COBEM 99
XV Congresso Brasileiro de Engenharia Mecânica
15th Brazilian Congress of Mechanical Engineering
22 - 26 de Novembro de 1999 / November 22 - 26, 1999 Águas de Lindóia, São Paulo,

ENERGY CONSERVATION TO IMPROVE GREENHOUSE CULTIVATION

Jorge R. Barral
Pablo D. Galimberti
Adrian Barone
Jorge A. Adaro
Universidad Nacional de Río Cuarto, Facultad de Ingeniería, Grupo de Energía Solar
Ruta Nacional 36 km 601, (5800) Río Cuarto, Argentina

Abstract. *A system to improve winter horticultural cultivation inside greenhouses has been developed in the central part of Argentina. Previous experiences showed that it is possible to avoid the harmful freezing effects using a combination of thermal curtains and heating tubes in which warm water flows coming from a geothermal source. But, in spite of these improvements, in many winter nights the temperature use to remain low inside the greenhouses, causing plant growth detention. This problem was prevented by concentrating the energy delivered by the tubes as near to the plants as possible, which was achieved adding to the previous improvements a transparent and light synthetic blanket to decrease convective heat transfer effects. The results were evaluated measuring temperatures at different parts of the prototype. Data of winter nights were plotted and compared with temperatures of other greenhouses. The system showed to be economically convenient. It maintained satisfactory temperature levels in the surroundings of the plants, allowing continuous growth of the cultivation, the raw material necessary for these improvements is a cheap common market material, the arrangement of all the system does not take more than a few hours, and the operation of the system is simple and no time consuming.*

Keywords: *Greenhouses, Heating, Thermal blankets, Geothermy, Thermal curtains.*

1. INTRODUCTION

Horticultural Greenhouses are used to grow plants in quantity, with high quality and at a good timing. In a greenhouse it is possible to use the soil intensively, to create favourable environmental conditions, and to maintain an effective sanitary plant control, which results in a massive production of high quality. The extension of good thermal conditions for the cultivation allows the obtaining of crops before and after the normal seasons, which results in higher prices for the product.

The adequate environmental conditions for each type cultivation are achieved controlling a set of variables, from which the most important are light, humidity, and temperature

(Albright, 1991). For the central part of Argentina, the photoperiod of many typical horticultural products is not a crucial variable in winter. Moreover, the climate in winter is generally dry and sunny, which causes no problems with the greenhouse ambient humidity, since the warm and dry daytimes allow the ventilation of the greenhouse to deliver the moisture accumulated during the night. Therefore, the critical variable to be controlled is the temperature, specially at night, and, for that reason, heating systems are used.

The use of fossil fuel is not recommended because of its contaminant effects, high prices and fastidious handling. The normal use of fossil fuels is the burning of them during the cold nights, which contaminate the inner greenhouse ambient at nights and the ambient globally. Moreover, it obliges the farmers to take care of the burning process and to have prepared some transport facilities to carry the fuel.

Many attempts have been made to provide thermal energy to production horticultural greenhouses by means of renewable energy (Santamouris *et al.*, 1994). Most of the works are based on the accumulation of energy during the day, delivering it at nights and on the energy conservation.

It is widely used the accumulation of energy in water, using plastic tanks or tubes placed on the greenhouse floor, which absorb solar energy during the day and transfer heat at night to the greenhouse ambient. The main problem of this kind of systems is that better accumulation of energy is obtained when large volumes of water are used (Santamouris *et al.*, 1994). On the other hand, it is possible to use plastic surfaces to transfer heat to the greenhouse ambient, taking the energy from a source (Saravia *et al.*, 1992). To avoid the energy losses, mainly at night, systems of thermal curtains are used, which basically are made of polyethylene of low quality (Chandra & Albright,1980) (Seginer & Albright, 1980).

