New Greenhouse Concept with High Insulating Double Glass and New Climate Control Strategies – Modelling and First Results from a Cucumber Experiment

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Abstract

The goal of the Dutch horticultural sector is to build new greenhouses in 2020 without the use of fossil energy and reduce CO_2-emissions with 45% compared to 1990. Until now, energy losses through the covering are reduced by closing energy screens, mainly during night time. In winter even during daytime transparent screens are closed resulting in a significant reduction of light in the greenhouse. However, even higher insulation values can be reached by insulating double covering materials. In an earlier study we showed that new developed coverings using anti-reflection coatings to increase light transmission and low-emission coatings to reduce energy losses only show minor light losses and are suitable as double glazing. One of the glasses developed in an earlier study has been integrated in a total greenhouse concept of 500 m^2, realized in summer 2010 at the research station of Wageningen UR Greenhouse Horticulture in Bleiswijk. The glass used has a light transmission of 88% perpendicular (τ_p) and 79% hemispherical (τ_h) and an u-value of 1.2 W m^{-2} K^{-1} (compared to τ_p=90%, τ_p=82%, u=6.7 W m^{-2} K^{-1} of single glass). In order to develop the optimum growing strategy scenario calculations of greenhouse climate (temperature, humidity, CO_2) and energy consumptions year-round were carried out with a validated dynamic climate model. Effects on cucumber production (dry matter) were calculated. That way the optimum growing strategy in terms of low energy consumption combined with a high cucumber yield was developed. Model calculations showed that a cucumber production of 75 kg m^{-2} a year should be possible with a gas consumption of 12 m^3 m^{-2}, an electricity consumption of 8 kWh m^{-2} and a CO_2 consumption of 43 kg m^{-2}. That way the energy consumption per kg cucumber would be reduced from 0.53 m^3 gas equivalents to 0.19. A first experiment in the new built greenhouse in Bleiswijk with an autumn crop of cucumbers seems to confirm the theoretical results.

INTRODUCTION

The goal of the Dutch horticultural sector is to build new greenhouses in 2020 without the use of fossil energy, to reduce CO_2-emissions with 45% compared to 1990, to increase energy-efficiency per amount of produce by 2% yearly and to use 20% of sustainable energy sources in greenhouses in 2020. The goals are formulated in the energy research program "Kas als energiebron" (PT and E,A&I, 2011). The goals of energy saving have to be reached by reducing energy losses through the greenhouse surface, to increase energy efficiency by new growing and climate control strategies and to make as much as possible use of free solar energy.

In Dutch greenhouses 75-90% of the energy is used for heating purposes and to reach an optimum temperature for crop production. With increasing energy prices the need for energy saving is high in horticulture. The energy saving potentials of double layered covering materials for greenhouse applications have been pointed out in many research studies before (e.g. Andersson and Nielsen, 2000; Bot, 2001; Villeneuve et al., 2005; Zhang et al., 1996). Since more than 90% of Dutch greenhouse area is covered with single glass, energy losses through the covering are high during heating period in winter.

Until now, in Dutch greenhouses energy losses through the covering were reduced by closing energy screens, mainly during night time, saving ca. 20-30% of the energy (Bakker et al., 2008). In winter even during daytime transparent screens are closed on cold days to reduce energy losses. This measure results in a significant reduction of light in the greenhouse, though.

High insulation values can also be reached by insulating the greenhouse surface with double covering materials. In 2009 Hemming et al. showed in a study that it is possible to develop new double covering materials without light reduction using anti-reflection coatings and realizing high insulation values using low-emission coatings. In model calculations the authors showed that a reduction in energy consumption of 25-33% should be possible while maintaining high production levels if enough CO_2 is available.

In Dutch greenhouses 10-25% of the energy is used for dehumidification purposes. The most common procedure used to remove moisture from a greenhouse is to open thermal screen and ventilation windows. This causes an exchange between the relatively dry air outside and humid greenhouse inside air. Greenhouses with high insulation values potentially lead to high humidity levels since dehumidification by condensation processes on the greenhouse inner surface is limited. It is therefore necessary to take measures to prevent accumulation of high humidity. Campen et al. (2009) have shown that energy saving dehumidification is possible by blowing in dry outside air. The authors proposed a mechanically controlled dehumidification system where outside air is exchanged with greenhouse air using ventilators and an air distribution system under the crop.

