Cultivation and energy 2SaveEnergy greenhouse

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Report GTB-1403

WAGENINGEN UR
For quality of life
LTO Glaskracht Nederland
Ministerie van Economische Zaken
KAS ALS ENERGIEBRON

Referaat
Energiebesparing door een isolerend kasdek van isolatieglas vergt een grote investering. In de zoektocht naar een goedkoper alternatief is door een consortium van bedrijven bestaande uit
VDH Plastic Greenhouses, Van der Valk Horti Systems, AGC Chemicals Europe en Boal Systems een Glas-Film-Kasdek, beter bekend als het 2SaveEnergy concept ontwikkeld en in de zomer van 2014 ook gerealiseerd. De combinatie van helder glas met een diffuse ETFE film en een dubbel scherm welke op slechts enkele centimeters afstand van elkaar gemonteerd is heeft in het teeltjaar 2015 tot een laag energiegebruik en een prima tomaten productie geleid. Tijdens de teelt zijn de principes van het nieuwe telen zoveel mogelijk aangehouden. Ten opzichte van de gangbare praktijk was het energiegebruik meer dan 50% lager bij een minimaal gelijke productie.

Abstract
Energy saving in a greenhouse with insulated glass requires a significant investment. In the search for a cheaper alternative, a consortium of companies comprising
VDH Plastic Greenhouses, Van der Valk Horti Systems, AGC Chemicals Europe and Boal Systems developed a Glass-Film greenhouse cover in the summer of 2014, and is better known as the 2SaveEnergy concept.
The combination of clear glass with a diffuse ETFE film and a double screen positioned just a few centimeters apart, resulted in low energy consumption and good tomato production in the 2015 cultivation year. The Next Generation Cultivation principles were adhered to as much as possible. Compared to standard practice, energy consumption was over 50% lower with at least equal production.

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Disclaimer

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Foreword

Inspired by experiences with a greenhouse constructed with insulated glass in 2010, a consortium of companies comprising VDH Plastic Greenhouses, Van der Valk Horti Systems, AGC Chemicals Europe and Boal Systems designed the 2SaveEnergy greenhouse concept. This 2SaveEnergy greenhouse concept was then actually constructed in the IDC in Bleiswijk in the summer of 2014. Since then, an autumn cucumber crop and one year-round tomato crop were tested in the greenhouse. To achieve good insulation, the 2SaveEnergy greenhouse concept comprises a combined "standard" greenhouse cover with an ETFE film beneath, and a double screen system with a cavity distance of only 5 cm. The further implementation of knowledge and experience gained with the Next Generation Cultivation in the VenlowEnergy greenhouse, described in the 'New greenhouse cover for Next Generation Cultivation', also contributed to reducing the energy use. This approach has been implemented as a "proof of principle" project within the framework of "The Greenhouse as Energy Source" innovation program, under contract by the Ministry of Economic Affairs and LTO Glaskracht. The Greenhouse as Energy Source is an innovation and action program established to ensure greenhouse horticulture's energy-saving and reduced CO_2 emission objectives. LTO Glaskracht Nederland and the Ministry of Economic Affairs are working together on this and greenhouse growers, suppliers, researchers, sector organizations and the government cooperate in the program.
The research investigated optimal crop control with efficient control of the heating and electricity consumption in order to save at least 50% energy compared to standard practice.
The success of the greenhouse trial was also due to the intensive support from a Research Supervisory Committee (RSC) comprising Kees Stijger, Jasper Oussoren, Ted Duijvestijn and Vincent van der Lans.

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Summary

Realizing the 2SaveEnergy greenhouse at the Innovation and Demonstration Center at Wageningen UR Greenhouse Horticulture in Bleiswijk was a new step towards creating greenhouse insulation using an insulating greenhouse cover. A consortium of companies comprising VDH Plastic Greenhouses, Van der Valk Horti Systems, AGC Chemicals Europe and Boal Systems designed and constructed the 2SaveEnergy greenhouse concept, inspired by a double-glazed greenhouse with insulated glass. Following construction, a short autumn crop of cucumber and one year-round crop of tomatoes were trialed in the greenhouse.
The 2SaveEnergy greenhouse concept comprises a combination of a "standard" greenhouse cover with an ETFE film beneath this to achieve good insulation. A double screen system with cavity was also fitted at a distance of just 5 cm. The further implementation of knowledge gained with the Next Generation Cultivation method in various projects such as the VenlowEnergy greenhouse and the availability of pure CO_2 contributed to minimizing energy consumption. This approach has been implemented as a "proof of principle" project in the framework of the Greenhouse as Energy Source innovation program, under contract by the Ministry of Economic Affairs and LTO Glaskracht.
In contrast to the optimum greenhouse cover of diffuse glass with a clear film determined in a preliminary study (regarding transmission properties), it was ultimately decided to use a familiar high-transparent clear glass with a diffuse F-clean film below. The reason for this was the unknown effect of condensation on a diffuse pane's transmission.

The tomato (Cappricia) production was 67 kg/m^2 higher than the set objective of 63 kg/m^2 and was in accordance with or even higher than standard practice companies. The diffuse greenhouse cover will undoubtedly have played a role in this. The cultivation generally went well without Botrytis or other diseases. What was striking was the disparity in and between the clusters during different periods. Although the cause is unclear, this undoubtedly had an effect on the total production. It is unlikely that this was caused by the greenhouse concept.

The 2SaveEnergy greenhouse experiments demonstrated that it is eminently possible to achieve practice-standard production with low energy input (15.5 m^3/m^2) with just a slight increase in electricity consumption (approx. 1 kWh) compared to a standard greenhouse. In the feasibility study prior to this project, calculations had already demonstrated that this concept should be able to generate savings of up to 50% compared to standard practice. Although this was confirmed in this trial, it should be emphasized that this is the joint result of both the greenhouse and cultivation concept. The cultivation period was also relatively short, because of circumstances not related to this trial, which meant that a few cold weeks that in practice would have required considerable heating leading to lower overall savings, were not included. The high savings achieved were compared to standard practice companies that do not use or hardly use the Next Generation Cultivation method. The Table below more closely compares the energy consumption of standard practice greenhouses and the 2SaveEnergy greenhouse.

Description of greenhouse setup	Standard practice [m^3/m^2]	2SaveEnergy [m^3/m^2]
Standard practice: 1 moveable screen, during start-up permanent film, cultivation period end January to end October	26.9 a)	12.6 a)
Standard practice: 1 moveable screen, during start-up permanent film, cultivation period end January to end December	31 b)	15.5 a)
Practice according to The Next Generation Cultivation method: 2 independent moveable screens, dehumidifying system and single cover, cultivation period end January to end December	23 b)	

a) Measured b) Estimated c) Calculated

The savings on heat show two clear seasons throughout the year: winter, in which in particular the greenhouse cover and screen provide savings, and summer, in which rather the cultivation concept provides energy savings compared to standard practice.

The low energy consumption in the summer does, however, have the disadvantage that, in order to achieve the production level, an external CO_2 source needs to be available. Even with the efficient dosing strategy used in this trial, it is likely that as much as 13 kg CO_2 will need to be purchased annually. This makes it vital that an alternative CO_2 source is available if these high savings are to be achieved.

Dehumidification using outside air intake and reheating performed as desired and not using a minimum pipe temperature did not lead to visible humidity or other problems.

The low-snow winter of 2015 did not allow for testing of snow-thawing via extraction of greenhouse air distributed through the gutter to the cavity between the glass and film. Test measurements did, however, demonstrate that the air in the gutter cools down very quickly, indicating that the thawing capacity will be minimal.
As the cavity between glass and film is not air-tight in this concept, condensation can occur in the cavity. Whether and what consequences this will have on transmission in the long term is not yet known.

A year of cultivating tomatoes in the 2SaveEnergy greenhouse demonstrated that the use of an insulated greenhouse cover and intensive (double) screen use has no negative consequences on production. This greenhouse and cultivation concept thus demonstrates possible heat savings in the region of 50% compared to standard practice. On the other hand at least 13 kg of CO_2 will need to be purchased.

1 The 2SaveEnergy greenhouse concept

Using The Next Generation Cultivation, heat savings are generally made through the installation of more (up to 3) screens, and cultivation regime modifications such as not adhering to the minimum pipe temperature as far as possible. Using multiple screens in winter leads to considerable loss of light. Instead of screens, another option to achieve “permanent” high greenhouse insulation is to use an insulated greenhouse cover.
A desk study was conducted in 2013 into the possibilities of a glass-film greenhouse concept as a cheaper alternative to an insulating greenhouse cover of (insulated) glass (Kempkes, 2014). The results of this study were such that a consortium comprising VDH Plastic Greenhouses, Van der Valk Horti Systems, AGC Chemicals Europe and Boal Systems further developed the glass-film greenhouse concept into a greenhouse. They constructed this at the IDC Energy at Wageningen UR Greenhouse Horticulture in Bleiswijk in the summer of 2014. Following realization of the greenhouse, the concept became known as the 2SaveEnergy greenhouse.

The 2SaveEnergy greenhouse uses significantly-improved insulation of the greenhouse casing through a combination of glass and an ETFE film that is positioned permanently, approximately 7 cm from the glass. Dehumidifying the greenhouse air with outside air (without heat recovery) and the application of an energy-efficient cultivation concept based on experiences using the Next Generation Cultivation, together with a double screen system, should ensure low energy consumption.

1.1 The greenhouse

The greenhouse is a Venlo type with a trellis bar of 9.60 and bay size of 4.8 meters. Figure 1.1 illustrates a cross-section of the greenhouse. 5 bays are positioned lengthwise in the greenhouse, 3 of 5 meters and the first and last being 4.3 meters, bringing the total length to 23.6 meters

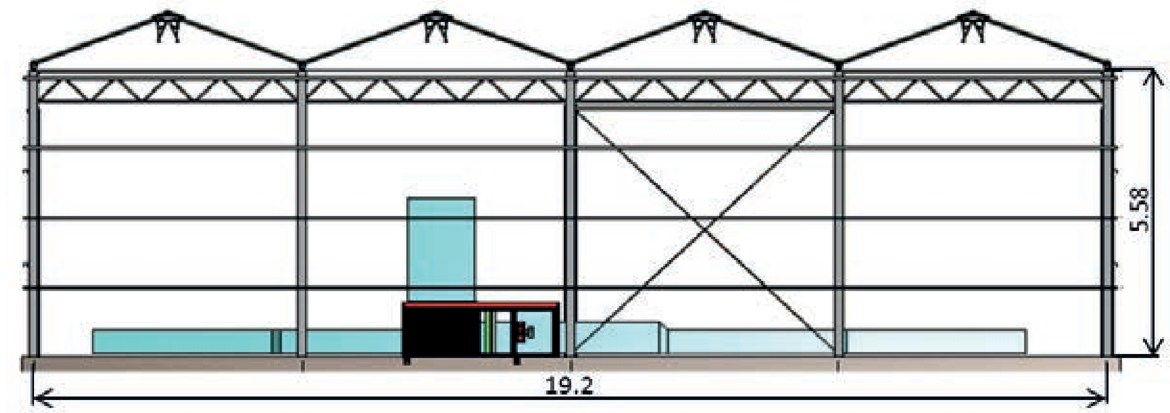

Figure 1.1 *Cross section of the 2SaveEnergy greenhouse.*

The roof sloop is 22°. A 3-meter wide concrete path is positioned in the east side of the greenhouse. This provides a cultivation area of approximately 395 m². Figure 1.2 shows the location of the greenhouse at IDC Energy in Bleiswijk.