Based on these elements a heating and energy conservation system was designed and tested in a farm in the central part of Argentina. The system took advantage of a natural artesian spring, a geothermal source of low entalphy (Dickson & Fanelli, 1995), which provides warm water at constant temperature of 28 ºC to the farm without pump requirements. First, black polyethylene tubes were arranged on the greenhouse floor, allowing the warm water from the geothermal source to flow during nights (Adaro *et al.,* 1997). This arrangement has the advantage, compared with the accumulation systems previously described, that not large volumes of water are necessary because the energy is provided permanently by a source at constant temperature. Second, inner thermal curtains were added to the walls and roof to decrease the energy losses by convection heat transfer effects. The system was tested during two years, showing to be very effective to prevent the freezing problems the greenhouses used to be. Moreover, it is used today in normal production greenhouses in the farm (Galimberti *et al.*, 1997).

However, many winter nights the temperature inside the greenhouse used to be so low that plants of many typical cultivations delay or completely stop their growing. As a consequence, they occupy the greenhouse, need watering and some horticultural tasks to live, but they do not bloom or fructify, which is expensive and useless. But, on the other hand, if it would be possible to maintain the temperature above some values during all the nights, an out of season crop would be harvested, allowing to the farmers to get a high price for their production in the local market.

The use of hermetic polyethylene low tunnels for small plants showed to be very effective to avoid energy losses at night, in greenhouses in the East-Central part of Argentina (Francescangeli *et al.*, 1994). Part of the energy arrived during daytime is accumulated in the greenhouse ground and the tunnels delay the heat transfer from the soil to the greenhouse ambient, exploiting effectively the heat storage capacity of the soil (Gauthier *et al.,* 1997).The arrangement of the tunnels is really simple: each of them is applied over the furrow covering a line of plants. Then, the convection heat transfer is strongly reduced and microclimatic conditions are created near to the plants.

This work describes the design of an assemblage to achieve acceptable temperature levels near to the plants in winter to allow them to grow, bloom, and fructify continuously. It is based on the system of polyethylene tubes and thermal curtains previously described, and the addition of thermal blankets over the plants resembling the operation principle of the low tunnels. The results were highly satisfactory and the response of the system is shown for a typical winter night through the comparison of temperatures measured in a prototype with the thermal blankets and another greenhouse with only tubes and curtains. First, a brief physical description and results of the old system is made; then, the addition of the thermal blankets is analysed and its results shown.

2. DESCRIPTION AND RESULTS OF PREVIOUS EXPERIENCES

2.1 Motivation

The work on greenhouses subject began in 1994, when a farm exposed their freezing problems to the Solar Energy Group of the Engineering College at National University of Río Cuarto (UNRC). The farm, called SIQUEM, is situated 10 km away from the UNRC**,** 33.2° S latitude and 64.3° W longitude, and has a low temperature geothermal source (ASHRAE, 1995), which provides underground water at 28 °C. The water flows freely and no pump is necessary for the farm consumption requirements.

SIQUEM and UNRC signed an agreement to work conjointly on the problem; the farm basically provides some materials and the standard greenhouse labour and the University does research work using its measurement equipment, providing new materials to be tested, and labour hours to perform the experiences.

To analyse the problem some materials were selected for the tubes and thermal curtains, which were tested in laboratory and in the greenhouses of the farm. Then, using the results of these experiences, the regional climatic data (Barral *et al.*, 1995), and the geometrical and physical information, some energy balances were approximated, which make the researchers to think it would be possible to prevent the freezing problem with the arrangement described in the next point.

2.2 Physical description and handling of the first system

The greenhouses used in the experiences are called “chapel greenhouses” because of their appearance. They are typical constructions in the central part of Argentina and they are made of wood beams and polyethylene walls and roof. These first experiences were developed on one of the main production greenhouses (1000 m^2), on a prototype built by the UNRC (105 m^2), and three production greenhouses (105 m^2 each one). The section of the greenhouse is shown in Fig. 1 a), where the mentioned polyethylene tubes (110 mm diameter) and the thermal curtains are represented.

