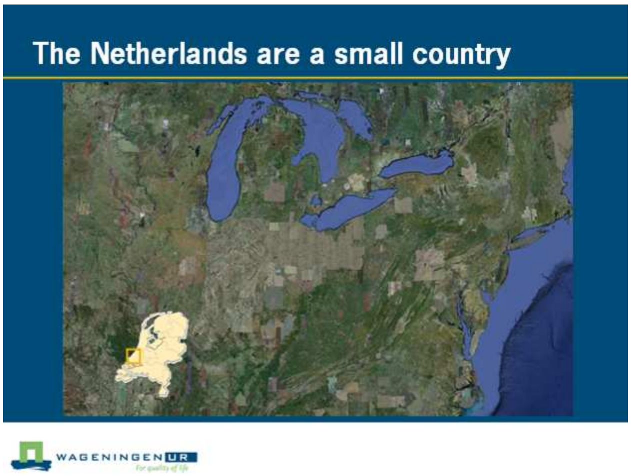
Handout OFA Short course contribution of Feije de Zwart, Columbus (Ohio, US) 11, July 2010

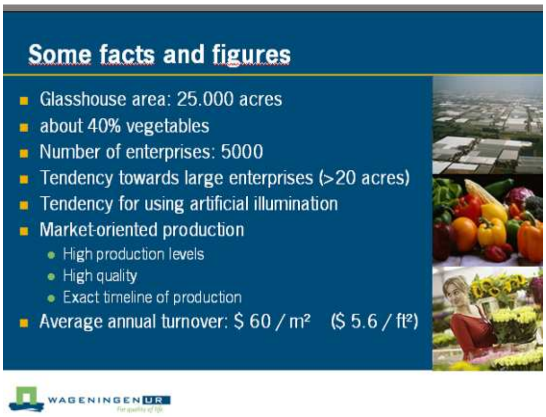
Good morning,

I am Feije de Zwart and I am working at Wageningen Research and University in The Netherlands.
In our department Greenhouse Horticulture, we work with a group of 120 people on the field of greenhouse construction, developments on new materials, crop protection, nutrition and greenhouse climate.
For me, the major field of research is the llinking between greenhouse climate, greenhouse construction, the crop and the energy consumption. This work is mostly done by developing simulation models that describe and explain what we see happening in experiments. With this explanatory models we can verify and interpret the measurements and we can predict what will happen in other circumstances.
The results of this work are mostly scenario studies that help policy makers and horticultural industry to select the right options.



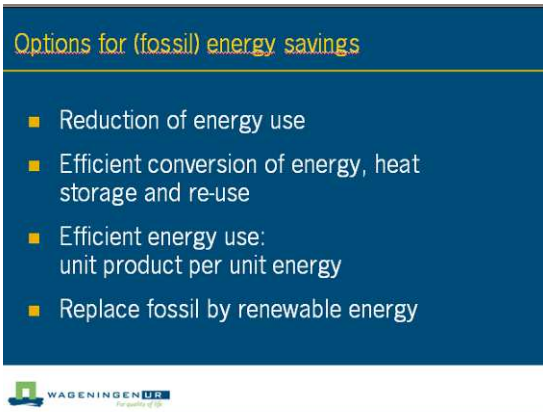
The Netherlands are just a small country, and within this country, Horticulture is very much concentrated in the Westland area, here marked with the square. This area is close to the big cities Amsterdam, The Hague and Rotterdam.

Seen from satellite the area can be seen clearly and seen at an angle from an airplane it is obvious that this region is really specialized in horticulture. All Ducth greenhouse builders and computer firms have their head offices in this area.

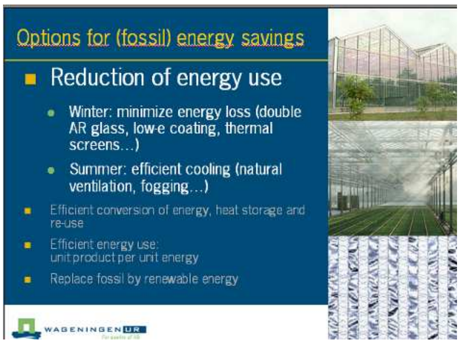


On this sheet I have stated some statistics.
The glasshouse area is more or less stable for already many years, but there is a gradual shift towards ornamental plants and cutflowers.
There is also a tendency to increase the scale of operation, especially in vegetable production.
The market oriented production means that the produce is less and less sold at the auction. Growers try to create their own brands and ship their products in specially designed packages. Growers try to negotiate on prices on forehand, which implies that accurate planning of the production becomes more and more important.
The mean annual turnover is around 60 dollars per m^2.