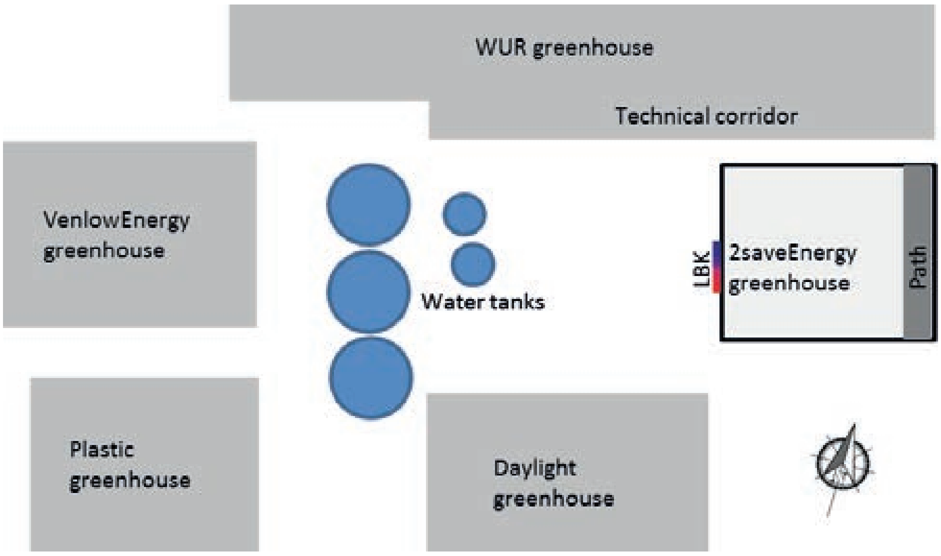

Figure 1.2 *The location of the 2SaveEnergy greenhouse at IDC Energy.*

Suspended gutters (14) are used in the design, at a distance of 1.60 m and a height of 0.7 m. This free space offers the option of positioning hoses or other distribution systems beneath the gutters. A double 51 mm pipe rail system was constructed for the heating system, 56 in total. The reason for this is two-fold. The greenhouse is fed via HDPE tubing from the technical corridor, with the water temperature being limited to 60°C. With a single grid, capacity would fall just short in extreme situations. With a larger heated surface area, lower pipe temperatures can also be used, which can improve boiler room efficiency.
In proportion to the ground surface area, the facade takes up an extremely large surface area. To counteract the facade effect with regard to energy consumption, the facade is supplied from a separately controllable grid. This heating grid is controlled in such a way as to compensate for the exact heat lost though the facade. This creates an “infinitely large greenhouse” for the horizontal section in which facade effects do not play a role. In the final energy calculation for this greenhouse, the horizontal energy consumption will be increased by 10%. This 10% includes the facade losses associated with a greenhouse of approximately 4 ha. with a square building block.
The CO_2 is distributed using hoses among the cultivation gutters. The CO_2 source is OCAP and the dosing speed can be set (manually) between 0 and 300 kg/ha/hr. During the trial a dosing capacity of up to 150 kg/ha/hr was generally used.
One screen system with a double fabric was installed. The distance between the screens is approximately 5 cm. Both screens are a Luxous 1347FR (LS) sheet, which is mainly used for energy saving purposes. The double screen runs from (bottom) trellis bar to (bottom) trellis bar. A wire bed usually comprises a support wire to support the sheet and an upper wire. The 2SaveEnergy greenhouse uses three wires for these 2 sheets (Figure 1.2A). The bottom wire supports the bottom sheet, the middle wire (5 cm from the bottom wire) supports the top sheet with the third upper wire above this. The sheets are fitted to 1 profile so that they both open and close simultaneously on 1 motor.

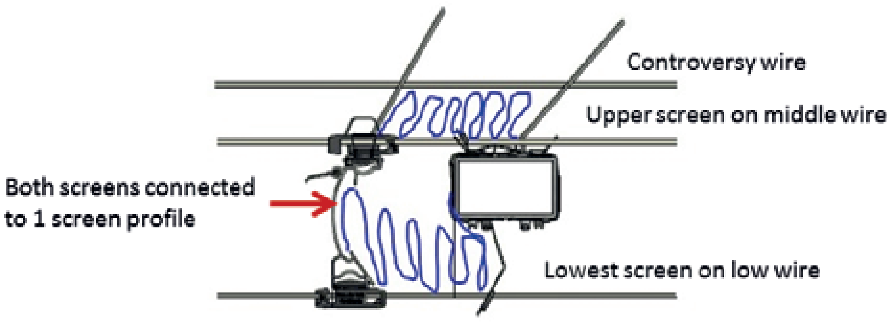

Figure 1.2A *Diagrammatic illustration of the double screen fitting.*

Water is fed using a drip system, with the system being adapted to the cultivation concerned. The irrigation (flow) of the entire compartment is measured using a flow meter. Drainage water from the entire greenhouse compartment is collected centrally, whereby the flow is determined.
As the film temperature on the inside of the greenhouse is higher with a double greenhouse cover, condensation against the greenhouse cover will be less than in a single-cover greenhouse. The condensation is collected and measured separately.

1.2 The greenhouse cover

Like a standard Venlo greenhouse, the greenhouse is single glazed. By modifying the gutters and vent rafters a film can be stretched below the rods. Continuous ridge ventilation was chosen in order to achieve the above in long straight tracks, Figure 1.3. The roof vents are 26 cm deep (glazing size). This creates a ventilation opening of around 9% in the greenhouse cover. This is a little less than a "standard" Venlo greenhouse (around 10%).
A "standard" greenhouse is assumed to be a greenhouse with a 4.8-meter saddle roof, bay of 5-meter (1.67 m glazing) with single pane aeration and 1.5-m deep roof vents. Of course, the stated percentage of the "standard" greenhouse depends entirely on the cover configuration.
For the sake of simplicity, the roof vent was finished in double glazing instead of in a glass-film combination.

Figure 1.3 *Position of the continues ridge ventilators in the 2SaveEnergy greenhouse. The film is shown as blue below the rod.*

This double-glazed panel in the roof vent comprises a clear and a diffuse pane.
As it is known that using a double-cover variant instead of standard single glazing will result in light loss, an AR coating was applied on both sides of the glass panel. To clarify the effects of the coatings and the double finish, Figure 1.4 illustrates the transmission of the basic materials and the combination of clear glass with diffuse F-clean. The hemispherical transmission of the single glazing with 2 sides AR-coated is 90.5%, that of the F-clean diffuse is 83.3 and that of the combination is 76.

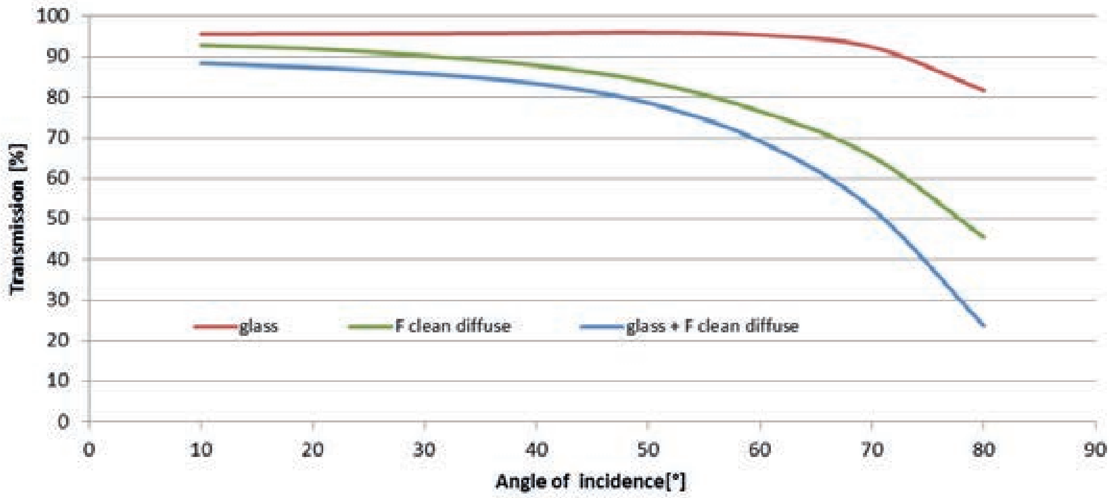

Figure 1.4 *The angle-dependent transmission of the basic materials used and the combination as used in the greenhouse's greenhouse cover.*

In order to exclude any wavelength-dependent effects, the wavelength-dependent perpendicular transmission of the basic material and the combination is also illustrated (Figure 1.5). The F-clean diffuse demonstrates an extremely consistent pattern, while the glass to UV light demonstrates a reduction in transmission. According to this information, no wavelength-dependent effect of the used greenhouse cover is to be expected on the crop.

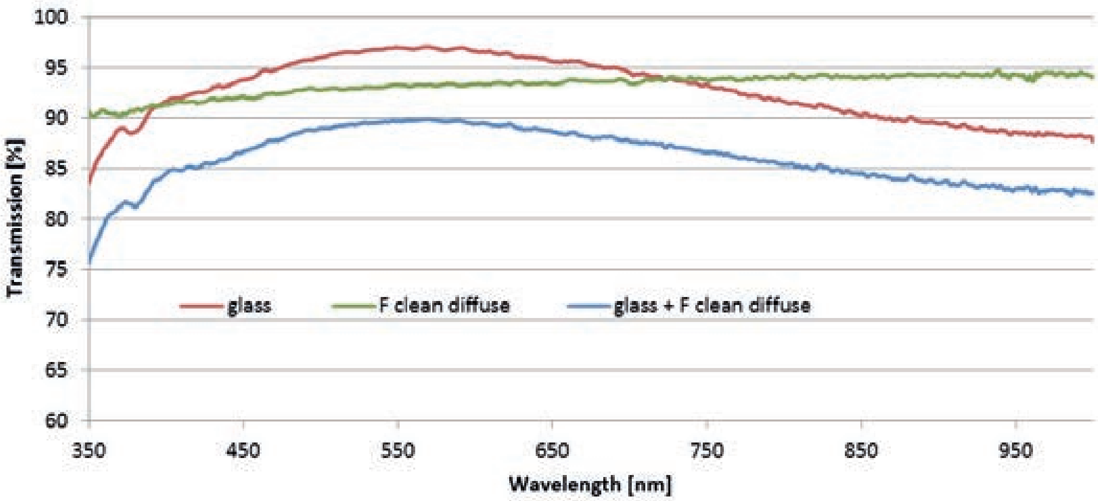

Figure 1.5 *The wavelength-dependent perpendicular transmission of the used basic materials and the combination as used in the greenhouse's greenhouse cover.*

As well as material, the greenhouse construction and greenhouse design also influence transmission of the greenhouse. In order to determine the transmission of the greenhouse under diffuse weather conditions, the transmission in the greenhouse at crop wire level (tomato) was measured. Measurements were taken with both open and closed screens. The results are shown in Figure 1.6. No measurements were taken on the concrete path and measuring entirely up to the rear facade is also not possible. To do justice to the effect of the screen, the same scale in Figure A and B was used for the color dispersion for both measurements. An error occurred in paths 3 and 4 during the measurement without screen, which meant that these results could not be used. The measurements in path 7 were somewhat lower because a cable tray inhibits light ingress at the measured height. To determine the overall greenhouse transmission, paths 5 to 9 from meter 4 to 22 were taken as the representative section. This showed that the transmission was 70% with open screen and 49% with closed screen. So closing the screen has considerable impact on light levels. This 30% loss is a direct consequence of the double screen.