It is further known that climate control strategies influence total energy consumption and that adaptations of set points for heating and humidity can lead to a reduction of energy use (Bakker et al., 2008). Temperature integration is an important measure next to allowing higher humidity levels for crop production. Based on that knowledge, new growing strategies have been developed and tested in The Netherlands for different crops. For example de Gelder et al. (2010) showed that a reduction of energy consumption in a cucumber crop by 40% was possible by applying new growing and dehumidification strategies. The total gas consumption was 25 m^3 m^{-2} $year^{-1}$, the electricity consumption 6 kWh m^{-2} $year^{-1}$ with a production of 75 kg m^{-2} $year^{-1}$ in their experiments in 2009. So they reduced the energy efficiency per crop from 0.53 m^3 gas kg^{-1} to 0.36 m^3 kg^{-1}.

Combining a modern high insulation greenhouse covering with dehumidification equipment and applying new energy saving growing strategies, it should be possible to reduce energy consumption without crop production losses. For that purpose a demonstration greenhouse of 500 m^2 is built at the research station of Wageningen UR in Bleiswijk, The Netherlands. In this paper we compare real experimental data of greenhouse climate, energy consumption and crop production with results of model calculations carried out before the experiment started. The goal of our study is to find out if it is possible to reduce energy consumption of a cucumber crop by at least 60% compared to usual horticultural practice, while maintaining the same crop production levels by the new greenhouse concept with high insulating double glass with modern coatings and new climate control strategies.

MATERIALS AND METHODS

Greenhouse Design and Equipment

A 500 m^2 demonstration greenhouse was built at the Wageningen UR research station in Bleiswijk, The Netherlands during summer 2010 (Fig. 1). The greenhouse is equipped with a new double glass covering material, a central dehumidification system with fans in the greenhouse side-wall blowing in dry outside air if necessary into a plastic tube distribution system under the cropping gutter in the greenhouse (Fig. 2). The system is also equipped with a heat regain unit, which is able to regain 75% of the sensible heat of the air extracted from the greenhouse by the dehumidification system. This “regain” heat exchanger is warming up outside cold air before distributed inside with heat extracted from inside warm air and condensation heat. The system is able to exchange 10 $m^3 m^{-2} h^{-1}$. A thermal screen (type XLS 10) is also installed.

Covering Material

In an earlier study several new glass covering materials were evaluated by Hemming et al. (2009). Glasses were covered with different anti-reflection coatings and/or low-emission coatings from different producers. Double glasses were produced and all glasses were evaluated. One of the producers scaled up the production, the glass was used in the new greenhouse concept. The glass consists of two single tempered glasses with a thickness of 3 mm. On three sides an anti-reflection coating was applied, one side was foreseen with a low-emission coating. The double glass has a split of 10 mm filled with argon gas. The glass used has a light transmission of 88% perpendicular (τ_p) and 79% hemispherical (τ_h) determined by Wageningen UR and an u-value of 1.2 W m^{-2} K^{-1} given by the producer. For comparison: traditional single greenhouse glass has a τ_p=90-91%, τ_h=82-83%, u-value=6.7 W m^{-2} K^{-1}. The optical properties of the material is shown in Figure 3.

Climate Control Strategy

The climate control strategy in the new greenhouse concept was determined before the experiment started in the demonstration greenhouse using experience from earlier experiments of de Gelder et al. (2010) with new growing strategies and model calculations with the dynamic greenhouse climate model KASPRO (de Zwart, 1996). Finally, in the experiment the following new climate control strategy was chosen. Temperature set point was 20-22°C during daytime, 16-20°C during pre-night and 19-20°C during night depending on outside climate conditions and crop stage. Humidity set point was based on values of vapour pressure deficit (vpd) and during night was >1-2 kPa vpd and during daytime >3-3.5 kPa vpd. At lower vpd the dehumidification system was used. At a vps higher than 4.5 fogging was turned on. CO_2 was applied at a set point of 1000 ppm. The energy screen was closed at set point of 50-100 W m^{-2} solar radiation and below an outside temperature of 10°C. Greenhouse air temperature, humidity, number of screening hours, CO_2 concentration, light level and energy consumption were measured permanently with an automated climate computer during experiments.