This presentation is about possibilities for energy saving, now and in the future.
In the Netherlands this is an important issue since the energy costs range between 15 and 30% of the production costs and I assume here this will be pretty much the same.
From business economical point of view it makes not so much difference whether energy savings are achieved by reducing the energy costs or by using the used quantity.
This presentation will focus on savings by reducing the demand.
However, costs will mostly not diminish in the same proportion as the decrement of energy use, since most savings need investments. So, when saving energy there will mostly be some shift from variable costs to investment costs.



There are many ways to realize energy savings. In this sheet I have made a categorizing, just to facilitate a better grip on the subject.
This list is not a priority sequence.
Of course, those measurements that give the best economical perspective are to be implied first.



With respect to possibilities to decrease the energy demand of greenhouses, screening systems currently get a lot of attention. Screens are relatively cheap so adding a second movable screen to the widely spread transparent thermal screen saves some 10 to 15% on energy demand, depending on the quality of the screen. Because most of the effect of a thermal screen is gained during the night, such a second screen can be fully aluminized, (resulting in 15% energy saving, compared to the 10% for the case where the second screen is transparent as well).

Next winter, a novel glazing material from Scheuten Glass will be tested on a 550 m² experimental greenhouse (6000 ft²) . It is a double layer glass panel with Anti Reflection coatings and a low emission coating (for reduced thermal infrared losses). These coatings are applied on the inner sides of the double glass pane and thus protected for erosion due to cleaning of the deck.

It is claimed that the transmissivity for light is comparable to that of single glass, but the thermal insulation is at least 3 times bigger than single glass.

In the experiment we will study potential drawbacks of this insulating glass for vegetable production in the warmer parts of the year. These could occur because the head of the crop will remain warmer due to the strongly reduced radiation loss.

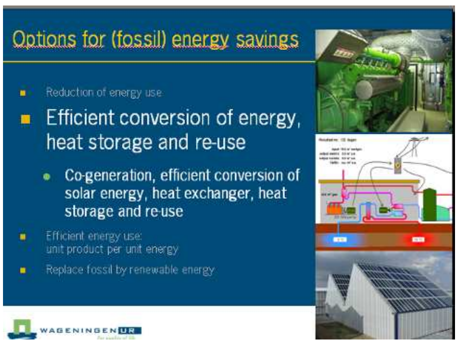
In summer, energy use is not so much caused by the need for heating, but origins from the CO2 from exhaust gases. Therefore, large parts of the heat consumption in summer is rather a way of getting rid of the heat associated with CO2 production. Since the application of fogging in situations with low outside humidity can reduce the ventilation rate, the demand for CO2 can be reduced and so the energy demand.

For canopies that need to be grown at low temperatures (*e.g.* 60 to 65 ºF) the energy consumption in summer will be dominated by the cooling demand. For these canopies, the application of heat pumps and seasonal storage gives large decreases in energy demand (typically 30 to 40%).

Here is a picture of the experimental greenhouse where this Scheuten Glass will be mounted.

The air duct that can be seen in the photo is part of a balanced ventilation system that enables dehumidification of the greenhouse while regaining the heat that would be lost if simply the inside air would be exchanged by outside air.

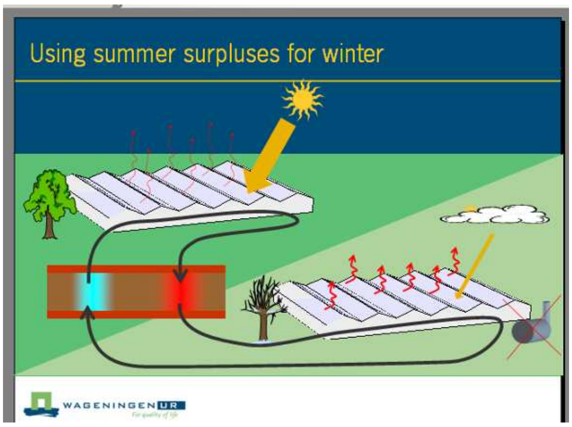
Especially in a greenhouse with double glazing, energy efficient dehumidification becomes more and more important since condensation will hardly occur.