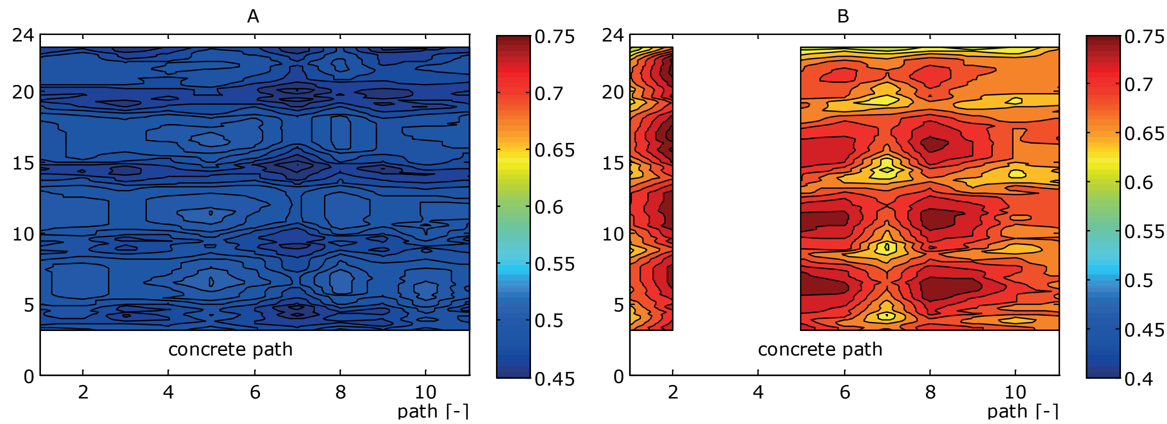

Figure 1.6 *Greenhouse transmission with closed screen (A) and open screen (B) on 27 December 2015.*

In a greenhouse cover with insulated glass, the insulation is so high that snow not melting can form a problem. In the 2SaveEnergy greenhouse concept a system was devised to reduce the greenhouse cover insulation level using ventilation of the air cavity with "heated" greenhouse air, which allows the snow to melt. Depending on the vent position, rubbers can be used to open or close the air cavity in the roof vent transom. This is illustrated in Figure 1.7. Holes were made on the gutter side from the lowest hollow space. These end up in the cavity between the glass and film. If the roof vents are fully closed, a rubber will be pressed onto the roof vent transom. There are holes in this transom, which are connected to the cavity. Because the rubber seals the holes, the air in the cavity will remain still (Figure 1.7 left). As soon as the vent is open more than 2 cm, the holes in the transom are opened (Figure 1.8 B). However, a rubber flap will still be lying on the greenhouse cover. This means that the window is closed to the outside air but it is possible to blow air via the gutter into the cavity, after which the cavity air will again be guided inside via the roof vent (Figure 1.7 right). The hot air is extracted from the greenhouse using a ventilator and is blown into the gutter (Figure 1.8A).

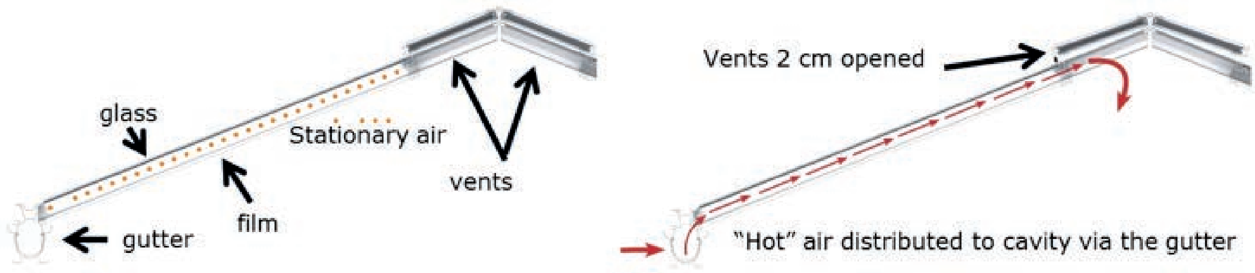

Figure 1.7 *Diagrammatic illustration of the closed (left) and open (right) cavity.*

A

B

Figure 1.8 *Extraction of greenhouse air with aeration on the gutter (A) and vent holes when the roof vent is open (B).*

This in fact creates an open cavity.
During the trial period there was hardly any snowfall. When there was a light snowfall, the outside temperature was either just below or just above freezing. The cavity ventilation was activated but this was not a real test case. Figure 1.9A shows that the snow almost completely covered the cover. It must be stated here that the snow was wet and heavy (27 December 2014). The photo also shows that it shifted from the ridge towards the gutter, a sign that the snow was not dry and was just above freezing. In the event of strong radiation and humid outside air, the greenhouse cover could freeze on the outside. This is illustrated in Figure 1.9B. Only the edges by the rods, gutter and transom show an ice-free zone. These situations were mostly only short in duration. The gutter ventilation was activated but before a possible effect was visible, the outside temperature had already increased to such an extent that the cover was free of ice.

A B

Figure 1.9 *Partly closed snow cover on 27 December 2014 (A) and ice-free edges around the gutter, rods and transom (B).*

As the gutter, in connection with leakage and drainage, will not remain dry, aeration of the air in the gutter can also result in condensation from the gutter ending up in the cavity, where re-condensation can easily occur. This condensation can then have negative effects on the greenhouse cover transmission. Figure 1.10 illustrates the effect of condensation on the film on the greenhouse side (A) and of condensation on the film on the cavity side (B). The differences in condensation formation are significant. The condensation on the greenhouse side is mainly a film/glaze (hydrophilic), but after the film was "dried" by hand rather large droplets remain, as can be seen on the right top corner of the photo (A). The condensation as illustrated on photo B demonstrates much more spherical pronounced droplets, also known as a hydrophobic effect. The droplets as illustrated in Figure 1.10 (B) will have a considerable effect on transmission. Table 1.1 illustrates the results of a dry and wet measurement on the inside of the film. The measurements show that condensation on the inside has a 'considerable' impact on light levels. It is then also important that the manufacturer's instructions are followed, as these indicate whether the film should be inside or outside.

A B

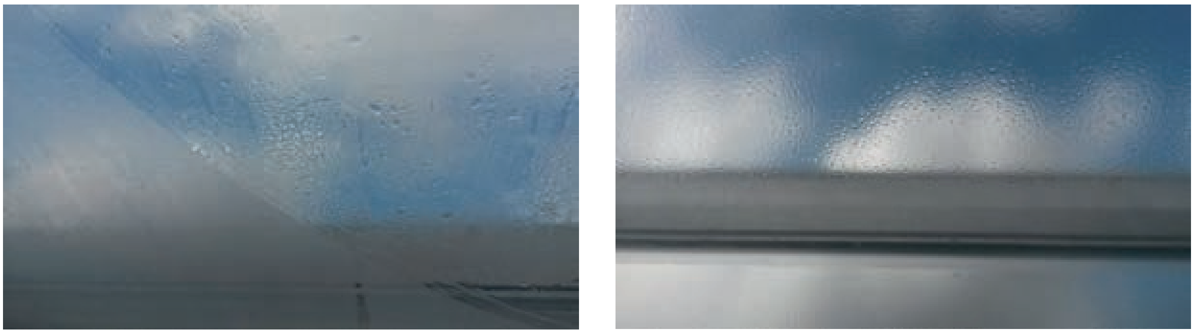

Figure 1.10 *Condensation formation on the inside of the film, hydrophilic (A) and condensation formation on the outside of the film, hydrophobic (B).*

Table 1.1

Effect of condensation on the inside and outside of the film on hemispheric transmission.

	Hemispheric transmission [%]
F-clean diffuse 80 micron inside wet	85.5
F-clean diffuse 80 micron outside wet	77.5

Condensation is identified in the cavity, as illustrated on the photo (Figure 1.9B), particularly around the gutters. After one year of using the greenhouse it is still too early to draw conclusions about the long-term effects of this on transmission.

On 1 July it was observed that one pane was broken. The reason for this is unknown. However, the film was strong enough to withstand the broken pane. During repair, from outside, glass splinters were removed from the film using a dustpan and brush. Figure 1.11 gives an impression of the broken pane lying on the film.

Figure 1.11 Broken pane captured by the film.

1.3 Dehumidification

The greenhouse is provided with an air handling system, extended for a capacity of 8 m^3/m^2.h which comprises:
An Air Handling Unit (AHU) 2.8(L) x 1(H) x 0.8(D) m) in the eaves, which includes:
A radial ventilator with EC motor (5,000 m^3/h – 500 Pa):
- Valve position and pressure differential monitor.
- Recirculation tube.
- Outside air valve.
- Recirculation valve.
- Heat exchanger.
- Mesh grid.

Two over-pressure valves in the facade to regulate air extraction. The unit is controlled via a control (TCS control system) from the climate computer. Every second gutter is fitted with Ø160 mm perforated hoses with 2 rows ø8 mm holes every 25 cm.
A measurement showed that the maximum capacity is more than double the design capacity. The control restricts the maximum capacity generally at 50 to 60% of the ventilator speed.

1.4 The cultivation concept

The cultivation concept is based on experiences with the Next Generation Cultivation. As run-up to these types of greenhouse trials a memorandum “new greenhouse cover for the Next Generation Cultivation method” (Poot, 2011) was prepared, describing the advantages and disadvantages of insulated greenhouse covers and how crop technology can be anticipated and controlled. The most important conclusions from the relevant report are incorporated below. The following conclusions were drawn for insulating greenhouse covers:

Effect on greenhouse climate	Any crop reaction	Possible solution	Opinion of expert panel
Slower evening cooling	Vegetation response, disturbance of plant balance.	More aggressive ventilation; larger DIF; adapted stem thickness, number of fruits; more reproductive variety	Agree, is seen as important point of attention.
Warmer nights	Higher 24-hour temperatures: higher maintenance respiration, weaker head	Ventilation	Agree. Is in line with the above statement.
Lower winter RH during day	More compact plant with lower Leaf Area Index.	Mist-spraying	Not problematic, solution is not useful.
Other periods: higher RH	Increased risk of diseases and physiogenic anomalies.	More aggressive ventilation, greater dehumidification capacity	Agree, is seen as important point of attention.
More humid micro-climate	Increased risk of diseases	Growing tube, dehumidification with air hoses between the crop, vertical air movement using vertical ventilators	Agree. Is in line with the above statement.
Temperature gradient at the bottom is colder	Slower fruit ripening/ growing	Growing tube	Agree, is seen as important point of attention.

The overall conclusion was that no obstructions were noted that would have been insurmountable for the crop. With steady heating, dehumidification using outside air and minimizing the minimum pipe temperature use will enable significant energy savings without having to make concessions on crop quality and production.

2 Greenhouse climate and energy management

A cucumber crop was cultivated following delivery of the greenhouse in early October 2014. Considering the extremely late start time it was decided that this crop should only be used to test the heating system, including the horizontal temperature distribution in relation to the facade heating, dehumidification and irrigation and to remove any control teething problems so that the tomato cultivation could start without a problem.
There were no reference greenhouses or crops present in the 2015 cultivation year. To compare energy consumption with standard practice, a large group of Cappricia growers were used, which were spread throughout the country.

