ANALYSIS OF THE ENERGETIC BEHAVIOR OF AGRICULTURAL GREENHOUSES THROUGH DYNAMIC SIMULATION IN TRNSYS

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ABSTRACT

This study uses dynamic simulation to determine the energy expenditures and wall-material costs of agricultural greenhouses. Based on a building size of 200 m^2, we perform a parametric analysis on the greenhouse cost by varying the wall material, the use of a single or double wall, three types of crops, four geographic locations (all in the state of Chihuahua, Mexico), and two temperature control strategies. The simulation tool we present makes it possible to determine the energy costs incurred by greenhouses operating for long periods of time under the weather conditions typical of any part of the country. The main objective of this work is to develop a calculation tool with which to better estimate the technical and economic feasibility of agricultural greenhouses, in order to reduce the enormous risk currently associated with investment decisions in this field.

INTRODUCTION

Background

A greenhouse is a glass or plastic building with an internal microclimate, used for growing plants by keeping temperature and relative humidity at optimal plant growth levels regardless of season (Rivera, 2007), (Sethi V. , 2009). Greenhouses also provide protection against wind, insects, and disease by creating a barrier (the wall material) with the exterior (Critten D.L., Bailey B.J., 2002).

The energy demand of a greenhouse depends basically on the difference between the exterior weather conditions and those required by the crops inside. Climate control improves plant comfort and helps achieve the productive objective of the greenhouse. To maximize production, temperature levels are kept at 16°C-20°C at night and 22°C-30°C during the day (IDAE I. p., 2008). The main objective of greenhouses with automated systems is to react to changing weather conditions to create a constant and controlled microclimate within the optimal range for plant development, in order to maximize crop growth and farm profits (Kolokotsa, 2010).

Objetive

The objective of this work was to develop a numerical simulation tool to determine the energy interaction between a greenhouse and its environment, and calculate the energy expenditures required for heating and cooling during a year of continuous operation. The tool makes it possible to analyze the effect of individual greenhouse design parameters, such as geometry, orientation, size, construction materials, and geographic location. It can also analyze different crops and internal climate control schemes. The annual energy results can be used to determine the net present value of the energy costs over a useful life of 10 years, which summed to the capital investment costs provide the total expected cost of a given project. In this way, a parametric analysis can be used to determine the optimal design for a given geographic location and the expected profitability of such a venture.

METHODOLOGY

We developed a numerical model of an agricultural greenhouse, which evaluates the energy interactions with its surroundings and the energy expenditures needed to keep its microclimate. The crops considered in this work are tomato, cucumber, and bell peppers, which are the most important crops in the state of Chihuahua, Mexico. Given their different metabolisms, each crop has a different temperature comfort zone. To maximize the production of each crop, the air in the greenhouse must remain within this range. An evaporative cooling system was considered for the greenhouse, but the relative humidity in the air entering the greenhouse was limited to 70% in order not to exceed the crops' requirement. We considered the energy requirements of the fans and the consumption of evaporated water. The heating system we considered was an air heater fueled by liquid petroleum gas (LPG). We considered the cost of fuel and the electricity used by the fans. In order to minimize the energy consumption of the heating and cooling systems, a system was designed that makes it possible to control all the air flows (heating, cooling, and ventilation). The system supplies atmospheric air to the greenhouse when the air's temperature is such that it can be used in place of the artificially conditioned air flows. All three flow systems are activated by a control system that measures the greenhouse's internal temperature and determines the flows required to maintain conditions of comfort. The model is composed of an LPG-fueled air heater, an evaporative cooling system, a control unit, three fans and two flow mixers (Figure 1).

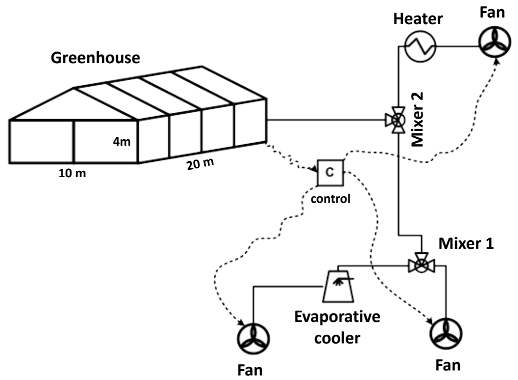

FIGURE 1. The proposed model

The model was implemented in TRNSYS, a software platform for the simulation of thermo-solar systems that operate through transient processes. A parametric analysis was performed on the operation of the greenhouse during one year. Table 1 shows the values of these parameters.