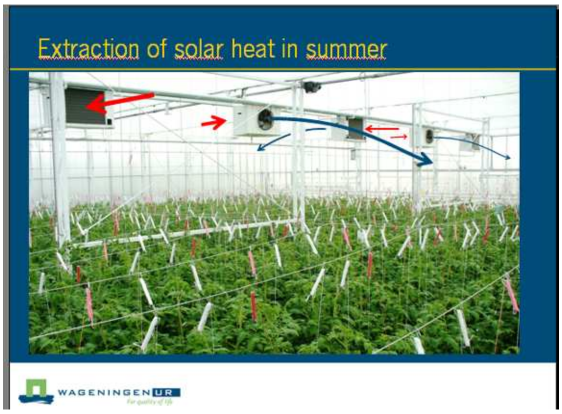
Besides the reduction of the energy demand, improving the efficiency of energy conversion gives large possibilities.

In the current Dutch energy market, the application of combined heat and power is the most common way to reduce the energy costs (but without reducing the energy demand of the greenhouse). Especially in vegetable production CHP-engines on natural gas run almost all daytime period. Electricity is sold to the public grid and the exhaust gases give 200 to 250 kg of CO2 per ha per hour (180 to 220 pound per acre per hour). This large amount of CO2 and the easy accessible electricity grid and the good possibilities to transport electricity trough Europe, CHP has a strong market position.

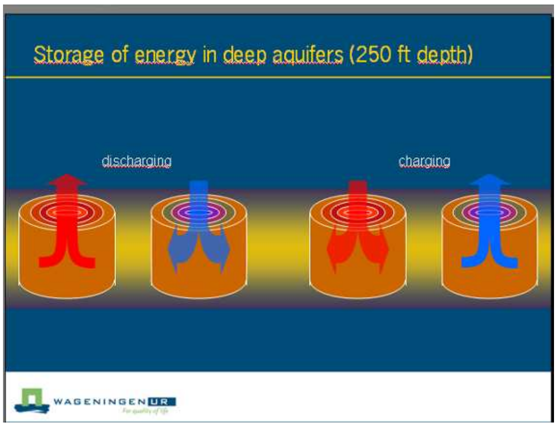
By selling the electricity, the reject heat from the CHP-engine becomes a relatively cheap heat source (order of magnitude $0.8 per thm ($7,70 per GJ)). This makes Dutch growers are interested in new possibilities to reduce their energy demand, but not so much for the short term. For the future it is expected that CHP remains to be important, but that increasing gas prices will not fully be accompanied with increasing electricity prices. Eventually this will result in less energy demanding greenhouses and a higher contribution of sustainable energy in horticulture.



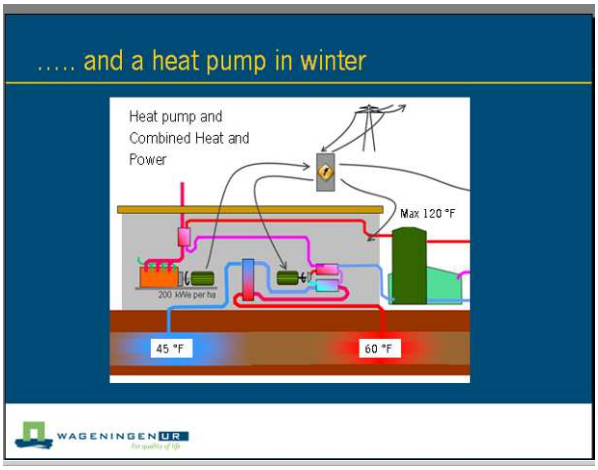
One of the possibilities to enlarge the use of sustainable energy in horticulture is to use the energy surpluses from summer for heating purposes in winter by means of a seasonal storage.



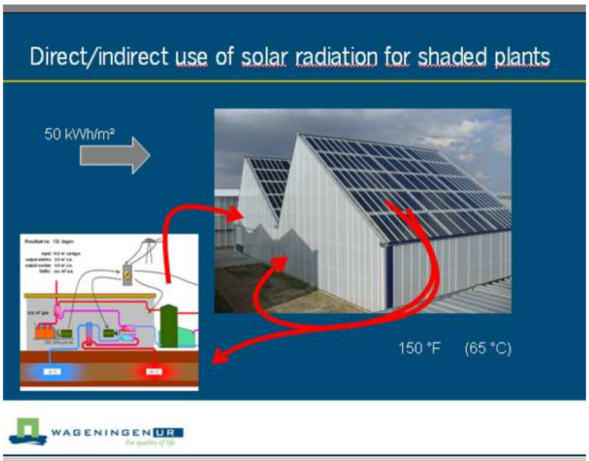
This principle starts with extraction of heat from the greenhouse by cooling devices. In this picture, a fully closed greenhouse is cooled by air conditioners that heat cooling water from 50 ºF to 65 ºF while keeping the greenhouse at maximal 85 ºF.