2.1 Greenhouse air temperature, air humidity and CO_2 concentration

Using the crop strategy developed for the Next Generation Cultivation means that there is a big difference between the minimum and maximum temperature on most days. By allowing large temperature range, a high 24-hour temperature can be realized making maximum use of sunlight. Setting the heating curve low and the ventilation curve high postpones heating for as long as possible and extraction of heat generated via the sun is kept to a minimum. The least possible use is made of a minimum pipe temperature or minimum window opening setting. If, following consultation with the RSC, more active cultivation was needed, it was decided that this should be realized using outside air aspiration. A minimum fan position (25%) was set from mid-May. Depending on the humidity conditions in the greenhouse, only greenhouse air was circulated or, in the event of a dehumidification demand, outside air was also extracted and reheated. This reheating was always set to 2°C above the measured greenhouse air temperature.

Figure 2.1 illustrates the development of the average, minimum and maximum greenhouse air temperature and the average setpoint heating in the greenhouse during cultivation.

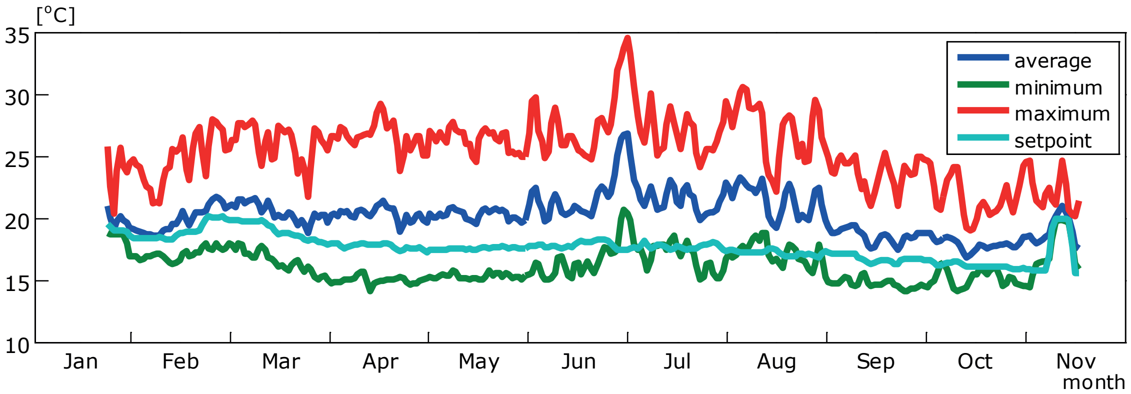

Figure 2.1 *Development of the daily average, daily minimum and daily maximum greenhouse air temperature and the average setpoint heating in the greenhouse during cultivation, illustrated as an overlapping average over 2 days.*

In Figure 2.1 the high peak (35°C) on 2 July stands out immediately, a day on which the outside temperature did not reach over 27°C but on which solar radiation was around 900 W/m². It was noted that the greenhouse can easily become hot. On 1 July the outside temperature reached 33°C, and the greenhouse air temperature remained approximately at outside temperature. A comparison with a standard practice company on 4 July, the day with the highest 24-hour temperature, shows that even with an insulated greenhouse cover the 2SaveEnergy greenhouse was clearly hotter on this day than the standard practice greenhouse, as well with an insulating cover, just a few kilometers from Bleiswijk (Figure 2.2). In 24-hour temperature the 2SaveEnergy greenhouse was 1°C hotter on this day. On other (hot) days the differences were often negligible. So on some days the ventilation capacity of the 2SaveEnergy greenhouse seems somewhat limited. A close analysis of the ventilation capacity of the 2SaveEnergy greenhouse in comparison with a standard greenhouse, see also paragraph 1.2, shows that because of a few choices made during the construction of the greenhouse the roof vents turned out a bit smaller than desired. A standard greenhouse 4.80 saddle roof, bay of 5 meter section with 1 roof vent of 1.67 x 1.40 which can open to 30° has a projected opening of 2.32 m² at an opening angle alpha of 30° in the sections ADE, BCF and ABFE in Figure 2.3. For an opening angle of 45° this can increase to 3.2 m². The opening in the cover in section ABCD in Figure 2.3, measuring in this case 1.67 by 1.4 m, is 2.34 m². In this calculation, therefore, 2.34 m² /(4.8 saddle roof, bay of 5 section) or 9.8% of the cover is open. In the 2SaveEnergy greenhouse the AE height is some 20 cm. Then the projected opening surface area of 2 m² / (4.8 saddle roof/bay x 5 section) is 8.3%, 15% less than in a standard greenhouse. In addition the ventilation efficiency of continuous ridge ventilation is somewhat less than for a standard Venlo greenhouse. The wind can blow through the ridge more easily without really mixing with the greenhouse air. This is also shown in calculations and measurements (wind direction perpendicular to the ridge) (Fernandez, 2013). During low wind speeds the most important strength for the ventilation is actually the temperature difference between inside and outside.

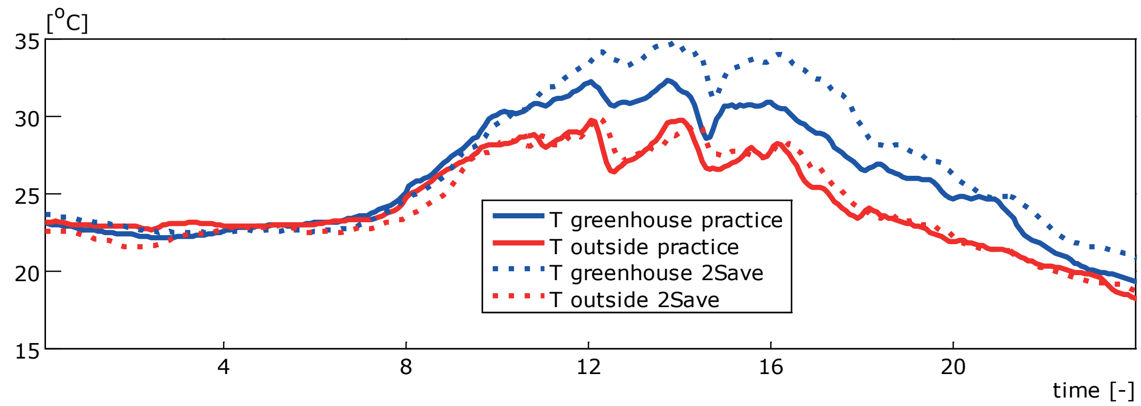

Figure 2.2 *Development of outside and greenhouse temperature of a standard practice greenhouse and the 2SaveEnergy greenhouse on 4 July 2015.*

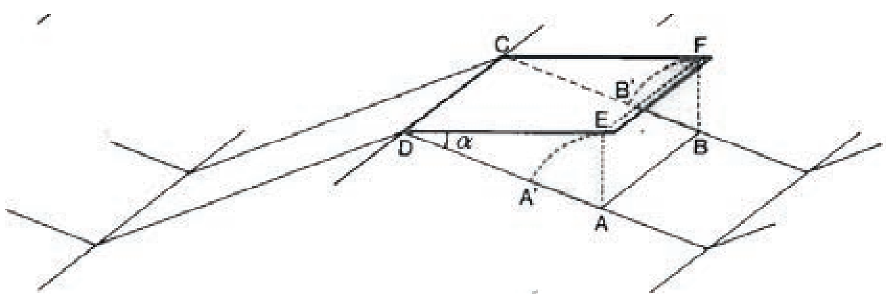

Figure 2.3 *Sketch of the opening of a roof vent in a standard Venlo greenhouse.*

The ventilation capacity of the greenhouse can be increased simply by making the roof vents bigger.

Another way of making this clear is to see whether the vents have reached the maximum vent position. If so, according to the regulation, more ventilation is required. During the hours in which the vents were not fully open, the ventilation capacity was not yet limiting. Figure 2.4 illustrates the maximum vent position of the protected side as well as the wind side. In June and July, therefore, the maximum vent position and thus maximum ventilation capacity was reached at some point each day. Expressed in hours, the vents in total were open more than 175% for over 500 hours.

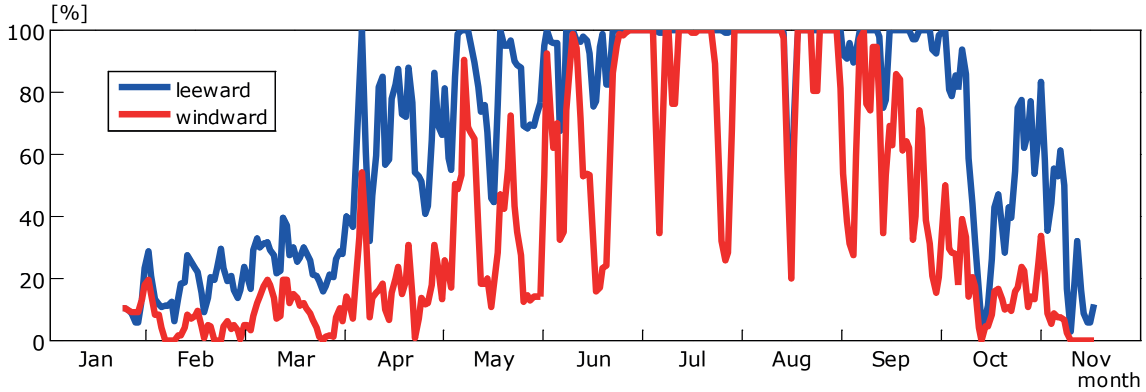

Figure 2.4 *Daily maximum vent position of both the protected side as well as the wind side.*

Part of the Next Generation Cultivation method involves cultivating with increased humidity. For this, in the scheme to the end of June the Vapor Deficit (VD) was controlled at a minimum 1 g/m^3. Later, at the RSC's request there was more active cultivation in the night/early morning and the setpoint was increased to 1.3 g/m^3. This method of control meant that every day at least the minimum VD reached in the greenhouse was around 1 g/m^3 or a little less. This never resulted in visible negative effects on the crop, such as Botrytis. Figure 2.5 illustrates the development of the daily average, daily minimum and daily maximum VD in the greenhouse during the cultivation. The dip around 20 September was the consequence of a fault in the outside air aspiration. An VD of less than 0.5 g/m^3 was measured at that time. In normal use of the dehumidification during cultivation, the VD did not fall below 0.7 g/m^3.