Crop Data

A cucumber crop 'Ranomi' was planted on August, 5th 2010 in the demonstration greenhouse in a high-wire system at a crop density of 2.2 plants m^{-2}. The crop ended on November, 16th 2010. During that period leaf development, plant length and cucumber production in pieces and kg was measured weekly.

Modelling New Greenhouse Concept

With the dynamic greenhouse climate model KASPRO the energy saving prospects of the new greenhouse concept (insulating double glass and new growing strategy) was determined before experiments in the new demonstration greenhouse started compared to a reference situation (traditional greenhouse, growing strategy like in horticultural practice) and compared to applying new growing strategies in a traditional greenhouse. The parameters for the three scenarios are described in Table 1. Modelled data were compared with experimental data.

RESULTS AND DISCUSSION

The first step in this research was to carry out model simulations of energy consumption, expected greenhouse climate and crop production in order to predict the prospects of the new greenhouse concept using high insulating double glass with modern coatings together with new climate control and crop growing strategies. The result of three scenarios of model calculations is given in Table 2. Applying new growing strategies in a traditional greenhouse results in a higher energy-efficiency and 40% lower gas consumption compared to traditional growing strategies used in horticultural practice. Applying new growing strategies in the new developed greenhouse concept with a high insulating greenhouse cover results in an even higher energy-efficiency, a 60% lower energy consumption can be realised following the model calculations including a higher electricity consumption for the dehumidification unit. The higher energy saving is mainly due to the insulating value of the covering, 3.5 m^3 m^{-2} $year^{-1}$ are due to the use of a heat regain unit in the dehumidification system. For a cucumber autumn crop (5th of August to 16th of November) energy consumption would be predicted to be 5 m^3 gas equivalents m^{-2} in the new greenhouse concept, yield is expected to be 22 kg m^{-2}. Experimental results show a good correlation with the earlier predicted values. The realised greenhouse climate is given in Table 3, the crop parameters are given in Table 4.

Figure 4 shows the calculated energy consumption per week for the reference situation in a traditional greenhouse with single glass, with the new growing strategy in a traditional greenhouse with single glass and with the new greenhouse concept with high insulating double glass year-round next to the measured energy consumption with the new greenhouse concept in the autumn experiment. An energy (gas) consumption of 12 m^3 m^{-2} $year^{-1}$ seems realistic, corresponding with an energy consumption of 5.0 m^3 m^{-2} during autumn period calculated and measured in the experiment.

Light levels can be expected to be higher in the new greenhouse concept with double glass especially during winter. In practice and in experiments with new growing strategies, screens are used intensively also during daytime in order to save energy. Using screens during daytime is not necessary within the new demonstration greenhouse; therefore light levels are calculated to be increased during winter (Fig. 5). In our experiments with an autumn crop cucumber the PAR level is comparable with the modelling results (Fig. 5). Further experimental data has to be collected in order to validate all data.

The dehumidification system is an essential part in the new greenhouse concept. Figure 6 shows the amount of humidity removed from the greenhouse by the mechanical dehumidification system. In winter the system is not used intensively, differences between single glass greenhouses and het new greenhouse concept with double glass is small. During summer months more moisture has to be removed during night and in humid autumn months also during daytime humidity has to be removed since less humidity is removed from the air due to condensation (Fig. 7). Year-round 35 L m^{-2} is removed by the mechanical system in a traditional single glass greenhouse, while this is 83 L m^{-2} in the new greenhouse concept with double glass. The system is working 2500 h under single glass and 3800 hours under double glass year-round. Experimental data show that in autumn this was 1060 hours, while 1540 hours was predicted in the same period (data not shown). This difference could be caused by the higher leakages of this small compartment with a large side wall effect.