For the heating system were selected cheap common market materials and a simple construction methodology was conceived to build it, in order to minimise labour hours and avoid specialised employees. The tubes are made of 200 μm thick black low density polyethylene and have a diameter of 10 cm. They were placed on the greenhouse ground, between furrows, allowing heat transmission to the air and the ground simultaneously. The tubes were connected in series with only one inlet and one outlet for each greenhouse as shown in Fig. 1 b). The water flow is controlled manually: the valves are opened before sunset, allowing the water to flow through the greenhouse tubes, and closed the next morning, when the sun begins to warm the greenhouse. The greenhouse exit water is used for watering in other farm open sectors, which is convenient in winter, since by that time the rain is scarce.

The thermal curtains were made of 50 μm thick transparent polyethylene with no special optical properties since their main function was to decrease heat losses by convection and infiltration and they are not exposed to the exterior climate adversities. The ceiling is not moved during all winter and the double walls are opened and closed for ventilation in the same operation made for the simple walls.

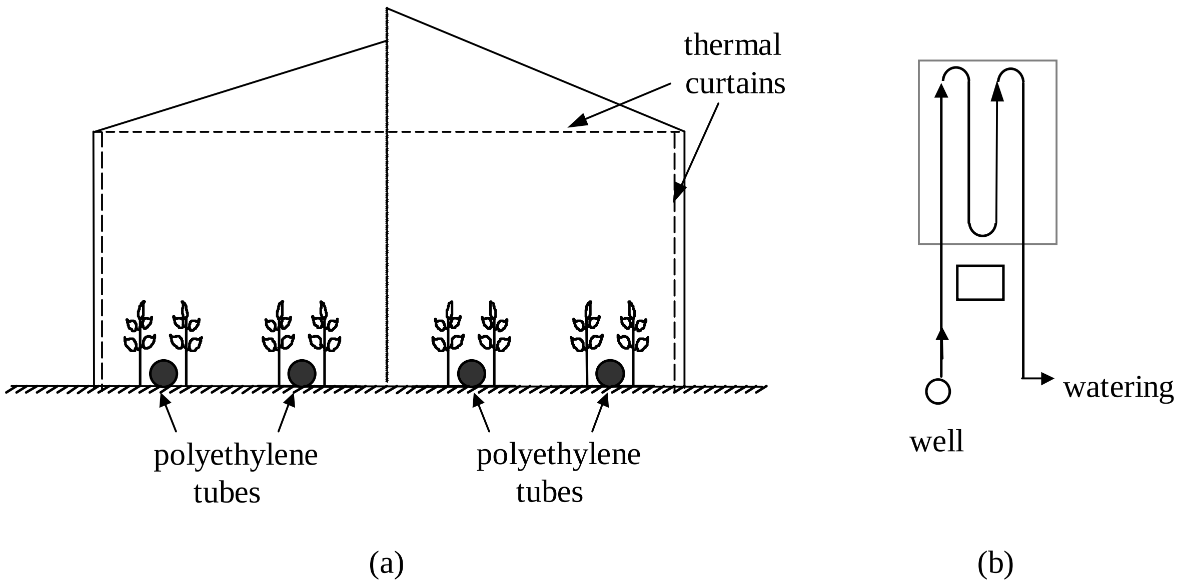

Figure 1- a) Section of the greenhouse prototype; b) Top view of the greenhouse prototype.

2.3 Experimental task performed

The temperatures in different places of the greenhouses were measured with data acquisition systems, every 15 minutes, during all the winter season. Other variables, like relative humidity and other temperatures, were measured by means of a portable weather station placed inside the greenhouse whereas water flow rate and water pressure were determined manually. A pyranometer was used to measure global solar radiation inside the greenhouses and outside.

Agronomist of UNRC worked in the determination of productivity and other aspects related to biological behaviour of the plants. The deterioration of the materials used in the system was checked visually.