The cooling water is extracted from a well in an aquifer. After being heated to this 65 ºF, it is infiltrated in the warm well of the aquifer.
In winter this process can be reversed.



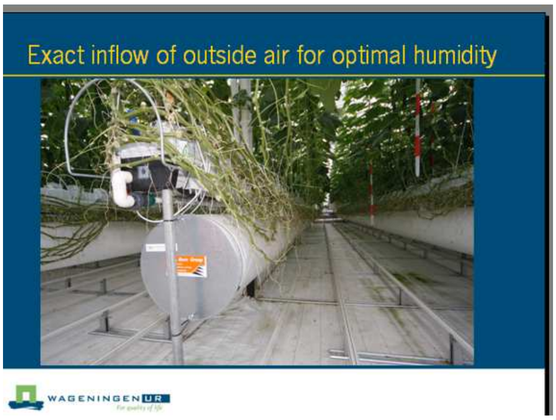
Of course, 65 ºF is not enough for heating a greenhouse. Therefore, such a greenhouse must be equipped with a heat pump. In this picture, this heat pump is driven by electricity from the CHP-engine when it's running on part-load, but if it's cold, more electric power is required which then can be obtained from the grid.
The heat pump supplies the greenhouse with water hot enough, and the evaporator of the heat pump cools down the water from the warm well to a low temperature of 45 ºF. Note that the temperatures shown in the aquifer are lower than the temperatures mentioned in the former sheets. That's because the separating heat exchanger induces some temperature loss and because of dispersion in the aquifer. The overall effect is an energy saving potential of some 30%.



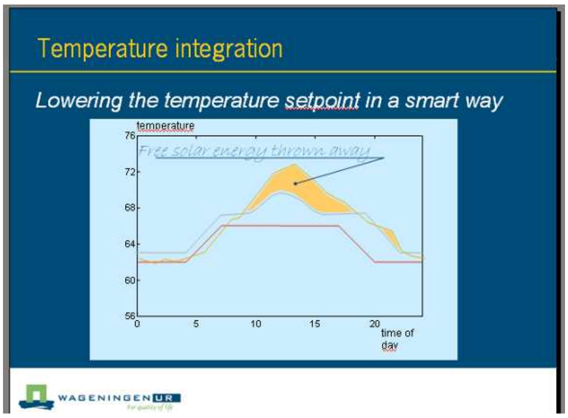
Last year, we also had an experiment in a greenhouse with turnable lamella's in the south facing roof panels. When solar radiation exceeded 200 W/m², the lamella's where shut, turning the roof into a large solar panel. The panels then can produce solar heat at 150 ºF, which can be stored in day-buffers.
Of course, the majority of the energy is gathered in summer, which means that most of the gathered energy is not going to be used in the coming night.
Thus, also this design needs an aquifer system for seasonal storage, and therefore a heat pump as well. However, since temperature levels are higher, this heat pump won't need as much as driving power as in the system presented in the former case. In Dutch weather conditions, 50 kWh/m² per year would do.

However, the direct conversion of solar energy to heat, keeps most of the light out of the greenhouse. For some crops this will be even an advantage, but for most crops you want almost as much as possible light inside.

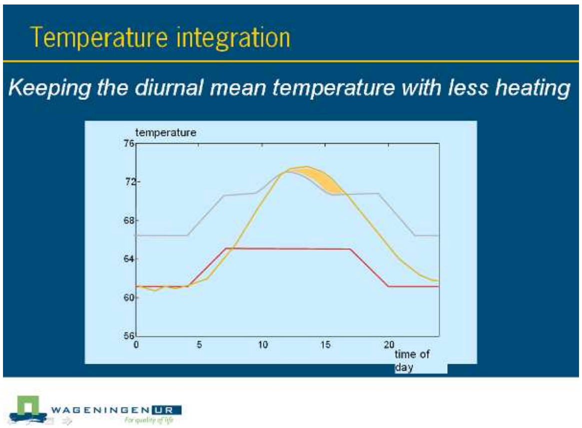
For you however, as growers today, the first thing to do is to try to increase the efficiency of your energy use. Producing more crop per unit of energy is a way to save energy too.
Higher light transmissivity of the greenhouse is one of these measurements that help. For many crops, more light turns almost linearly into more produce.
Building better greenhouses with better materials is one possibility, but for ornamental crop production, a number of experiments in the past years have shown that a good quality of the crop could be achieved while shading much less than common practice. As long as the humidity is kept at favourable levels (like 80% RH) ornamentals appeared to grow equally well under 40 umol/(ft² s) as under 20 umol/(ft² s). The crop grown at higher intensity grew allmost 50% faster. This favourable humidity was achieved by fogging if necessary.