During the experiment from 5th of August until 16th of November 21 kg cucumbers were harvested, which is approximately comparable with yield values in practice. Earlier we predicted a crop yield of ca. 75 kg per year, corresponding with the experimental results. Finally it has to be remarked that the new energy saving greenhouse concept is only possible if CO_2 is gathered from an external source. In our case we used waste CO_2 from Shell industry. This is necessary since energy saving greenhouse concept in general demand less heating energy, which reduces CO_2 production by the boiler or co-generation at the same time (Hemming et al., 2009).

In summary we can conclude that the new developed greenhouse concept with high insulating double glass with modern coatings and new climate control strategies is promising. Energy saving of 60% compared to horticultural practice seems to be realistic. Gas consumption is decreased while electricity consumption is increased. In total an increase in energy efficiency is likely at a level of 0.23 m^3 gas equivalents per kg produce. Experimental results gathered from an autumn crop in 2010 correspond with model simulations in the same period and make it likely to correspond also on the long term with year round calculated results. However, more experimental data has to be collected. Currently a tomato crop is evaluated in the same demonstration greenhouse.

ACKNOWLEDGEMENTS

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Literature Cited

Andersson, N.E. and Nielsen, O.F. 2000. Energy consumption, light distribution and plant growth in greenhouse partly insulated with non-transparent Material. Gartenbauwissenschaft 65(5):190-194.

Bakker, J.C., Adams, S.R. and Boulard, T. 2008. Innovative technologies for an efficient Use of Energy. Acta Hort. 801:49-62.

Bot, G.P.A. 2001. Developments in indoor sustainable plant production with emphasis on energy saving. Comp. Electr. Agric. 30:151-165.

Campen, J.B., Kempkes, F.L.K. and Bot, G.P.A. 2009. Mechanically controlled moisture removal from greenhouses. Bios. Eng. 102(4):424-432.

Gelder, A. de, Sterk, F., Grootscholten, M. and Kieviet, J. 2010. New growing strategies: energy in control – cucumber. (in Dutch: Het nieuwe telen : energie onder de knie - komkommer). Wageningen UR Glastuinbouw report GTB-1013.

Hemming, S., Kempkes, F.L.K. and Mohammadkhani, V. 2009. New glass coatings for high insulating greenhouses without light losses – energy saving, crop production and economic potentials. Acta Hort. 893:217-226.

PT and E,A&I 2011. Yearplan energy research program "Kas als energiebron". Productboard of Horticulture (PT) and Ministry of Economic Affairs, Agriculture and Innovation (E,A&I).

Villeneuve, J., Halleux, D. de, Gosselin, A. and Amar, D. 2005. Concept of Dynamic Liquid Foam Insulation for Greenhouse Insulation and the Assessment of Its Energy Consumption and Agronomic Performances. Acta Hort. 691:605-610.

Zhang, Y., Gauthier, L., Halleux, D. de, Dansereau, B. and Gosselin, A. 1996. Effect of covering materials on energy consumption and greenhouse microclimate. Agr. For. Meteor. 82:227-244.

Zwart, H.F. de 1996. Analyzing energy-saving options in greenhouse cultivation using a simulation model. IMAG-DLO rapport 96-05.

Tables

Table 1. Parameters for three different greenhouse concepts and climate control strategies simulated with KASPRO.

	Reference (traditional greenhouse, climate control like horticultural practice)	New growing strategy (traditional greenhouse, new climate control strategy)	New greenhouse concept (double glass with new climate control strategy)
Covering	Single glass τ_p=91%, τ_h=83%	Single glass τ_p=91%, τ_h=83%	Double glass τ_p=88%, τ_h=79%
Screen	AC plastic film XLS 10	AC plastic film XLS 10 XLS 18 Firebreak	XLS 10
Dehumidification	Minimum heating pipe temperature and ventilation	Dehumidification system blowing in dry outside air, capacity 5 m^3 m^{-2} h^{-1}	Dehumidification system blowing in dry outside air, capacity 10 m^3 m^{-2} h^{-1}
Climate setpoints	$T_{heating}$=18-21°C, CO_2=1000 ppm*, rh=85-88%	$T_{heating}$ =18-21°C, CO_2=1000 ppm, rh=88%	$T_{heating}$ =18-21°C, CO_2=1000 ppm, rh=88%, vpd=4.5 day**

*OCAP: dosing capacity 180 kg ha^{-1} h^{-1}; **Fogging: dosing capacity 200 g m^{-2} h^{-1}.