2.4 Results and conclusions of this previous experiences

The following results can be summarised after the experiences:

a) The system is cheap and simple to operate.
b) The tubes and curtains materials did not suffer deterioration, which allowed they to be used for other winter seasons.
c) Since the thermal curtain is transparent and very thin, it did not cause a significant decrease on the solar radiation absorption of greenhouses.
d) The two improvements are necessary to prevent freezing effects in hard winters.
e) The night temperature is a decisive factor in the plant growth acceleration.

f) It is possible to obtain a good early production and extended winter production.
g) It would be possible to obtain out of season production with a few more degrees.

3. ASSEMBLY AND OPERATION OF THE THERMAL BLANKET SYSTEM

After these previous satisfactory experiences for freezing and noting that out of season production was likely, the Solar Energy Group decided to test a system of thermal light blankets to minimise the heat losses in the plants vicinity. In addition to these thermal blankets, bigger tubes were adopted (16 cm diameter), because taking into account that the temperature inside the tubes is almost constant, the heat transfer would be increased if greater surface of transmission were used. Since the greenhouse floor works as the accumulator of energy, the placement of these blankets, cut the convection currents in contact with the floor surface and reduce them to an small circuit near to the plants. Then, not only the heat provided by the tubes is concentrated, but also the energy absorbed by the greenhouse ground on sunny days is retained to some extent.

Figure 2 shows the section of the greenhouse provided with the thermal blankets. These thermal blankets are made of transparent synthetic material, they are light (17 g/m^2) and not impervious to gases. The mounting process of the blankets is easy and no time consuming. The synthetic light blankets are simply supported by the same wires used to guide the plants and are maintained in position by means of clothespegs, avoiding displacements during daytime ventilation operations. Also, the blankets are set in such a way that allow the farmers to walk along the greenhouse during normal inspection tasks. Since the blankets are transparent, must not be moved if no horticultural work is necessary, and if they must be moved, they can slide effortlessly along the supporting wires.

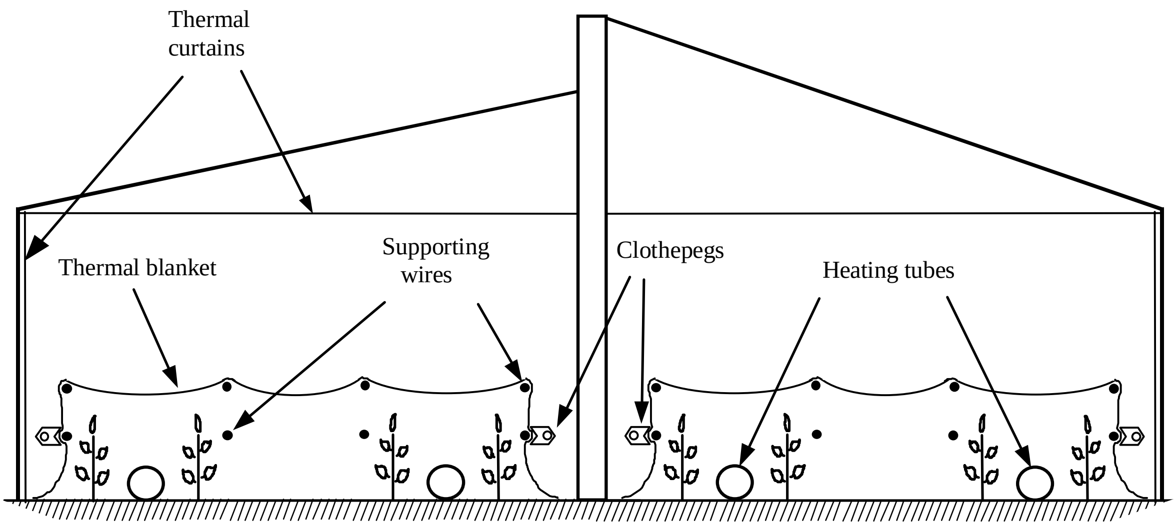

Figure 2- Section of the greenhouse with tubes, thermal curtains and thermal blankets.

