A Concept for Reduced Energy Demand of Greenhouses: the Next Generation Greenhouse Cultivation in the Netherlands

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Abstract

In high tech greenhouse cultivation like in The Netherlands, large amounts of fossil energy are used to optimize climate conditions like temperature and humidity. To achieve a more sustainable greenhouse horticulture, a considerable reduction in energy use is needed, but tradeoffs with production and quality are not acceptable. Therefore, we developed a novel cultivation system for tomato to meet the goal: reduction of the energy input by 40% from 1.3 to 0.75 GJ.m^{-2}.y^{-1}, maintaining a production level of 60 kg.m^{-2}.y^{-1}. This concept, the Next Generation Greenhouse Cultivation, is based on the intensified use of thermal screens combined with control of humidity, maximizing the use of the integration capacity of the crop, growing at high humidity, improved efficiency of CO_2 supply by reduction of ventilation and the use of cooling combined with a heat pump and an aquifer. In this approach, the main element is the prolonged use of screens with a high insulating value (>70%) to reduce the energy demand, combined with a forced ventilation system that injects relatively dry outside air into the greenhouse. The maximal use of the integration capacity of the crop implies a strong relation between daily radiation sum and diurnal mean temperatures, and a large difference between night and day temperatures on sunny days. This reduces the energy input and ventilation rate. Growing at increased humidity, achieved by misting, reduces ventilation rates because of the increased enthalpy of the greenhouse air. When supplying CO_2, reduced ventilation results in higher CO_2 concentrations and hence a higher energy efficiency. Cooling can be used in combination with a heat pump and an aquifer to reduce the need for fossil fuel. This approach, in which proven technologies are combined, enables growers to implement the elements step by step, leading to an easy acceptance.

INTRODUCION

Reducing the energy consumption in greenhouse horticulture is a major challenge for sustainable cultivation. At the end of last century important steps were taken to realize that goal. In the 1980s, energy screens were introduced (Grange and Hurd, 1983), the possibilities of temperature integration were investigated (Koning, 1990) and greenhouse constructions were improved to avoid leakage (Post, 1988). The Dutch agro industry has set the goal to reduce the CO_2 emission with 48% compared to 1990. This can only be achieved if the use of energy is reduced by all growers. In the last decade research in semi-closed greenhouses aimed at harvesting energy in summer to re-use in winter (Opdam et al., 2005). However, semi-closed greenhouses require high investments and are therefore only profitably when sufficient extra production is realized. The introduction into practice was found to be difficult (Gieling et al., 2011). Therefore another approach is necessary which has lower investment costs but still a significant contribution to energy saving.

Lysen (1996) stated that the best approach to grow sustainable is the use of three important steps: first - reduce the heat requirement by insulation; second - use sustainable resources and third - if fossil energy is required, use this as efficient as possible. Energy consumption for growing tomatoes in the Netherlands is 1300 MJ.m^{-2}.y^{-1} (Vermeulen, 2010). Elings et al. (2005) calculated the effect of 11 individual energy saving measures.

The maximal calculated reduction of energy use was 27% with improved insulation. However, these results were not validated in practice yet. To grow sustainable and achieve the goal of 48% less CO_2 emission a further reduction of the energy use is required.

A desk research was performed aiming to develop an integrated concept for the growth of tomatoes with a heat requirement of 750 $MJ.m^{-2}.y^{-1}$. This paper describes the major components of the concept and the results of a simulation study.

CONCEPT DESCRIPTION

The ambitious goal and prerequisites for the new approach are:

- Energy consumption for heating should not exceed 750 $MJ.m^{-2}.y^{-1}$.
- Techniques to be used have to be commercially available.
- Growers have to be able to introduce the techniques in their greenhouses stepwise.
- Production and product quality should be comparable to a normal commercial farm.

After discussions with experts on topics like photosynthesis, growing techniques and energy saving, a draft approach has been written, using the experience of ongoing research in semi-closed greenhouses as well. This draft was used to formulate the input information to simulate the greenhouse climate and energy use with the greenhouse climate model KASPRO (Zwart, 1996). Effects of the different measures: additional screens, temperature, planting date, fogging and temperature integration on crop production were evaluated as well. The result of this study was a concept to grow year round tomatoes with a reduced energy use.