Table 2. Results of model calculations carried out with KASRPO for three different greenhouse concepts and climate control strategies.

	Reference (traditional greenhouse, climate control like horticultural practice)	New growing strategy (traditional greenhouse, new climate control strategy)	New greenhouse concept (double glass with new climate control strategy)
Gas [m^3 m^{-2} $year^{-1}$]	40	25	12
Electricity [kWh m^{-2} $year^{-1}$]	7	13	18
Cucumber yield [kg m^{-2} $year^{-1}$]	75	75	75
Energy efficiency [m^3 gas equivalents kg^{-1} produce]	0.56	0.39	0.23

Table 3. Realised greenhouse climate during the first cucumber crop experiment in the new greenhouse concept from 5th of August until 16th of November 2010.

Week number	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
Temperature day [°C)]	24.7	24.8	23.5	24.9	24.1	23.2	24.3	23.5	23.9	23.2	22.2	22.2	21.7	21.9
Temperature night [°C]	20.8	20.3	19.6	19.4	19.5	19.3	19.5	19.5	19.2	18.6	18.4	18.4	18.3	20.0
Temperature pre-night [°C] 2h after sunset	21.7	21.1	19.7	19.8	20.0	19.4	20.1	19.7	19.3	17.8	17.3	17.2	17.3	20.0
DIF [°C]	7.6	7.7	7.4	8.6	7.6	6.4	8.2	6.9	7.9	8.2	7.3	6.8	5.8	4.4
Screen closed [h week^{-1}]	10							18	10	71	86	69	53	140
rh day [%]	73	78	78	77	79	78	80	79	79	74	72	77	76	78
rh night [%]	86	87	86	84	84	83	85	83	84	78	76	78	80	81
vpd day [g m^{-3}]	6.6	5.3	4.8	5.6	4.8	4.8	4.7	4.6	4.9	5.6	5.6	4.7	4.7	4.3
vpd night [g m^{-3}]	2.7	2.4	2.4	2.7	2.7	2.9	2.6	2.9	2.7	3.5	3.9	3.5	3.1	3.3
CO_2 day [ppm]	618	604	661	608	711	730	707	786	761	803	803	932	932	977
Daily light integral [J cm^{-2}]	1645	1361	1060	1481	1087	948	936	736	756	728	591	378	246	214
Gas consumption [m^{3}m^{-2}week^{-1}]	0.03	0.08	0.11	0.31	0.33	0.33	0.48	0.44	0.41	0.33	0.45	0.59	0.56	0.5

Table 4. Realised crop parameters during the first cucumber crop experiment in the new greenhouse concept from 5th of August until 16th of November 2010.

Week number	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
leaf development [no. week^{-1}]	6.7	7.5	7.8	4.9	5.3	5.7	5.6	5.7	5.9	3.2				
cumulative leave number [no.]	12.6	20.0	27.8	32.8	38.1	43.8	49.4	55.0	61.0	64.2				
yield cucumbers [fruits m^{-2}]			3.6	4.4	7.1	6.4	5.1	5.6	4.2	2.9	4.3	2.8	4.2	2.7
yield cucumbers [kg m^{-2}]			1.6	1.8	2.8	2.6	1.9	2.3	1.6	1.1	1.7	1.2	1.5	0.9
average fruit weight [g fruit^{-1}]			449	406	398	402	383	413	392	377	396	439	364	342

Figures

Fig. 1. Building and demonstration of new greenhouse concept on 500 m^2 with high insulating double glass.

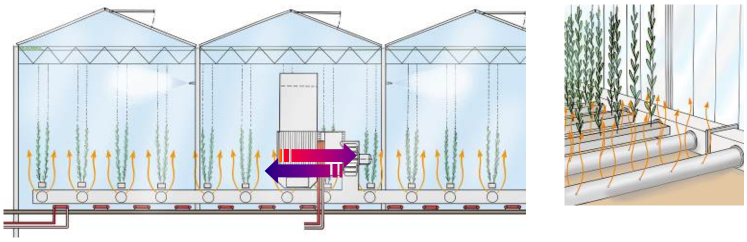

Fig. 2. Demonstration of new greenhouse concept on 500 m^2 with new dehumidification equipment.