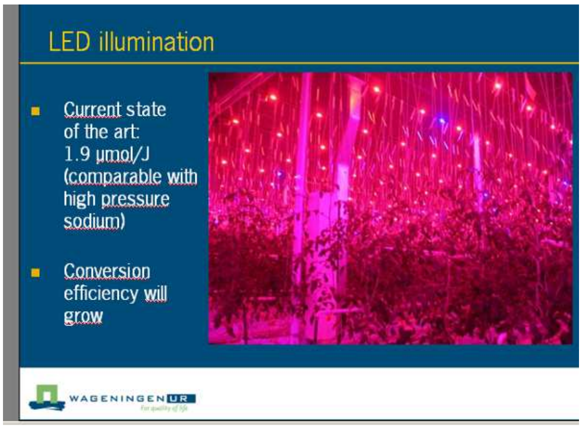
Another important development of the past two years is to apply well distributed outside air for dehumidification instead of just opening the windows. Bringing the relatively dry outside air into the lower regions of the canopy by air ducts like shown in this picture reduces the development of typical high humidity problems such as botrytus.
Although it is just an active inflow of outside air, and in that sense comparable to opening the windows, this way of dehumidification saves energy. This because directing the air towards the places that have to be dried enables that in the end less air has to be exchanged, giving less energy loss. In practice this means that the average humidity in the greenhouse becomes higher, whereas dangerous high local humidities are prevented.
Also, because of the fact that the air is actively blown into the greenhouse means that energy screens can be kept closed for many more hours and this saves energy as well.
Still the electricity consumption of the fans, in Dutch weather conditions, is limited to 5 to 10 kWh/m² (0.5 to 1 kWh/ft²) per year.



With respect to temperature management, in general a lower temperature results in a lower energy demand. However, in order to have a balanced crop development, there will always be some optimal temperature, which limits the freedom in choosing a low temperature.
Luckily it appears that a canopy has quite a flexibility; realizing some diurnal mean temperature gives mostly enough steering for balanced crop development.
With the diurnal mean temperature as a major control objective, there is a way to increase the contribution of solar energy to heating of the greenhouse.
This so called, temperature integration, avoids spilling of free energy from the sun, while keeping track of a favorable diurnal mean temperature
When the temperature at which windows are opened is close to the temperature setpoint for heating, ventilation of heat excesses will occur during the day. In fact, during these moments, free solar energy is thrown away.

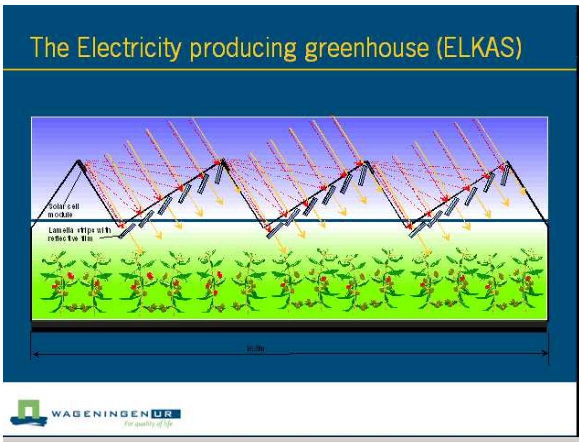


A number of practical experiments have shown that serious energy savings can be reached when the setpoint for heating is lowered and the setpoint for ventilation is shifted upward.
In essence, this is what happens when a control strategy which is called *Temperature Integration* is applied.
When doing this in a proper way the same a diurnal mean temperature can be achieved as in the situation on the former sheet, but with a larger difference between daytime and nighttime. This means that instead of a large heat loss during the day, the heat loss can be much smaller, whereas the demand for heating during nighttime is diminished.
Experiments in practice have shown that canopy growth is hardly affected by this alternative strategy and energy savings up to 10% can be achieved.
Of course these savings are concentrated in spring and autumn. In summer, quite often, the major concern of the grower is how to keep a low diurnal mean temperature, which means that the setpoint for ventilation must cannot be shifted upward.
In winter there will be not too many occasions where lower temperatures during the night are compensated enough by solar heat during the day. Still, it is important to know that most canopies appear to have quite good possibilities for balancing periods of lower and higer temperatures, even over some days.