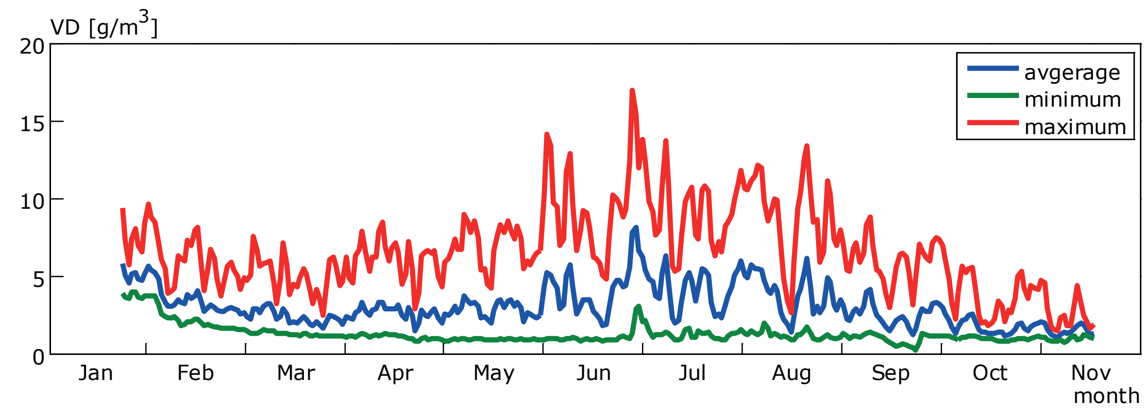

Figure 2.5 *Development of the daily average, daily minimum and daily maximum VD in the greenhouse during cultivation, illustrated as an overlapping average over 2 days.*

The low humidity setpoint means that the AHU was not used during the cultivation start-phase until end April. As well as a low humidity setpoint, 2 other factors restrict the dehumidification system's operational life. In the winter and spring, there are significant inside and outside temperature differences, which result in condensation on the facade as well as considerable dehumidification of the greenhouse. The unit was also set to be switched off in the event of a vent position of over 20%. For such vent openings the air exchange as a consequence of ventilation could quickly be many times greater than could ever be realized with the system. Figure 2.6 illustrates the use of the dehumidification unit. During cultivation the unit was used for 1,624 hours.

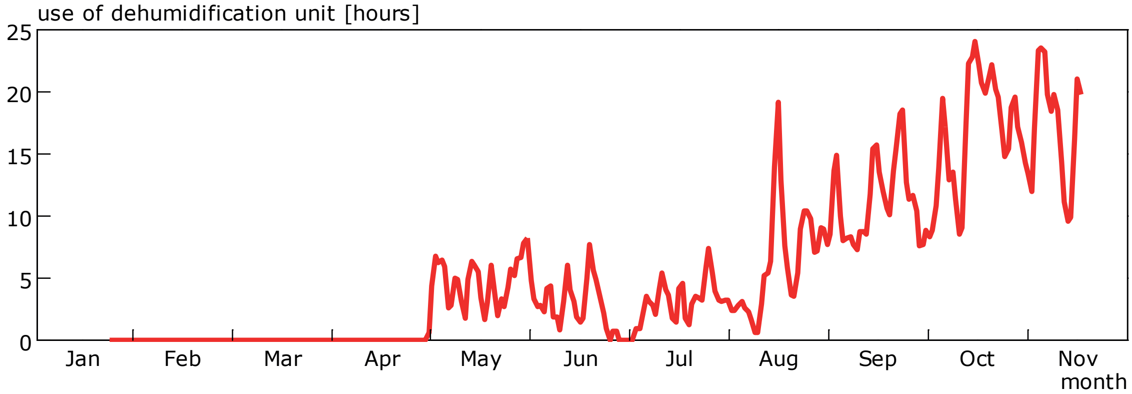

Figure 2.6 *Use of the dehumidification unit during cultivation illustrated as an overlapping average over 2 days.*

As well as more humid cultivation, intensive screen use was another important part of the Next Generation Cultivation method. The screen system comprises one control with two screen sheets that can be opened and closed simultaneously with a cavity distance of around 5 cm. For almost the entire cultivation period, the criterion for screen closing was an outside air temperature of below 12 degrees and there must have been a demand for heat. This was to prevent that the screen would close in the early evening, which would delay cooling down and mean that the designed temperature would not be realized. Figure 2.7 illustrates the screen use during cultivation (24-hours).

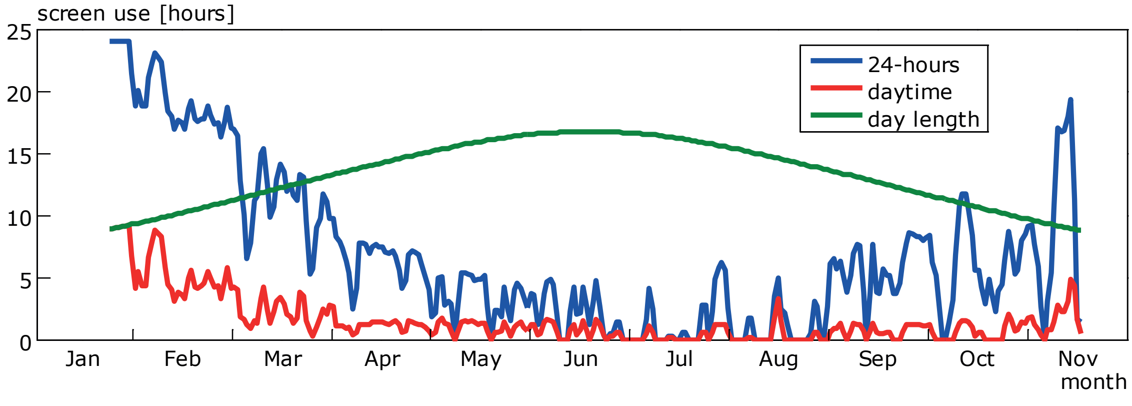

Figure 2.7 *Use of screens during cultivation, illustrated as an overlapping average over 2 days.*

The Figure shows that screening is used almost throughout the year, with the total number of screen hours being 2,020. During intensive screen use, depending on external conditions, daytime screening will also be needed. This is illustrated in Figure 2.7 with 'daytime', in which the pre-conditions are that the screen must be over 50% closed and the overall solar radiation must be over 20 W/m^2. According to this method, screening is still used for 290 daytime hours, with many screen hours at nightfall therefore. If the criterion is set to 100 W/m^2 overall solar radiation, daytime screening is 70 hours. Day length is also illustrated in the diagram in order to demonstrate daytime screening intensity.

A component of the 2SaveEnergy greenhouse concept is that greater light ingress can be achieved because the double cover enables good daytime savings to be achieved if the screen is open, while in the cultivation start-up phase the fixed film screen remains permanently closed until it is removed.
A direct comparison with standard practice is not possible here, although, an indication of the effect can be given. If a fixed film screen is fitted in the first 5 weeks of cultivation with a hemispheric transmission of 80% and the moveable screen were to open at dawn, then with a total greenhouse cover transmission of 72% in these 5 weeks, 214 moles PAR light would be available for the crop (plant level) in the reference situation. In the 2SaveEnergy greenhouse, which has a somewhat lower transmission than the standard practice greenhouse (70%) and an overall transmission of 49% with closed screen, in the first 5 weeks a total light intensity of 239 moles was available for the crop (plant level). This strategy meant that 12% more PAR light was available for the plant in the first 5 weeks in the 2SaveEnergy greenhouse.

The CO_2 was increased during the light period to 750 ppm. In the first 3 weeks of cultivation there was no CO_2 enrichment. Figure 2.8 illustrates the achieved daytime CO_2 concentration in the greenhouse and outside. In the summer there are days that, due to the significant ventilation need, the greenhouse CO_2 concentration realized was hardly above the outside concentration in spite of CO_2 enrichment, which was maximized at 110 kg/ha/hour.

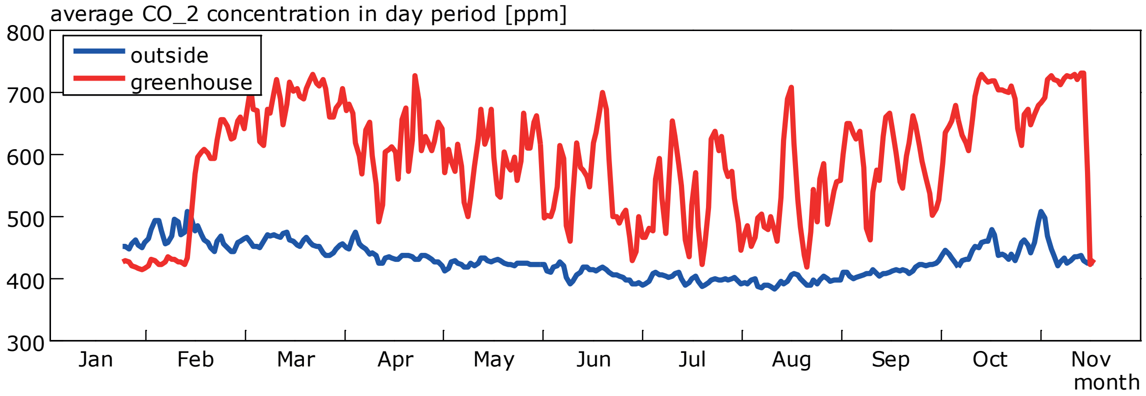

Figure 2.8 *Average daytime CO_2 concentration of the greenhouse and outside air, illustrated as an overlapping average over 2 days.*

CO_2 enrichment was 21.7 kg in total for this crop. This will be further elaborated in paragraph 2.2.

2.2 Energy management

The 2SaveEnergy greenhouse is heated with a double 51 mm pipe network, enabling the greenhouse to be heated with relatively low pipe temperatures. Figure 2.9 illustrates an annual load duration curve of the calculated pipe temperature. During this cultivation the pipe temperature was calculated at above 40°C for only 40 hours. The heating can thus justifiably be called a Low Temperature heating. The dehumidification unit’s AHU is not primarily used to heat the greenhouse. The AHU heating is controlled to heat the supply air flow to 2°C above the greenhouse air temperature. Together with the limited amount of air that is sent through the system, the heating capacity of this is almost zero.

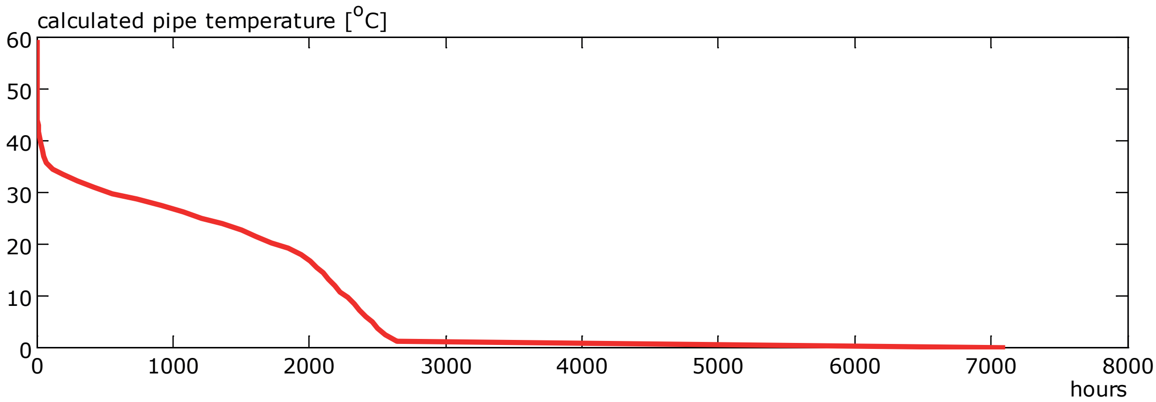

Figure 2.9 *Annual load duration curve of the calculated heating temperature of the sub-network.*

The energy input from the pipe rail system, together with that of the AHU is illustrated in Figure 2.10. The energy consumption is compared with 2 standard practice groups. Standard practice group 1 is an average of 3 companies all located in the Westland growing a comparable variety, but with a somewhat earlier planting date. The "standard practice Rijk Zwaan (RZ)" group is a group of 8 companies, all growing the Cappricia variety, but spread across the country with a concentration in Limburg and Brabant. There was a greater spread of planting dates across these groups of companies, from early December to mid-January. Compared with the two standard practice groups, the 2SaveEnergy greenhouse performance can undoubtedly be called good. The low absolute consumption was caused partly by the "short" cultivation period and still needs to be corrected for this. Although the cultivation started late, it also ended early after over 42 weeks in connection with refurbishment activities; so early that a number of clusters were harvested green. If the cultivation had ended at the usual period, this would need to have continued for a further 3.5 to 4 weeks and even then the cultivation period would still have been relatively short. In order to make a good estimate of energy consumption in this extra month, the greenhouse climate model Kaspro was used to calculate the cultivation period as though this had ended on 23 December. The climate realized in Bleiswijk in 2015 was used for this calculation. The climate setpoints were retained as they were in early November. No data was available for the practice groups for this extra period. Table 2.2 summarizes the results. As this is a comparison with standard practice, a comparison based on estimates and calculations was also made with standard practice companies that work in accordance with the Next Generation Cultivation techniques and principles.