The final concept consists of:

1. Improved insulation by the use of multiple screens;
2. Forced ventilation to control humidity;
3. Maximal use of the integration capacity of the crop realized by optimal use of the possibilities of advance climate control;
4. Adjustment of the production plan;
5. Use of fogging to reduce ventilation and retain CO_2 in the greenhouse;
6. Use of a combination of a heat pump, aquifers as energy storage and active cooling.

Screens

To improve insulation, screens should be used more intensively by increasing the number of hours the screens are closed and by using screens with higher insulation values. Night length in the Netherlands is more than 16 hours in winter. In those hours insulation is possible without loss of light. Double movable screens offer even more possibilities to conserve energy. Model calculations showed that by adapting the criteria to close or open a normal screen it was possible to save 30 $MJ.m^{-2}.y^{-1}$. Addition of a screen with a high insulating value decreased the energy demand by 115 $MJ.m^{-2}.y^{-1}$. The number of hours the screens were closed in the control situation and in the new concept is shown in Figure 1. To save even more energy in winter under natural light conditions, a light transmitting anti-condense film can be used. However, this was not used in the model simulations.

Forced Ventilation

Humidity can become an important problem when using screens, since little condensation against a cold greenhouse cover can take place and less vapour is transported. Therefore, in current practice, frequently screen gaps are used (Braak et al., 1998; Dieleman and Kempkes, 2006). As a spin-off of growing in closed greenhouses (Opdam et al., 2005), Campen (2008) investigated a system which enables forced ventilation, which is used in our concept. By this forced ventilation humidity can be lowered in a precisely controlled way without opening the screen. Natural chinks and holes usually are sufficient to get rid of the air blown in. At the same time, the distribution of temperature and humidity becomes more uniform so that a higher humidity can be allowed for the crop. This reduces the ratio between latent heat loss per gram humidity and the latent heat loss per m^3 air, which allows a more energy friendly humidity control. By the improved humidity control, the screens can be closed longer, which gives an additional energy conservation by a reduced heat exchange.

The effectiveness of this humidity control depends on the absolute humidity outside and the air flow rate. Forced ventilation itself does not save energy, but the extended use of screens and the fact that screen gaps are not used does. The reduction of energy use due to this combined effect of closed screens and forced ventilation is 75 $MJ.m^{-2}.y^{-1}$. Simulations showed a higher average humidity in the greenhouse due to these changes (Fig. 2A), but the number of hours with a relative humidity above 90% decreased (Fig. 2B). This will most likely not affect growth of the tomato, since tomatoes can grow very well at high humidities. Botrytis can be a serious threat, however, since the number of hours with a humidity above 90% (i.e. a high risk for botrytis) was reduced, this might even have favourable effects for crop production.

Temperature Integration

Research on semi-closed greenhouses and temperature integration showed that tomato has wide boundaries in accepting high day-time temperatures. Therefore, in this concept, temperatures during day were allowed to reach 27°C, provided that during the night low temperatures can be realized to obtain the required diurnal temperature. This resulted in larger differences between day and night temperature. The diurnal temperature will be adjusted to the light sum, since at higher radiation sums a higher growth rate can be realized (Elings et al., 2006). The strategy to realize the diurnal temperature has to be adjusted to the demands of the canopy with an advanced climate control system. The combined effect of decreasing the base temperature by 1°C, increasing the adaptation of ventilation to light intensity by 2.5°C and temperature integration, is calculated to be a reduction in energy use of 130 $MJ.m^{-2}.y^{-1}$.

Adjustment of the Production Plan

For year round tomato cultivation young plants are planted in the cold and dark month of December. Shifting the planting date to early January does not lead to a lower production level, it only slightly delays first production. This can be an energy saving option, as the greenhouse in the cold month of December can be left empty and does not have to be heated. Model calculations show that the change in planting date saves 75 $MJ.m^{-2}.y^{-1}$.

Strategic CO_2 Supply

Higher temperatures and a uniform distribution of humidity allow the reduction of ventilation during day-time. Lowering ventilation will result in a higher CO_2 concentration in the greenhouse at a given supply capacity, which is favorable for growth. This increase in growth is required to compensate for the adverse effects of the light reduction by the screening installations. Dosing of CO_2 is not a measure to reduce the energy demand but is necessary to keep the production at the desired level.