Figure 3 shows the arrangement of the thermal blankets in a top view. In this case for a greenhouse covered by six panels. It is also shown how the tubes are connected at the ends by PVC pipes, which was a improvement from the old system, taking into account the pathways of the farmers, where the damage for the tubes was more likely.

It is important to remark that the blankets are going up following the growing of the plants, and although the convection effects became greater with this growing, the coverage of the plants can be maintained in good degree if the total width of the blankets is foreseen taking into account this growing.

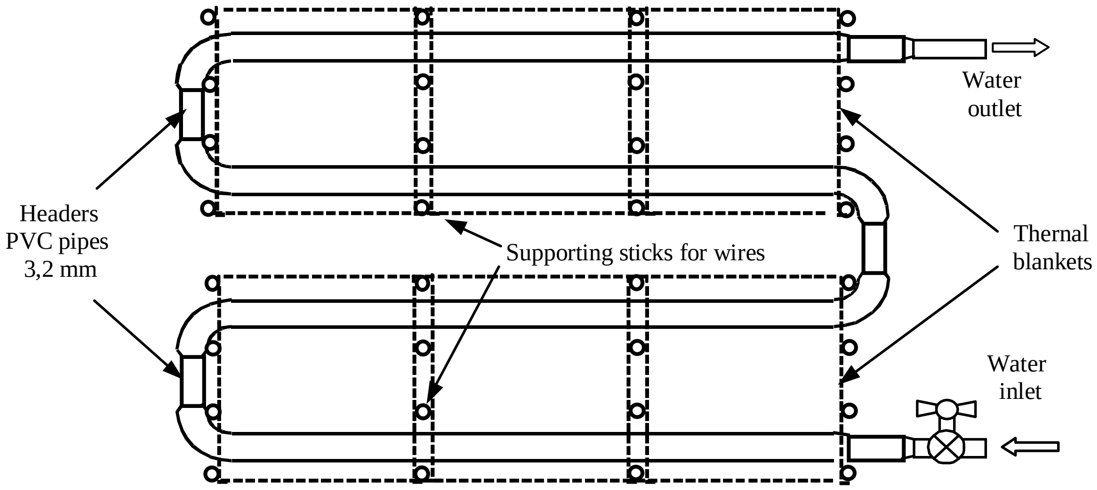

Figure 3- Top view of the blankets and tubes arrangement.

4. RESULTS

The results of the experiment were evaluated from the measurement of temperatures at different locations of the prototype and in another greenhouse furnished only with thermal curtains. Figure 4 shows a plot of the temperatures in the greenhouse with thermal blankets for a typical winter night. The temperature of the water inside the tubes is also plotted and it can be seen that there is no more than two degrees between the inlet and the outlet, which supports the stated previously about constancy of the heat source.

The temperatures for the greenhouse without thermal blankets are plotted in Fig. 5 for the same winter night selected for the prototype. Comparing the two greenhouses it can be concluded that for this cold night, under the thermal blanket the temperature maintained values over 13 °C for all the night, while for the other greenhouse, the temperature was under 11 °C for more than 7 hours. Over 12 or 13 °C must be maintained the temperature for cultivation of tomatoes and peppers, two of the most common products of this part of the country, if continuous growing and fructification is desired. Then, although the differences seem to be small, they are crucial to define a profitable or not economical production.

5. CONCLUSIONS AND FUTURE RESEARCH

The system proved to be very efficient to provide the temperature levels required for the continuos growing of some important typical horticultural cultivations. It is important to remark that this thermal improvement does not imply structural changes in the greenhouses, and only is necessary to think in some wire to support the blankets for those plants that do not require wires to be guided and supported, which is not the case for tomatoes and peppers.

