by the sun during the day feasible to be used for heating, presented in Table 3, resulting in 12,331,830 joules/m² on average. This shown that the energy provided by the sun is approximately 10 times necessary for heating, feasible to be used to heat the greenhouse in the winter nights, with consequent cost savings.

Conclusions

The thermal climate characterization of the greenhouse at Aramberri, Nuevo León, allows us to conclude that there are 2 problems for the optimal performance, the low temperatures during winter nights and the shortage of rainfall.

For low temperatures during winter nights, this study proved that it would be convenient to use the energy provided by the sun during the day to heat the greenhouse at night. Due that the estimated energy necessary for heating during the winter nights is one tenth of that provided by the sun. And with the developing of one solar storage system it could be enough to heat the greenhouse at night, with the resulting economic savings.

For the water shortage, a more detailed study would be necessary, based on the topography and rain statistics of several years in the area where the greenhouse is located, in order to establish the economic feasibility of developing solutions as water storing in tanks and reservoirs, or seeking the possibility of exploitation of groundwater.

The results show the relevance of these kinds of studies, where if we quantify the mass and energy flows, it could be feasible to use them for establishing recommendations and procedures that seek to optimize

the operations of a greenhouse.

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