Cooling, Heat Pump and Aquifer

The sun provides more than sufficient energy during the summer. Excess energy can be used sustainably and can be stored by using coolers. While cooling, the greenhouse temperature will fall slightly, and reduce ventilation. At warm outside conditions (temperature >18°C) coolers can also be used to lower night temperature in the greenhouse. The collected heat has to be stored in long-term buffers and can be combined with a heat pump used to heat the greenhouse. Coolers with a capacity of 100 $W.m^{-2}$, according to the technical specifications, can save 375 $MJ.m^{-2}.y^{-1}$. Dehumidification with cooling and heating is possible with this installation and profitable if combined with heating of the greenhouse (Campen et al., 2003). Cooling and the use of a heat pump and aquifer contributes to the reduction of input of fossil energy, which is replaced by the sustainable solar energy.

Model calculations showed that the combined effects of all elements of this concept reduced the demand for natural gas. Energy input drops to16 $m^3.m^{-2}.y^{-1}$ (Fig. 3). This is an equivalent of 520 $MJ.m^{-2}.y^{-1}$. This is used in the combined heat and power generator. The engine delivers 280 MJ to heat the greenhouse, 200 MJ electric power for circulation pumps, aquifer and heat pump and 40 MJ is lost via exhaustion gases. The heat pump delivers 595 MJ to heat the greenhouse.

CONCLUSION AND PRACTICAL APPLICATION

According to the model simulations, combining options - excluding cooling, heat pump and aquifer - resulted in a production level and energy demand close to the goals set. With the first 5 steps of the Next Generation Greenhouse Cultivation it should be possible to produce 60 $kg.m^{-2}.y^{-1}$ tomatoes with a heat demand of 875 $MJ.m^{-2}.y^{-1}$, compared to a heat demand of 1300 $MJ.m^{-2}.y^{-1}$ in the reference situation. The last measure, installing a cooling system with a heat pump and aquifer results in a further saving of 355 $MJ.m^{-2}.y^{-1}$. However, this is the most expensive step to implement. Since so far semi-closed greenhouses are not economically feasible, the cooling system was left out of the concept of the Next Generation Greenhouse Cultivation. The goal for heating demand in this desk study set was arbitrary set at 750 $MJ.m^{-2}.y^{-1}$. Results showed that this is too ambitious. However, a decrease of the heat demand to 875 $MJ.m^{-2}.y^{-1}$ was found to be realistic.

For crop growth positive (control of humidity reduces the number of hours with RH above 90%) and negative effects (more screens reduce light transmission of the greenhouse) can be expected. Air movement and a lower temperature of the heating pipes will occur. Some of this effect can be simulated with a model, such as a reduction in light integral due to an additional screen. Others such as a change in plant temperature due to lower pipe temperatures and air movement are hard to evaluate. In closed greenhouses vertical temperature gradients occur and growers had to learn to grow under these different conditions compared to normal greenhouses (Gieling et al., 2011; Qian et al., 2011). For this new concept of growing the effect on climate and crop development has to be tested. For practical application, the options 1 to 3, i.e. the use of multiple screens, the use of forced ventilation and integrated climate are relatively simple to apply. A substantial energy saving by applying described measures is possible. Cooling in combination with a heat pump and aquifer requires a high investment. The results of the desk research are a sufficient basis to test the concept in practice. An accompanying paper (De Gelder and Dieleman, 2012) shows the results of a validation experiment to test the application of the concept and the energy performance in practice in a greenhouse of 1000 m^2 with a tomato crop.

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Tables

Table 1. The contribution of elements of the concept for the Next Generation Cultivation to energy saving.

	Energy demand (MJ.m^{-2}.y^{-1})
Reference	1300
Screens	-145
Forced ventilation	-75
Temperature integration	-130
Adjustment of the production plan	-75
Strategic CO_2 supply	0
Cooling, heat pump and aquifer	-375
Concept	500

