Closed Greenhouse: a Starting Point for Sustainable Entrepreneurship in Horticulture

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Abstract

Between 1998 and 2003, the company Ecofys from Utrecht developed and tested a new concept of an integrated climate and energy system that permits permanently closing the ventilation windows of a greenhouse. The technical concept consists of a combined heat and power unit, heat pump, underground (aquifer) seasonal energy storage as well as daytime storage, air treatment units, and air distribution ducts. Active air circulation is one of the key elements for controlling the climate (T, RH, CO2) at crop level. This paper discusses the technical aspects and the results of a trial using a fully closed 1400 m² demonstration greenhouse for tomato production. Results showed: 1) reduction in primary energy (fossil fuel) use of 20 and 35% respectively for an “island” closed greenhouse and a closed-conventional combination greenhouse, 2) increase in tomato yield of 20%, 3) an 80% reduction in chemical crop protection, and 4) a 50% reduction in use of irrigation water. The energy efficiency was improved by 50%. Finally, some preliminary environmental data will be shown for the first 14,000 m² of closed greenhouse installed at a commercial greenhouse operation. The concept of a fully closed greenhouse will be discussed in relation to sustainable greenhouse production.

INTRODUCTION

Modern greenhouse production requires a high level of environmental control. In this context, it has been recognized that fully closing a greenhouse, i.e. without air exchange with the outside environment, would have a number of advantages. In 1997, the Dutch government and the greenhouse industry agreed to the so-called GLAMI covenant.

The main objectives for the year 2010 described in this covenant are as follows:

• 65% improvement in energy efficiency compared to 1980
• 72% and 88% reduction (respectively) in use of chemical crop protection for fruit/vegetable and flower production compared to the 1984-1988 levels
• 4% of the energy use provided by sustainable energy

A fully closed greenhouse could be a significant improvement towards reaching the goals of the GLAMI covenant. However, the main challenge of closing the greenhouse is to be able to continuously control temperature (T) and relative humidity (RH) under varying inside and outside conditions. For example, on a cloudless summer day with high solar radiation, the amount of heat to be removed from a greenhouse is significant. In the Netherlands, the solar radiation can reach a peak level of 800 W/m².

In 1995 an entirely closed greenhouse was considered as not economically feasible in the Netherlands, due to high electricity prices and investment costs (Van de Braak, 1995).

Between 1998 and 2003, Ecofys in Utrecht developed a new concept for an integrated climate and energy system that allows for the permanent closure of the ventilation windows in a greenhouse. Ecofys, in cooperation with Applied Plant Research from Naaldwijk, has tested the concept in a 1400 m² experimental greenhouse located in Naaldwijk, the Netherlands. The objectives of the demonstration project included both tomato production as well as climate control and energy use. The tomato production results are described in an accompanying paper (De Gelder et al. 2005). The environmental control and management objectives included an evaluation of the:
1. Climate control system,
2. Temperature distribution (horizontal and vertical), and
3. Energy use.

In 2003, a new company named Innogrow was started for the purpose of commercializing the closed greenhouse concept developed under the name GeslotenKas®. In March 2004, the first project totaling 14,000 m² of closed greenhouse for tomato production was realized. This project is located at the commercial greenhouse operation Themato in Berkel en Rodenrijs, the Netherlands. In this paper, results of the 1400 m² demonstration greenhouse and some of the preliminary results of the 14,000 m² commercial operation will be described.

MATERIALS AND METHODS

Figure 1 shows the concept of a closed greenhouse. To control the inside climate, air will be circulated and conditioned by means of air conditioning units. These units are designed to cool, dehumidify, and heat the air. After treatment, the air is distributed through air distribution ducts that are crucial for a uniform air distribution. The outlets of the air ducts are designed to realize optimal vertical and horizontal temperature distribution. Thus, a grower will be able to control the temperature, relative humidity, and CO₂ concentration.

The Demonstration Project

During 2001-2002, a demonstration project of 1400 m² of tomato production was conducted. The air distribution ducts (0.8 m diameter, 45 m length) were placed underneath the growing channels. During this trial, the aquifer and the combined heat and power (CHP) were not incorporated for economical reasons. The cold water supply from the aquifer was provided by a cooling machine. The following parameters (in addition to crop parameters) were measured: solar radiation, outside temperature, wind direction and velocity, inside temperature, inside relative humidity, and inside CO₂ concentration. In order to get insight in the vertical and horizontal temperature distribution, additional temperature measurements were performed. Furthermore, electricity use and heat flows of all relevant components were recorded.