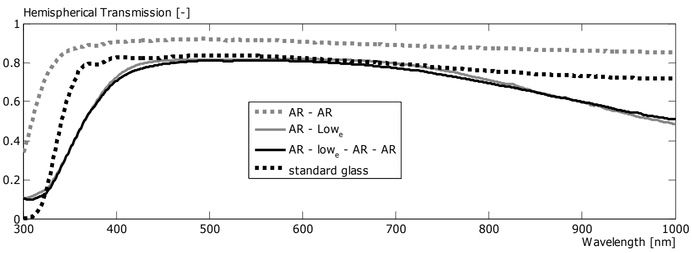

Fig. 3. Optical properties of the double greenhouse glass used. Spectral hemispherical light transmission of single glass with two anti-reflection coatings (AR-AR), single glass with one anti-reflection and one low-emission coating (AR-Low e) and double glass consisting of the two types of single glasses (AR-Low e-AR-AR) compared to a single reference glass.

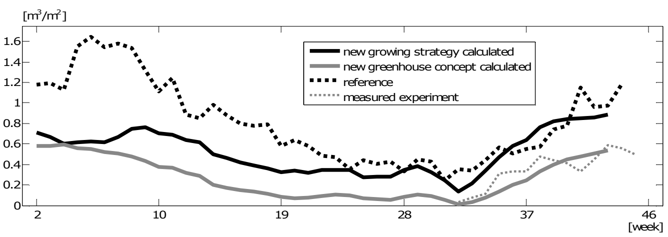

Fig. 4. Calculated (year-round) and realised (week 32 until 45) energy consumption in a cucumber crop for three different scenarios: Reference (traditional greenhouse, climate control like horticultural practice), New growing strategy (traditional greenhouse, new climate control strategy), New greenhouse concept (double glass with new climate control strategy).

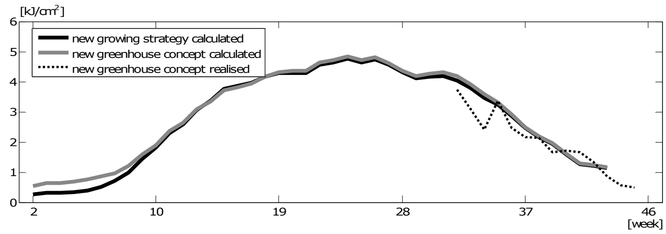

Fig. 5. Calculated (year-round) and realised (week 32 until 45) light level in a cucumber crop for two different scenarios: New growing strategy in traditional greenhouse with single glass and screen use in winter, New greenhouse concept with double glass.

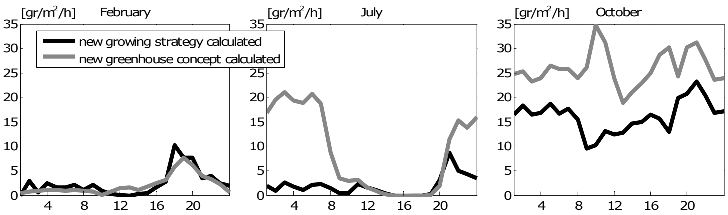

Fig. 6. Dehumidification by the mechanical system calculated for typical months.

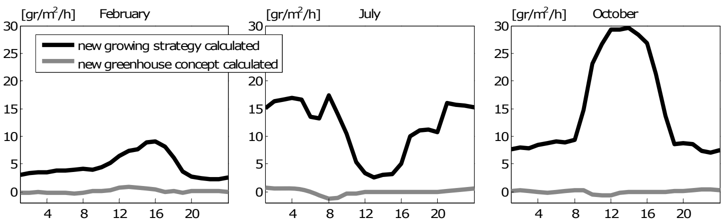

Fig. 7. Dehumidification by condensation at the inner surface of the greenhouse covering calculated for typical months.