Figures

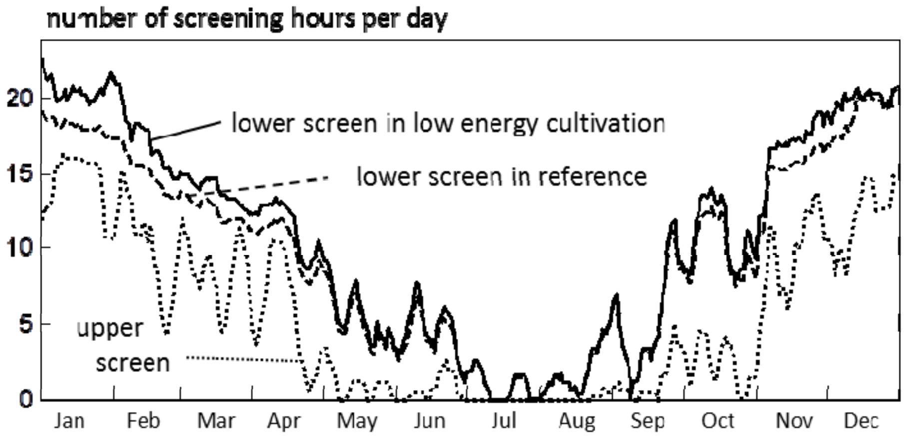

Fig. 1. Number of screening hours with a normal screen in the reference crop, the number of hours after the adjustment of the closing criteria and number of screening hours of a second high insulation screen (upper screen).

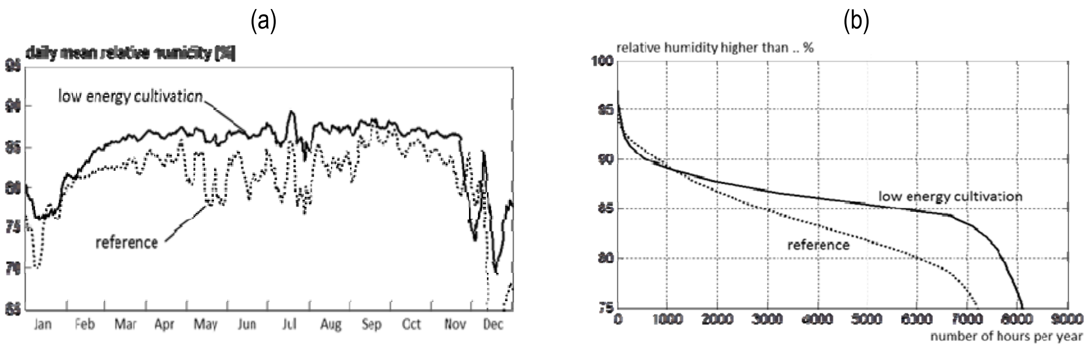

Fig. 2. The effect of the low energy cultivation on daily mean relative humidity and on the number of hours per year where humidity is above a certain threshold value.

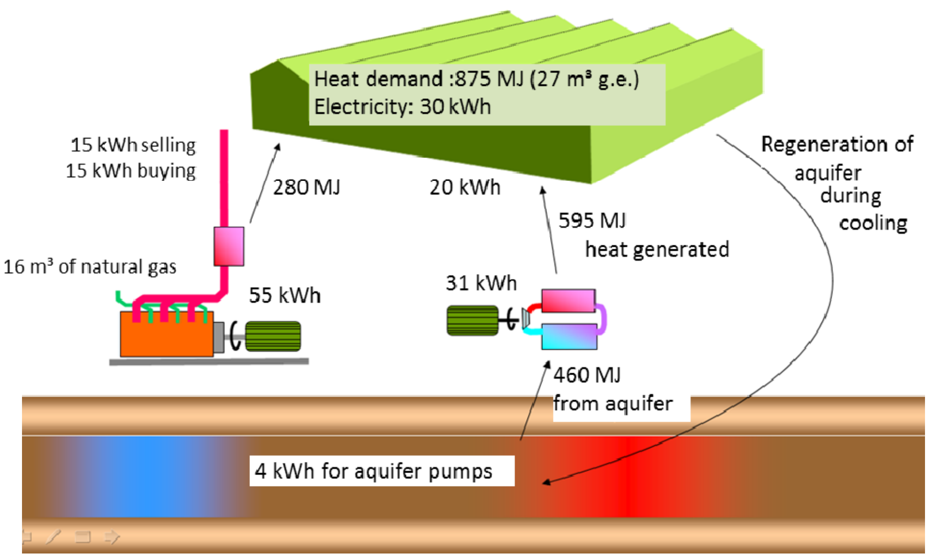

Fig. 3. The energy sources and their use in the concept of the next generation cultivation.