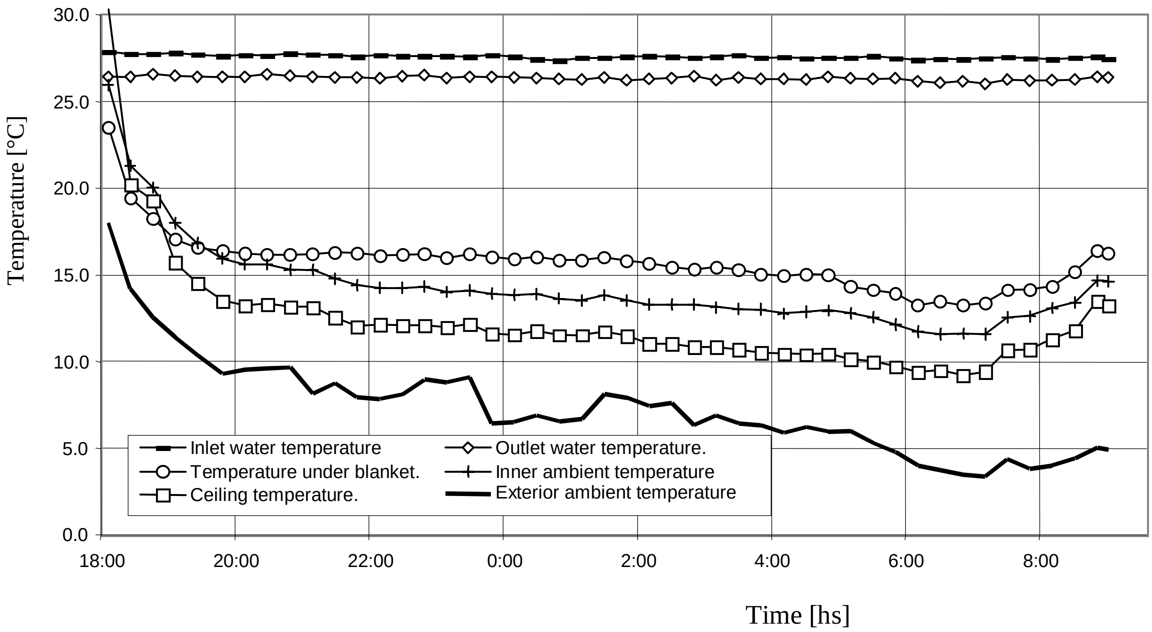

Figure 4- Temperature measurements in the experimental greenhouse

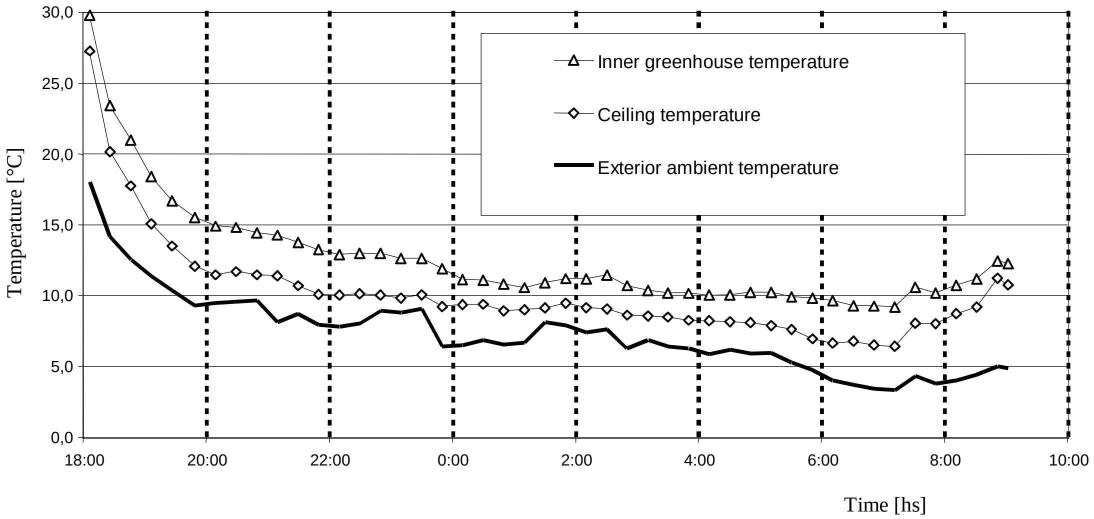

Figure 4- Temperature measurements in the greenhouse without thermal blankets.