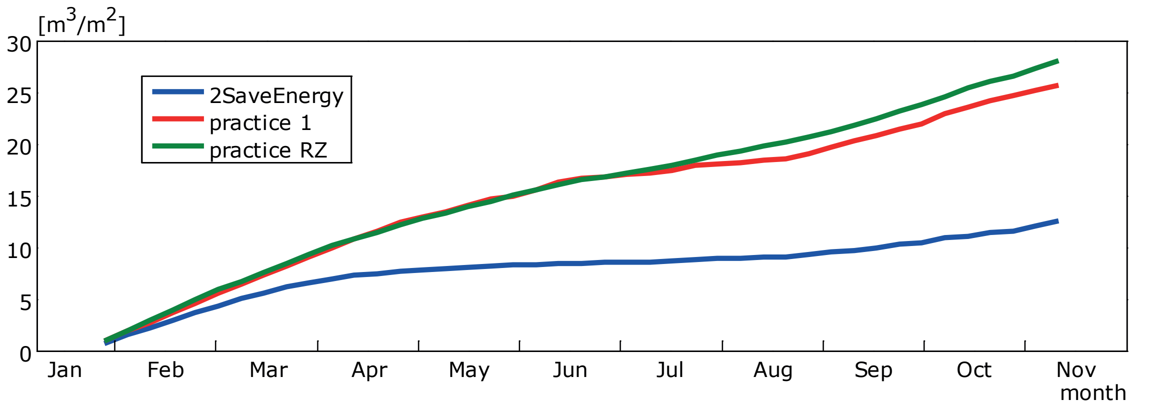

Figure 2.10 *Cumulative energy consumption of the 2SaveEnergy greenhouse and 2 practice groups.*

The share of the AHU reheating is approximately 1 m^3/m^2. As well as heat consumption, the AHU also uses electricity for the ventilator.

Table 2.1

Energy consumption in the 2SaveEnergy greenhouse during the 2015 cultivation for an extended cultivation up to 23 December and at the practice companies.

	Cultivation 2015 27/01 to 18/11	Calculated 2015 27/01 to 23/12
Heat consumption [a] (m^3/m^2)	12.6	15.5
Electricity consumption AHU [b] (kWh/m^2)	0.8	0.9
Heat consumption standard practice 1 (m^3/m^2)	25.7	29.2 [d]
Heat consumption RZ practice (m^3/m^2)	28.0	31.5 [d]
Saving 2SaveEnergy compared with standard practice (m^3/m^2)	14.3 [c]	14.8 [d]
CO_2 purchase (kg/m^2)	12.7	12.7
Heat consumption standard practice according to The Next Generation Cultivation [e] (m^3/m^2)		23.0 [d]

[a] This includes 10% facade loss, thus for a greenhouse on a scale of approximately 4 ha.

[b] The electricity consumption of pumps, motors for water decontamination etc. which amounts to some 6-8 kWh/m^2 annually in modern companies, is not included here.

[c] This saving concerns a non-year round situation.

[d] Estimate.

[e] The Next Generation Cultivation comprises: 2 independent moveable screens, dehumidifying system and a single cover.

The saving varies throughout the year. In the summer this is clearly higher compared with standard practice, which is certainly because of the availability of CO_2 and crop activation. The weekly consumption in the standard practice and 2SaveEnergy greenhouse, and the weekly saving are illustrated in Figure 2.11. As cultivation in the 2SaveEnergy greenhouse was totally different from standard practice in the final weeks of cultivation in connection with accelerated ripening of the fruits, a dotted line is used for the 2SaveEnergy consumption and saving to indicate what the consumption and the saving would have been when using a climate control (temperature) as in standard practice.

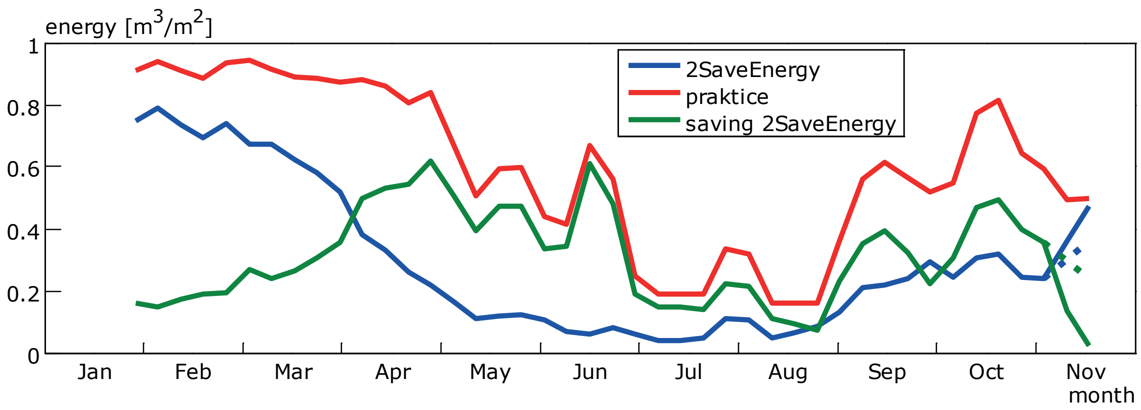

Figure 2.11 *Energy consumption and saving in the 2SaveEnergy greenhouse compared with standard practice.*

The percentage saving compared with standard practice is illustrated in Figure 2.12.

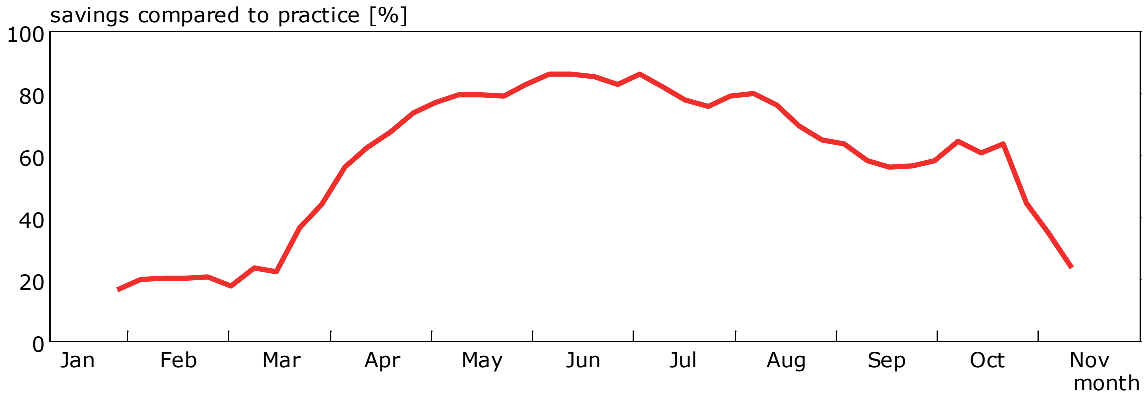

***Figure 2.12** The percentage saving compared with standard practice.*

The AHU was only used from mid-April. Part of the dehumidification of the greenhouse ran via the side walls, which reduced the use of the AHU. The extent to which dehumidification via the side walls contributed to the total greenhouse dehumidification cannot be quantified. Weekly electricity consumption for this is illustrated in Figure 2.13. The AHU consumed a total of 0.8 kWh/m^2.

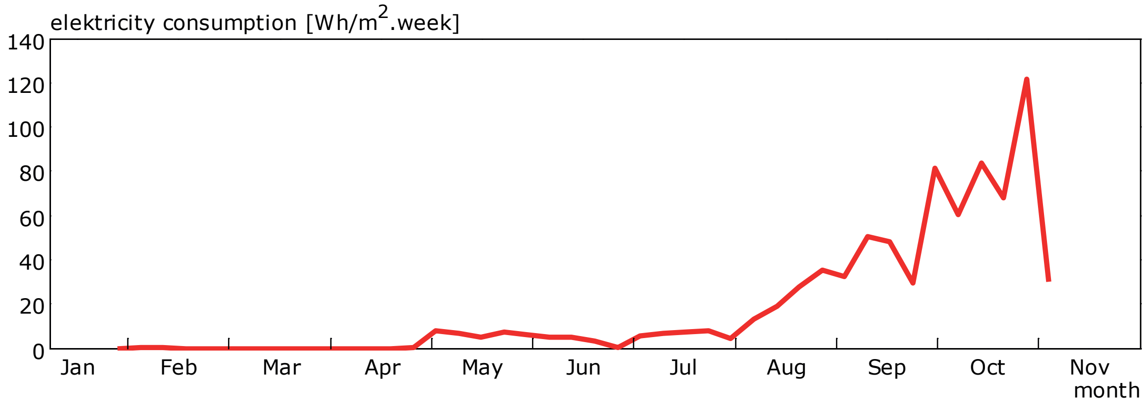

***Figure 2.13** Weekly AHU electricity consumption in the 2SaveEnergy greenhouse.*

As already discussed in section 2.1, CO_2 enrichment was 21.7 kg in total for this cultivation period. With such low energy consumption, particularly in the summer period when CO_2 demand is highest, there will be a considerable mismatch between CO_2 production such as flue gas and the demand for CO_2 enrichment. This mismatch is illustrated on a weekly basis in Figure 2.14. Although the produced CO_2 (22.6) and CO_2 enrichment (21.7) almost balance out on an annual basis, the mismatch is 12.7 kg CO_2. This will thus need to be taken from another CO_2 source.

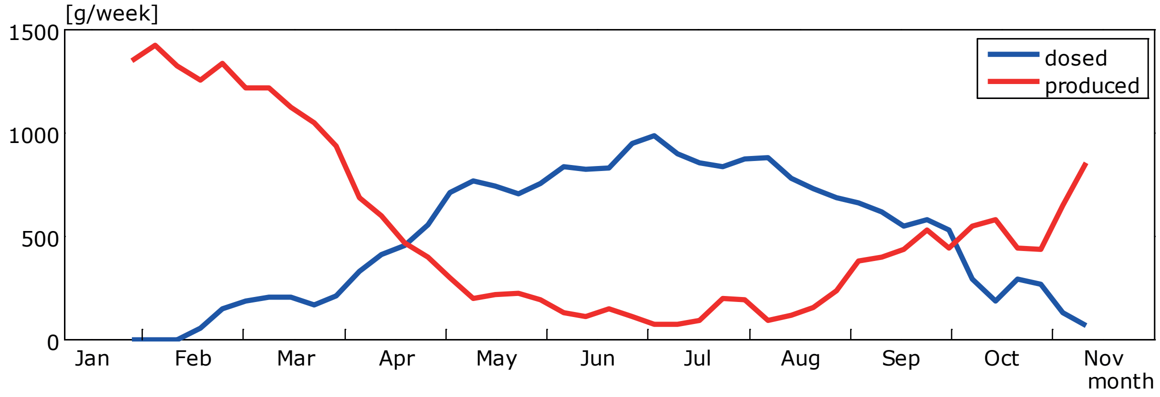

Figure 2.14 *CO_2 production and enrichment in the 2SaveEnergy greenhouse.*

The achieved saving can undoubtedly be called good. It is important to make 2 comments here. 1) the CO_2 mismatch of 12.7 kg (7 m^3 gas) and 2) the not/little activation of the crop, which is part of the Next Generation Cultivation, together form a substantial component of the achieved saving. Although these two points cannot be separated from the greenhouse concept of the double cover comprising glass-film combination and the double energy screen, this greenhouse concept is undoubtedly the reason for the biggest share of the saving.