The Themato Project

During 2003-2004, Innogrow designed for 14,000 m² of the 54,000 m² existing greenhouse to be fully closed at the commercial tomato producer Themato in Berkel en Rodenrijs. Priva Hortimation designed and installed a new environment control computer. The air treatment and distribution systems were the same as used for the demonstration project. The air distribution ducts were 85 m long. For the Themato project, an aquifer with three cold (6°C) and three warm (20°C) volumes was used. This project has been operational since March 2004. The surplus in heat energy from of the fully closed greenhouse area was delivered to the remaining “open” area of 40,000 m². Based on calculations, a reduction in the total energy use was expected to be 30-40% for the entire greenhouse area of 54,000 m². In fact, the closed portion can be considered as an energy delivery system.

RESULTS AND DISCUSSION

Climate Control

Figure 3 shows the 24-hour averages of the observed climate during the demonstration trial for the period February-November 2002. The CO₂ measurements (ppm/10) represent the daytime averages. The CO₂ concentration was maintained at approximately 1000 ppm. Figure 3 shows that an increase in outside temperature results in a decrease in inside set point temperature and therefore a decrease in inside temperature. Through the middle of April, the relative humidity (RH) increased as a result of crop development. For the remaining period, the RH remained quite stable.
Figure 4 shows the environmental conditions in both the “open” and closed greenhouse at the commercial tomato operation Themato in Berkel en Rodenrijs. Figure 4 shows that on a warm, sunny day with a solar radiation of up to 800 W/m², the temperature in the closed greenhouse section increased to 26-27°C while in the “open” conventional section the temperature reached 31°C. Outside temperature rose to approximately 28°C. During the daytime, the RH decreased to approximately 80 and 60% in the closed and “open” section, respectively.

In the closed greenhouse, the CO₂ concentration remained around 1000 ppm whereas in the “open” section the concentration remained at approximately 500 ppm.

At the time of writing this article, the project at the commercial grower Themato operates with great success. One could conclude that the new concept of climate control is well able to permit the permanent closing of the ventilation window independent of inside and outside conditions.

**Temperature Distribution**

The horizontal temperature distribution was measured during the 1400 m² demonstration trial. The deviation was within 1-1.5°C from the mean. Figure 5 shows measurements on a warm day in August 2002 as an example. During the night the temperature remained very uniform. From 10:00 hr through 19:00 hr in the center of the greenhouse the most effective cooling was measured. The largest temperature deviations (upper left side during the middle of the day) were explained by the position of sun.

Figure 6 shows differences in temperature between 1.35 and 2.50 m height for three locations in the 1400 m² demonstration trial (front, middle, and back). The vertical gradient is limited to about 1°C for a solar radiation range of 200-800W/m². Below 200 W/m², the gradient is approximately 2°C. The explanation can be found in the low sky temperature at night (solar radiation is zero), influencing the temperature at the height of 2.50 m more than at 1.35 m.

One could conclude that the use of air distribution ducts is quite appropriate for providing uniform temperature levels.

**Energy Use**

One of our main goals was to determine the reduction in primary energy use (fossil fuel). Storage of the surplus of summer heat for use during the winter may substantially reduce energy consumption. On the other hand, active circulation of air and pumping of water in and out the aquifer requires extra energy. The reduction in primary energy use will depend on the net result of all energy uses. A closed greenhouse can be considered as a solar collector. On an annual basis there will be a surplus of solar energy. A combination of a closed greenhouse with a conventional "open" greenhouse is profitable due to heat delivery from the closed to the “open” greenhouse. The “open” greenhouse does not require active circulation so in that respect there is no need for extra energy.

The relevant energy flows were measured during the demonstration greenhouse trial. In order to correctly interpret these data, the relative small area (1400 m²) must be taken into account. Furthermore, the experiment was performed in a 12-year old greenhouse. Therefore, measured energy data were scaled up to an imaginary 3 ha greenhouse built in 1990. In the scaling process, some reasonable assumptions were made with respect to for example the Seasonable Performance Factor (SPF = 5) of the heat pump, and the magnitude of the energy supplied by the heat pump compared to the total energy demand.

It can be seen from the Table 1 that an “island” closed greenhouse can reduce the energy use by 19%, whereas the combination of closed and “open” greenhouse can save 33% in primary energy use. The 33% reduction in primary energy use concerns the entire area of closed and open greenhouse (a total 9 ha in Table 1). The closed/open greenhouse combination will more significantly reduce the primary energy use compared to the “island” greenhouse mainly because of the excess in collected solar energy in the “open”
greenhouse. The energy efficiency calculated based on increased production and energy savings improved by 50%. The contribution of sustainable energy is approximately 45%. For each greenhouse design an optimal ratio between conventional “open” and closed area must be determined based on energy flows.