Although the duration of the blankets is not yet tested, they are cheap, and the time to perform the mounting is very short. There is also no time consuming the time necessary to slide the blankets over the wires when horticultural tasks are required, and no specialised labour is demanded. Since they are transparent and impervious can be covering the plants during the day without problems, which means they can be in permanent for many days.

The system does not present heat regulation problems. The valves just have to be opened before night and closed the next morning. Since the temperature of the resource is low, there is no problem of overheating for the typical greenhouse cultivations

The next steps in this work is to select different kinds of horticultural products, with different seedtimes, in order to determine which is the most profitable work methodology for the out of season production using thermal blankets. To do that it must be taken into account that the behaviour of the plants is not the same, mostly in times of bloom and fructification, than those times in normal season production. The study will imply a degree day analysis to determine the energy levels required for each kind of plants.

REFERENCES

Adaro, J., Galimberti, P., Lema, A., Barone, A. and Fasulo, A., 1997, Calefacción de invernaderos con energías renovables, International Journal of Environmentally Conscious Design & Manufacturing, Vol 6, No. 4, pp. 3-7.

Albright, L. D., 1991, Production Solar Greenhouses, Solar Energy in Agriculture (B. F. Parker Eds.). New York: Elsevier.

ASHRAE, 1995, Ashrae Handbook, HVAC Applications, American Society of Heating, Refrigerating and Air-Conditioning Engineering, Atlanta.

Barral, J. R., Adaro, J. A., Lema, A. I. and Fasulo, A., 1995, Variables climáticas en la región centro sur de Córdoba, Proceedings of ASADES 95 (1), pp. 04.67-04.72.

Chandra, P. and L. D. Albright, 1980, Analytical Determination of the Effect on Greenhouse Heating Requirements of Using Night Curtains, Transactions of the ASAE 23(4), pp. 994-1000.

Dickson M.H. and Fanelli M. (1995) *Geothermal Energy*, pp. 14-15. John Wiley & Sons, Inc., Chichester.

Francescangeli, N., Ferrato, J.,Levit, H., and Lara, M. A., 1994, Comportamiento de distintos materiales opacos y transparentes en la cobertura de túneles bajos , en el interior de invernaderos, durante el invierno. Rivista di Agricoltura Subtropicale e Tropicale, vol 88, n° 3, pp. 529-538.

Galimberti, P., J. Adaro, A. Lema, A. Barone, L. Grosso, and A. Fasulo, 1997, Estudio Comparativo de Diferentes Mejoras en Invernaderos. Avances en Energías Renovables y Medio Ambiente 1(1), pp. 21-24.

Gauthier, C., Lacroix, M., and Bernier, H., 1997, Numerical Simulation of Soil Heat Exchanger-Storage Systems for Greenhouses. Solar Energy 60(6), pp. 333-346.

Santamouris, M., C. A. Balaras, E. Dascalaki, and M. Vallindras, 1994, Passive Solar Agricultural Greenhouses: A Worldwide Classification and Evaluation of Technologies and Systems Used for Heating Purposes. Solar Energy 53(5), pp. 441-426.

Saravia, L., Echazú, R., Cadena, C., Cabanillas, C., 1992, Calentamiento solar de invernaderos en la provincia de Salta, Proceedings of ASADES 92 (1), pp. 04.67-04.72.

Seginer, I., and L. D. Albright, 1980. Rational Operation of Greenhouse Thermal- Curtains. Transactions of the ASAE 23(5), pp. 1240-1245.