Parameter	Values	Combinations
Location	Chihuahua, Ciudad Juárez, Nuevo Casas Grandes, Temósachic	4
Crop	Tomato, Cucumber, Bell Pepper	3
Material	Polycarbonate, Polypropylene, Horticultural Glass	3
Type of wall	Single and Double	2
Control	Broad and Narrow	2
Total		**144**

TABLE 1. Parameters and their possible values

Once the parametric analysis was performed, consumption was calculated for the following systems:

- LPG for heating
- Water for evaporative cooling
- Electricity consumed by the heating, cooling, and ventilation fans

With the costs of energy, water, and building materials, we performed a financial analysis to calculate the net present value of all the costs of the project. We used the following cost increase predictions, based on historical data:

- Inflation of 5%
- Annual LPG price increase of 9%
- Annual electricity price increase of 5%
- Annual water cost increase of 4%

Construction material and energy costs were calculated for the city of Chihuahua. The greenhouse has 200 m^2 of floor area, 120 m^2 of wall area, and 200 m^2 of pitched roof.

RESULTS

The effect of temperature control

Figures 2 and 3 show a comparison of broad and narrow temperature control of the greenhouse air. Narrow temperature control is much more expensive than broad control, but this effect dwarfs in comparison to that of geographic location.

City	Narrow Band Control	Broad Band Control	Savings %
Chihuahua	$62,169.72	$45,276.56	27
Cd. Juárez	$76,468.59	$ 60,865.15	20
Nvo. Casas Grandes	$102,304.07	$85,791.14	16
Temósachic	$158,039.44	$138,979.88	12

TABLE 2.- Energy savings (MX $) from the LPG heater achieved just by switching between narrow- and broad-band control schemes (data for tomato and polypropylene).

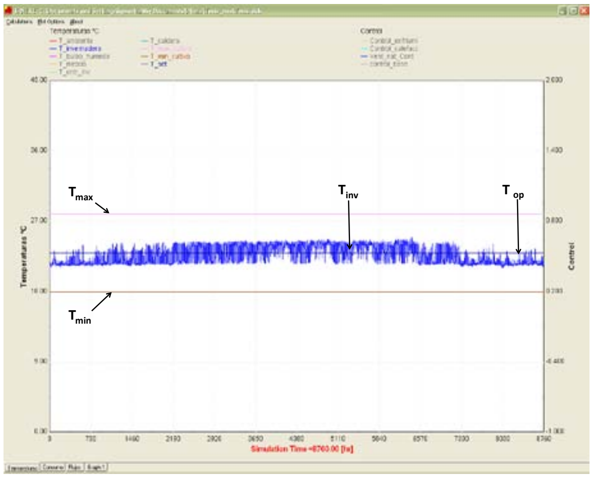

FIGURE 2.- Narrow-band temperature control

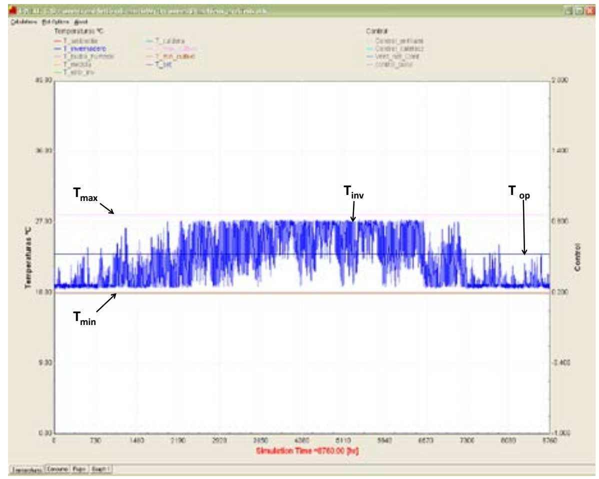

FIGURE 3.- Broad-band temperature control

Construction material

Figures 4 and 5 shows that the energy consumption pattern is similar for all simulated materials. The graphs show that the material which generates the least energy cost in the greenhouse is polycarbonate, followed by polypropylene and horticultural glass. It should be noted, however, that the energy savings are very similar for polycarbonate and polypropylene while their material cost is not. Polycarbonate is about 2.75 times more expensive than polypropylene, therefore durability should be the decision factor.