3 Crop growth

3.1 Research design

This type of energy research is usually implemented without a specific reference crop. For the different crops the best possible reference crop for the production was sought, with the most important criteria being the same variety and plant date. Cultivation choices such as plant density or variety can then still result in differences that could influence the final production and product quality result. Comparisons with the references must therefore particularly be considered indicatively in order to be able to answer the research questions “does the double greenhouse cover have negative consequences for production”.

3.1.1 Cucumber 2014

Crop choice
Cucumber was selected as control crop in the autumn of 2014 as it concerned a short cultivation period and the greenhouse became available on 20 October.

Cultivation conditions
The Venice variety (Rijk Zwaan) cucumbers were planted on 27 October. This is a rather late planting date for an autumn crop, but the greenhouse was not ready earlier. A variety was selected that is suitable for winter cultivation and for spacious planting density, namely 1.5 plants/m^2. The plants were cultivated using a high-wire system. This control cultivation, which was mainly intended to test the greenhouse systems, ended on 23 December.

Measurements
Considering the short cultivation period and the extremely late planting date, no crop observations were carried out.

3.1.2 Tomato 2015

Crop conditions
- Variety: Cappricia (Rijk Zwaan).
- Grafts: Topped at the 2-leaf stage and grafted on Maxifort (De Ruiter Seeds).
- Planting date: 27 January 2015 in greenhouse (sowing date 2 December), placed on matting on 13 February 2015.
- Plant density: 2.5 plants/m^2.
- Extra stems: In week 8 extra shoots (for 2nd cluster) were retained in 1 in 2 plants: 3.75 stems/m^2.
- Topping: Topped on 22 September 2015.
- Clearing date: 19 November 2015 (somewhat earlier in connection with conversion of greenhouse for another trial).

Cultivation conditions
There was no direct comparison object in this trial. There was close consultation with the RSC regarding the cultivation. The harvest was compared on an incidental basis with a group of growers growing the same variety. During cultivation, the climate was controlled as far as possible in accordance with the Next Generation Cultivation principles.

Measurements
Plant registration
Various measurements were carried out each week on 2 x 10 plants (with the extra stems this means 2 x 15 stems) in 2 counting areas. One section was located east and one section west of the path. The following parameters were registered:
- Spring growth.
- Head thickness (at the height of the top of the plant in the previous week).
- Leaf length (first leaf below the flowering cluster with already set fruits).
- Flowering cluster.
- Number of set fruits.
- Plant load.
- Harvested cluster.

Harvesting observations
Average fruit weight was calculated based on the weight and number of fruits within the two fields of observation plants. The kilo production was measured of all plants from 2 carrousels (double rows) in the greenhouse.
Of the 2 fields per compartment, the following observations were carried out:
- Number of clusters.
- Cluster number of harvested cluster.
- Net weight in kg.
- Number of good fruits.

Fruit quality
The shelf life of the fruits was determined twice, on 27 May and 31 July.

3.2 Results

As no crop observations were carried out on the late cucumber crop in 2014, this section only discusses the results of the 2015 tomato crop.

3.2.1 Tomato 2015

Crop development
Representatives from the Research Supervisory Committee (RSC) visited the trial almost weekly, the crop was examined critically and advice was issued regarding climate settings and other cultivation issues. A number of issues regarding the crop are discussed briefly below per cultivation month period.

February
Differences were observable between both plant stems, but this is often the case in plants that are topped at the 2-leaf stage. In the first weeks after planting, attempts were made to strengthen the cluster by not maintaining very high night temperatures. The 1st cluster was pruned at 5 fruits, after which the switch was made to 6 fruits/cluster. The first cluster was unkempt and somewhat uneven. This cluster was therefore clipped high and the following clusters were clamped in place. In the 2nd half of February the crop was strong and the bottom fruits were growing quickly. Because of the late planting date, attempts were made to accelerate this crop by aiming for relatively high temperatures. At the end of February a start was made with pinching a small leaf from the head.

March
In early March the crop was strongly productive and the cluster/flower development progressed quickly. A number of leaves at the head were, however, somewhat speckled with some yellowing at the edges. This is probably a consequence of continuing irrigation for a bit too long, combined with early screen closing, while the temperature and RH were still high. The combination of a double cover with a double screen requires some climatological modifications. The bottom cluster development was progressing well. By mid-March, the head was also looking good. It was advised to accelerate the process somewhat: a somewhat lower basic temperature but with a stronger light increase. At the end of March no further small leaves were pinched from the head. The RSC considered the irrigation to be a bit on the low side. Cappricia needs sufficient water and drainage needs to take place in time. Attempts were made not to ventilate too aggressively at the end of the day and to utilize the heat present in the greenhouse as far as possible.

April
In early April the fruits at the bottom of the plant were very good. At the top of the plant there was tip burn and poor clusters. By mid-April the head had recovered well, but could have been more productive, the flowering of the clusters was poor and the head color could have been darker. In connection with the tip burn it was advised to cultivate ‘more actively’ in the morning by making small differences between the heating and ventilation temperatures. As relatively high temperatures were adhered to in connection with the late planting date, the harvested fruits were not so robust. The roots were fine. At the end of April, the head was darker, thicker and tending towards vegetative growth. Cluster points were somewhat behind in development. For this reason the set temperature was somewhat reduced.

May
In early May the head was strong with short clusters and beautiful yellow flowers. The afternoon temperature was allowed to peak at 27°C. The first dehumidification took place in early May using a ventilator at 20% of maximum capacity, start of dehumidification at VD <1 g/m^3. By mid-May the daytime temperature was extended during intense solar radiation in order to make bigger differences with the darker days. 80% of the top clusters were well-developed at that time. Leaves were regularly topped from the head. Fruits formed in the tip burn period often presented an unequal ripening within the cluster. The form and color of the harvested fruits were good. There were some buckled clusters, as a result of which the weight of the fruit of these clusters had a delayed development. Clusters at the top remained rather weak with sometimes a somewhat delayed flowering, which meant that there were occasional failures. And yet the RSC was amazed that the crop looked so good in this greenhouse.

June
The top was somewhat weak and generative in early June. For this reason the heating temperature was set 1°C lower for a 24-hour period. One week later this showed in tip burn and setting irregularities. Attempts were made to achieve greater temperature differences between days with little and days with a lot of solar radiation. There were still no problems with botrytis. The roots were still fine. By mid-June the top was too weak and generative and somewhat rigid, while the cluster was rather weak. Tip burn and buckled clusters occurred. In the second half of June the head status varied per week, although with continued unequal flowering within a cluster.

July
The weather was extremely hot in late June/early July with considerable solar radiation. Partly because of the limited ventilation capacity, the temperature in this well-insulated greenhouse can be higher than a standard greenhouse if there is a lot of solar radiation and little wind. The status of the crop and the setting were reasonable at the start of the month considering the extreme weather conditions. The relatively good setting compared to standard practice was possibly related to a lower humidity deficit in this greenhouse compared to standard practice. There was, however, still an uneven growth and weak clusters. In mid-July the crop became stronger, but unequal flowering continued. Various plants had chlorotic symptoms. Tip burn also occurred too often. At the end of July the plant heads were good, some were somewhat yellowish in color, with sometimes a hitch in the setting. Regular Manganese modifications were needed in the feed.

August
Plants with yellowish heads also had weaker clusters, but still had good roots. These plants were pruned selectively, with entire clusters sometimes being removed. The plant variation was considerable: as well as extremely strong plants there were also weak, yellowish plants with delayed flowering and poor setting. This latter was not related to the bumble bees. The RSC advised even more active cultivation in the morning, making a bigger difference between the night and daytime temperatures and extending the day when solar radiation was high. Dehumidification was also increased: maximum ventilator capacity was increased from 30 to 50%. The bottom clusters colored irregularly too often through poor setting. To reduce plant load the switch was made to harvesting twice a week. No topping had taken place for weeks. There were absolutely no Botrytis problems.

September
In general the fruit form was good. The top clusters were stronger and the latest clusters were clamped. The yellowing in the head appeared not to continue. Dark weather in week 36 resulted in the plant having poor head strength the following week. By mid-September this had hardly improved. The cause of the weakness remained unclear. It seemed as though the plant was unable to transport certain nutrients effectively to the head. However, there were still no root problems. In the 2nd half of the month, however, there was improvement in crop status, but most clusters remained somewhat weak. There was still some tip burn. The plants were topped on 22 September.

October
In spite of the good weather a number of plants started to demonstrate chlorotic symptoms in early October and cluster irregularity remained. This later led to differences in coloration within the cluster. It is striking that, in spite of recurring setting irregularities, in comparison with standard practice, production was excellent. Sucker growth was strong. There remained huge differences between the plants. The roots of all plants were continuously good. At the end of October few yellow heads were to be seen.

November
Application of Ethrel took place on 9 November and on 20 November cultivation ended as work still needed to take place in the greenhouse in connection with the follow-up cucumber research. However, the top cluster fruits had still not completely colored.

Figure 3.1 illustrates the day and night-time setpoint temperatures achieved during cultivation and the achieved day and night-time greenhouse air temperatures.

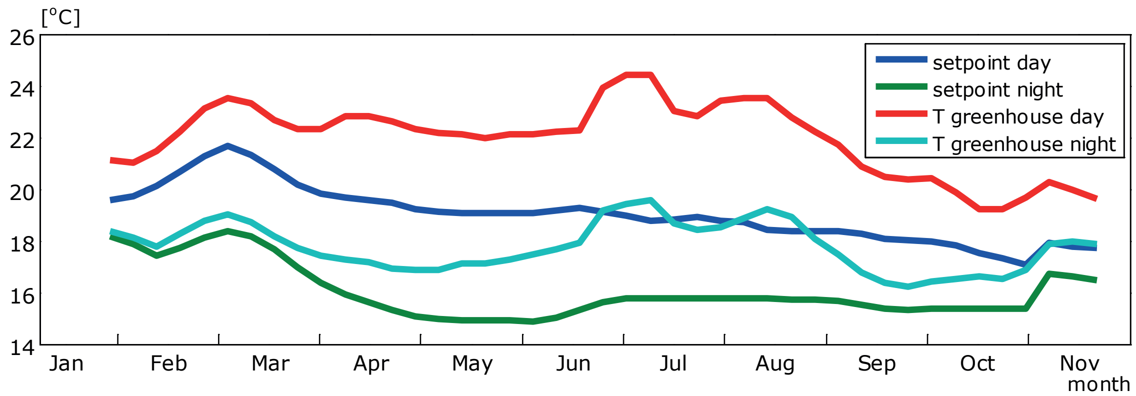

Figure 3.1 *Day and night-time setpoint temperatures and achieved day and night-time greenhouse air temperatures, as a weekly average.*

Plant measurements
Figures 3.2 to 3.4 illustrate consecutively the head thickness, the number of set fruits and the plant load per week.