All former sheets predominantly discussed savings on heating the greenhouse. However, for the Dutch horticultural sector, the amount of energy needed for illumination is much more than the amount of energy needed to heat the greenhouse.
Moreover, due to improvement of the greenhouse buildings, the heat demand tends to decrease whereas due to market developments, the use of illumination has shown a gradual increment. Three years ago, there were large expectations of the application of LED-systems for plant growth. There were some suppliers with different systems (air cooled, water cooled, different ratios of red and blue light). A number of growers have tested these systems without clear results. Last year, our experimental station has carried out an conscientious comparative research on different type of LED illumination in comparison with high pressure sodium illumination (SON-T). The most important conclusion was that the systems currently available on the market yield an overall energetic efficiency comparable to SON-T. However, it is reasonable to assume that the conversion efficiency of LED-light will improve in the coming years since the large scale LED-technology is still in an early development stage. We have already heard of LED-systems with a conversion efficiency of 2.2 µmol/J for red light. This means a more than 5% improvement compared to the results of last year.

Finally, after having put effort in all ways of reducing the energy consumption, horticulture can become more sustainable by using renewables.
For horticulture, CHP on biogas would fit well because horticulture can give added value to low grade heat and to the CO2 from the exhaust. In the Netherlands there is one example of a grower that combusts biogas from a potato processing factory in a 1 MW CHP engine with exhaust gases clean enough to be fed to his greenhouse as CO2 fertilizer.
There are also some growers that combust chipwood. In most cases the energy is turned into heat only, but in some cases electricity is produced as well by means of a steam cycle.
Some three year ago, a tomato grower has started to heat his greenhouse with geothermal heat. It works satisfactionary, also due to the fact that this grower has his nursery in a region with a CO2 distribution infrastructure. This is waste CO2 from the chemical production plants near Rotterdam.



In the area of using solar energy for electricity production, our research station is working on two types of concentrated PV. In the first project, the greenhouse is equipped with spectral selective mirrors that reflect Near Infra Red radiation and pass the Photosynthetic Active Radiation.
The mirrors are turnable, so large amounts of solar radiation can be focussed on a relatively small PV panel. This limits the costs of the most expensive component of a PV-system which is the PV-cell.

The other development is the use of lenses to concentrate direct radiation.
As can be seen in this picture, the mean radiation intensity behind the linear frensnel lens is lower than the undisrupted light since the direct light is focussed in a line. When these kind of lenses are mounted in the south facing roof, a collector can be placed in the focus.
Contrary to the former example, based on spectral separation, the fresnel greenhouse separates between diffuse and direct light. With the collector in focus, almost all direct-PAR will be used for electricity production, which means that this light is no longer available for canopy growth. This means that the fresnel-greenhouse will be applicable for plants that must be cultivated in the shade.

These last, most futuristic greenhouse designs bring me to my final remark, which is that there is no thing like an optimal greenhouse design. Every region on earth has its special opportunities to grow high quality fruits and ornamentals and it needs skills and understanding of the horticulture and physics to assemble these local opportunities to profitable business.
For northern regions, energy consumption is an important issue and that's why most of my work is linked to this topic. However, as an international operating group, we also work for arid regions. In these regions the water use efficiency is one of the most important qualifications of a design. There, spectral selective foils might help a lot in reducing the heat load to the canopy and thus the evaporation.
For greenhouses in the Emirates, for example, it is even shown that cooling a greenhouse at the expense of 30 kWh/ft² is worthwhile because this saves 0.6 yd³/ft² of good quality water per year.
We do also have some research projects in the tropics. Water and heating are hardly problems there. In those regions, pests and diseases are the most severe threats for a profitable horticulture so for those regions we work on the development of greenhouses with dense insect screens in the vents, but yet enough ventilation capacity.

It is the combination of horticultural skills and technology that makes this sector challenging and innovative. With 3000 visitors a year, our research centre in Bleiswijk is one of the centres that facilitate an ongoing improvement of the sector. It is a meeting point for growers, researchers, industry, students and the general public.