**Crop**

The demonstration trial with 1400 m² of tomatoes showed that a closed greenhouse is able to improve crop production. A 22% increase in tomato production was achieved (based on a comparison using the simulation model TOMSIM compared to a conventional greenhouse (De Gelder et al., 2005). The use of chemical crop protection decreased by 80%, and the use of irrigation water dropped by 50% (De Gelder et al., 2005).

**Closed Greenhouse: a Starting Point for Sustainable Production**

For all industrial activities worldwide, it has been recognized that sustainable production is highly desirable. Sustainable greenhouse production should focus on, for example, zero-energy use (no fossil fuels), zero chemical crop protection, recycling of irrigation water and improvement of working conditions. A closed greenhouse (with no ventilation openings) can be a starting point. A closed greenhouse requires means for regulating the heat (temperature), humidity, and CO₂ concentration. Free energy is provided by solar radiation. Substantial energy savings can be achieved when during the summer solar energy is stored and reused during the winter. On an annual basis there is a surplus of stored energy and that surplus can be delivered to adjacent greenhouses or to residential and industrial sites. In order to truly achieve zero-energy (fossil fuel) usage, the remainder of the energy demand can be covered by renewable energy like biomass, wind power and/or photovoltaics. The main challenge to implementing this renewable energy will be economics.

**CONCLUSIONS**

The feasibility of the closed greenhouse system has been demonstrated through a demonstration sized trial as well as a commercially scaled trial at an innovative tomato grower. From an energy point of view, the closed greenhouse system should be combined with an “open” area, allowing the reduction of energy use to be as high as 20-35%. The contribution of sustainable energy can be as high as 45%. The achievable temperature and relative humidity levels during the summer period are quite acceptable. CO₂ levels can easily reach 1000–1200 ppm continuously. An increase in tomato production of 22%, a 50% reduction in irrigation water, and an 80% decrease in chemical crop protection was achieved (De Gelder et al., 2005). Energy efficiency was improved by 50%. The scaling up from 1400 m² to 14,000 m² closed greenhouse was completed successfully. The closed greenhouse concept can be considered a starting point for sustainable greenhouse production.

**Literature Cited**


Tables

Table 1. Energy balance in a new (2003) 3 ha closed “island” greenhouse and a combination of a 3 ha closed with 6 ha conventional “open” old (1990) greenhouse.

<table>
<thead>
<tr>
<th>Heat flows</th>
<th>Closed 3 ha (2003)</th>
<th>Combination 3 ha closed with 6 ha open (total 9 ha)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Nm³/m² (Gas)</td>
<td>Contribution (%)</td>
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<td>Reference</td>
<td>52.1</td>
<td>52.1</td>
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<td>Heat storage</td>
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<tr>
<td>Heat demand</td>
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<td>Heat pump (seasonal performance factor = 5.0)</td>
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<td>55</td>
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<tr>
<td>Combined heating power (ηh = 38% / ηn = 53%)</td>
<td>20.6</td>
<td>36</td>
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<tr>
<td>Boiler (n = 100% u.v.)</td>
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<tr>
<td>Sustainable energy</td>
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<tr>
<td>Primary gas use</td>
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<td>-19</td>
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</table>

Figures

Fig. 1. Closed greenhouse concept including: subsoil longterm energy storage, boiler, heat pump, combined heat and power supply (CHP).
Fig. 2. Air distribution ducts with a length of 85 m located underneath the growing channels at the commercial operation Themato in Berkel en Rodenrijs.

Fig. 3. Greenhouse climate and outside temperature recorded in the demonstration greenhouse trial during 2002. A= CO₂-concentration (ppm, average between 10:00–18:00 hour) B= RH (%), 24-hour average). C (line)= set point temperature (°C); D (dots)= greenhouse temperature (°C, 24-hour average); E= outside temperature (°C, 24-hour average). Dots in the center of the figure are low CO₂-concentrations due to problems in CO₂-supply.
Fig 4. Measured environmental parameters (T, RH, irradiance) in the 40,000 m² conventional “open” and the 14,000 m² closed greenhouse on 7 June, 2004. The solar radiance curve peaks at 800 W/m² at 01.00 PM.

Fig 5. Horizontal temperature distribution (hourly average) at a height of 2.5 m for every hour (left to right and top to bottom) on August 16th during the demonstration trial. The grey tones indicate the deviation from the measured average value. Numbers along the axes indicate the distance in meters.
Fig. 6. Temperature differences between 1.35 and 2.50 m height (hourly averages, June 2002).