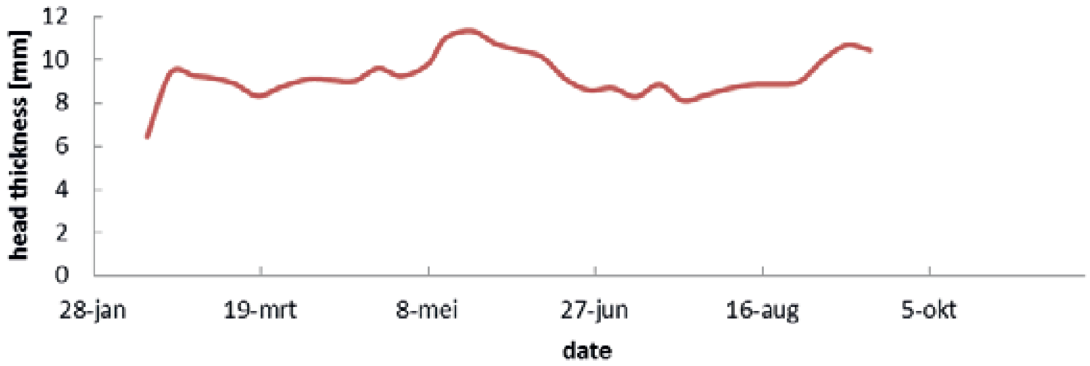

Figure 3.2 *Head thickness per week measured in the 2SaveEnergy greenhouse.*

The stems were the thickest from mid-May to mid-June. Towards the end of cultivation, the head thickness increased again.

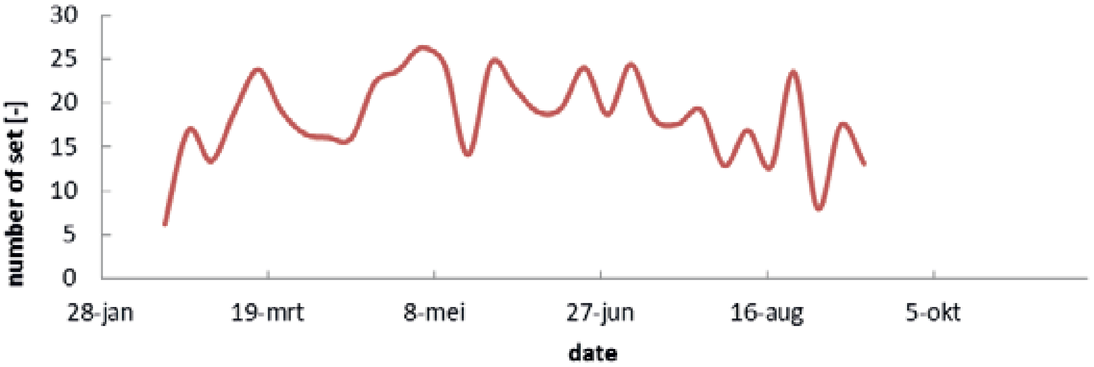

Figure 3.3 *Number of set fruits per week in the 2SaveEnergy greenhouse.*

The number of set fruits fluctuates somewhat over time. Particularly around 1 April the number of set fruit was relatively low. This is probably partly related to the poorly-formed clusters in this period.

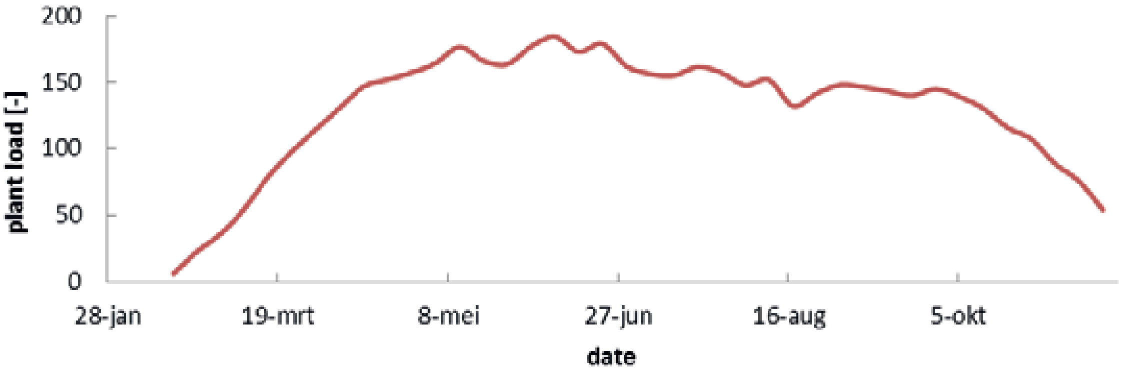

Figure 3.4 *Plant load per week in the 2SaveEnergy greenhouse.*

The plant load increased at the beginning of May and reached its peak in the 1st half of June. This then reduced gradually.

Production and quality
Figures 3.5 and 3.6 illustrate, respectively, the weekly production and the fruit weight.

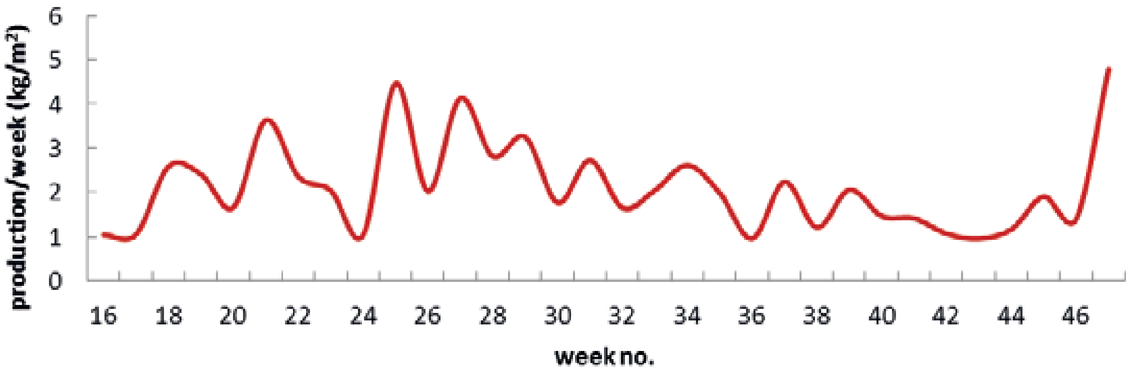

Figure 3.5 *Production per week in the 2SaveEnergy greenhouse.*

The production showed some peaks and troughs, but this is partly because harvesting took place 3 times in 14 days. This means that in one week there was one harvesting but two in the next week. The application of Ethrel created a peak at the end of cultivation. The final net production amounted to 67.1 kg/m^2. This is 4 kg more than the prior set objective of 63 kg/m^2.

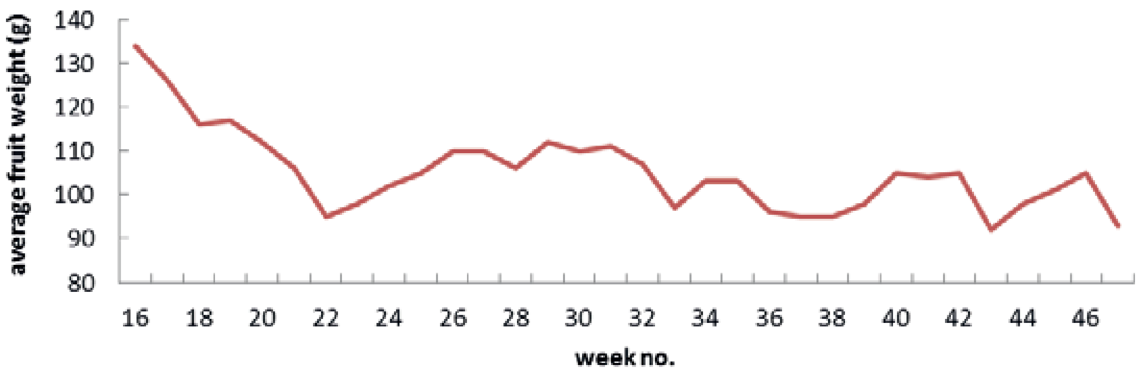

Figure 3.6 *Average fruit weight per week in the 2SaveEnergy greenhouse.*

The first clusters were clearly the most robust. Particularly in week 22 (end May) the average fruit weight was on the low side. This could be related to the stem buckling that occurred in this period. The average fruit weight over the entire period was 104g.

The shelf life of the tomatoes on 27 May and 31 July was 18.3 and 14.2 days respectively. This shelf life is rather good.

4 Publicity

Publicity regarding the 2SaveEnergy greenhouse as part of the IDC Energy was considerable. As well as large numbers of visitors, including dozens who visited the greenhouse on special request, the project attracted regular and considerable attention from the printed press. Appendix 1 presents an overview of the most relevant articles and publications/presentations given.

5 Conclusions

The 2SaveEnergy greenhouse experiments demonstrated that it is indeed possible to achieve practice-standard production with low energy input (15.5 m^3/m^2) from the end January - end December period, with only a slight increase in electricity consumption compared with a standard greenhouse. In the feasibility study prior to this project, calculations had already demonstrated that this greenhouse and cultivation concept should be able to generate savings of up to 50% compared to standard practice. For standard practice greenhouses in which crops are grown according to the Next Generation Cultivation principles, a heat consumption of 23 m^3/m^2 has been estimated.
Although this trial confirmed that significant savings in energy consumption can be achieved, it must be emphasized that this is the joint result of both the greenhouse and cultivation concept.
In addition to the insulation level from the double greenhouse cover and the double moveable screen, a significant proportion of the savings were achieved through crop management and the availability of an alternative CO_2 source.
Not using a minimum pipe temperature did not lead to visible problems. The savings on heat also showed two clear seasons throughout the year: the winter, in which the greenhouse cover and screen provided savings, and the summer, in which the cultivation concept in particular provided energy savings.
However, the low energy consumption in the summer has the disadvantage that an external CO_2 source must be available in order to achieve the desired production level. Even with the efficient CO_2 dosing strategy used in this trial, it is likely that as much as 13 kg CO_2 will need to be purchased annually.
The dehumidification system using outside air intake and reheating performed well.
The low-snow winter of 2015 did not permit testing of snow-thawing via extraction of greenhouse air distributed through the gutter to the cavity between the glass and film. Test measurements did, however, demonstrate that the air in the gutter cools down very quickly, indicating that the thawing capacity will be minimal.
As the cavity between glass and film is not air-tight in this concept, condensation can occur in the cavity. Whether and which consequences this will have on transmission in the long term is not yet known.
The tomato (Cappricia) production of 67 kg/m^2 was higher than the 63 kg/m^2 aimed for and was similar or even higher than standard practice. The diffuse greenhouse cover will have undoubtedly played a role in this. The crop cultivation period generally occurred without Botrytis or other diseases. The disparity in and between trusses however, was striking during different periods in the crop cycle. The cause of this is unclear.
Regarding crop production it can thus be concluded that using an insulated greenhouse cover and intensive (double) screen use has no negative consequences for production.

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