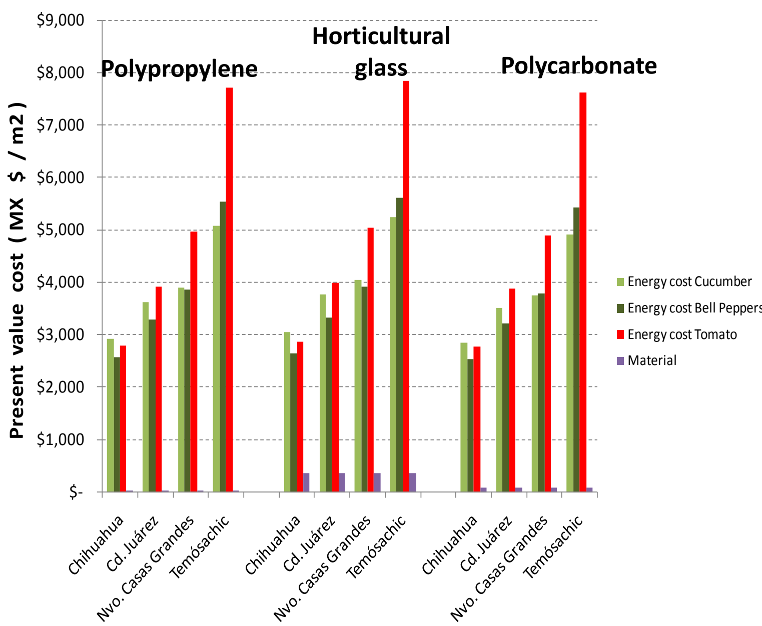

FIGURE 4.- Energy and materials cost with single wall (present value, 10 years operation)

Geographic location of the greenhouse

Figures 4 and 5 show how the energy cost of the greenhouse depends on the weather conditions of its location. It shows how the energy cost, per m^2 of floor surface, changes considerably for different cities with different climate. For a greenhouse growing tomato and built from single-wall horticultural glass, changing location from Chihuahua to Temósachic represents an increase in energy cost of 173% (Figure 4).

Double versus simple walls

Figures 4 and 5 compares a single-wall and double-wall greenhouses. The latter result in significant energy savings, even though material costs are doubled. Double walls made from polypropylene result in energy savings of 29% (tomato), which far exceed the cost of adding the second wall.

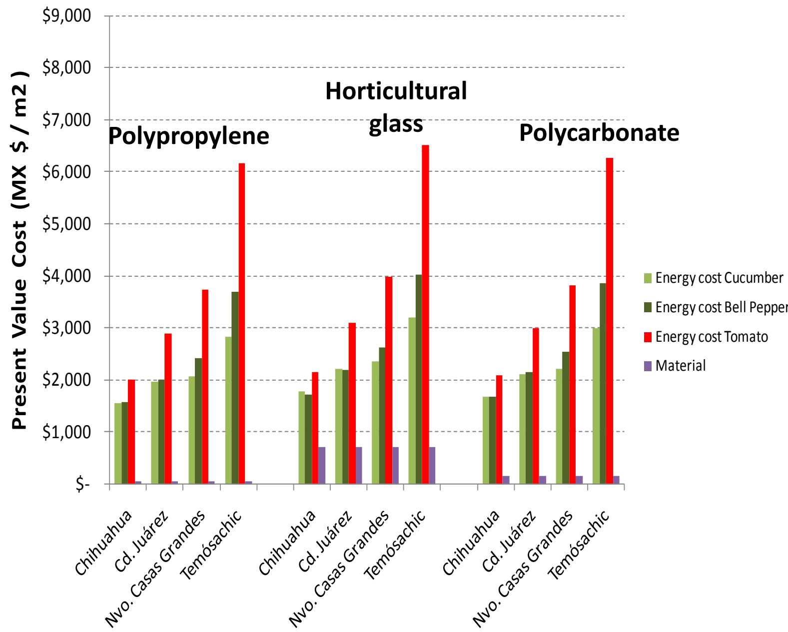

FIGURE 5.- Energy and materials cost with double walls (present value, 10 years operation).

CONCLUSIONS

The use of dynamic simulation, capable of modeling weather variations over extended periods of time and the energy interactions between a simple building and its environment, is indispensable to estimate the energy consumption of greenhouses. From the parameters analyzed in this work, we can conclude that geographic location has an enormous impact on the energy cost of agricultural greenhouses.

In climates like those of the state of Chihuahua, the insulation boost from double walls results in energy savings that far exceed the cost of the second wall. Considering only energy and wall materials costs and 10 years of continuous operation, the energy cost of a properly operated greenhouse can represent 96% of the total, with construction materials comprising the remaining 4%. The profitability of this kind of businesses depends mostly on energy consumption, and great care should therefore be taken in analyzing their design. Any variation in the design can determine the economic success or failure of the venture.

The profitability of each possible design can be calculated from the results of this work, the expected productivity per unit area, the market value of the crops, and the costs of construction and transport. This calculation, then, provides a key element for making investment decisions. The software tool presented in this work can analyze the behavior of any type and size of greenhouse, operating in any location for which weather data is available, and provide valuable information on the expected energy expenditures.

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