Whitepaper:

Plant empowerment

Optimizing growth climate by steering the plant's balances

hoogendoorn
growth management

Introduction

Next Generation Growing (NGG) is a new way of growing introduced in the Dutch greenhouse industry by the Dutch Cooperative Grower Association. Hoogendoorn has been involved in the research since 2006. Although NGG is mostly associated with energy savings, the primary aim is to optimize plant growth by improving the greenhouse climate conditions. So the main focus is on plant growth and development. Although substantial energy savings are achievable as well this is regarded as a bonus rather than a goal.

In the Netherlands, an intensive educational program was introduced. Within this program already over hundreds of Dutch growers and consultants have been educated and trained to expand their knowledge of physics and plant physiology. By applying the principles of NGG they improve their results and minimize energy costs at the same time.

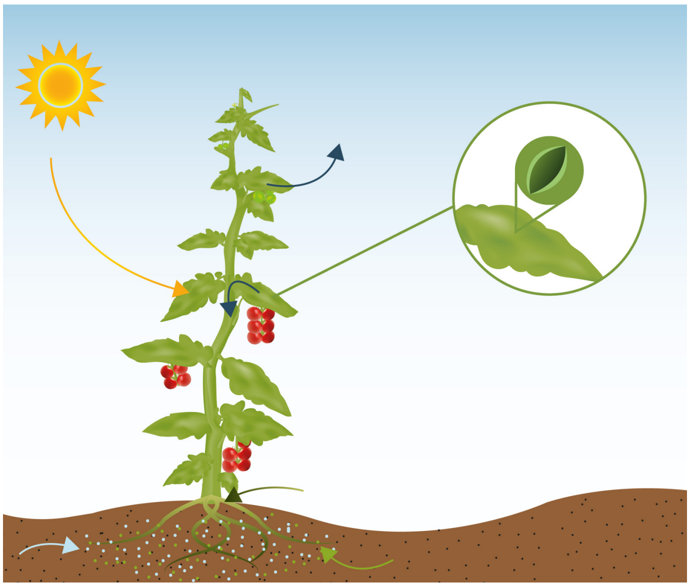
This whitepaper provides in short some backgrounds and applications of the Next Generation Growing methods.

Photosynthesis as starting point

Photosynthesis is the starting point to optimize plant growth. Green plants contain a pigment called *chlorophyll*. Chlorophyll absorbs part of the solar spectrum that we call Photosynthetic Active Radiation (PAR). This is light in the range from 400 to 700 nanometer wavelength. PAR light drives the photosynthesis process in which CO_2 and water are photo chemically converted into assimilates and oxygen. Assimilates are also referred to as carbohydrates or sugars. Assimilates provide the building blocks for growth and energy to keep the internal biochemical processes inside the plant going. So the first step for optimal growth is optimal production of assimilates, thus maximum utilization of available PAR light from the sun or artificial lighting like SON-T lamps or LEDs.

The best way to optimize photosynthesis is to supply much PAR light and to support the plant in keeping its energy and water balances in balance. In general this means: high CO_2 level, high humidity (e.g. 75% depending on the type of crop) to keep the stomata open and also high temperature, because this speeds up the photosynthesis process.

Of course there are limitations. Each type of plant has its own maximum photosynthesis capacity expressed in micromole / m^2.sec PAR light level. Higher PAR levels can't be processed efficiently and can even bring damage to the chlorophyll. Besides that, each type of plant has a maximum evaporation capacity expressed in grams / m^2.hour. Forcing the plant to a higher evaporation rate causes crop damage. However, NGG research has shown that for many plant types photosynthesis capacity can be stretched to much higher levels than usually has been practiced by keeping a high humidity under high radiation conditions.


Photosynthesis process

In short, in many cases photosynthesis and assimilates production can be increased by simply keeping the ventilation windows of the greenhouse more closed, and sometimes applying additional misting, instead of closing the shading screen or applying white wash to temper the sunlight.

Plant Balances

The growth process of a plant is mainly determined by three plant balances: the water balance, the energy balance and the assimilates balance. These plant balances are interlinked via the stomata; the microscopic little pores in the leafs that let water vapor out and take CO_2 in.

If evaporation is high under sunny conditions and the water availability inside the plant becomes too low, stomata start closing in order to decrease evaporation and prevent dehydration. As a consequence the temperature of the leaf will rise, resulting in a shift of the energy balance. Besides that, closing of the stomata obstructs CO_2 uptake, thus slowing down the photosynthesis process which negatively effects the assimilates balance.

So, as all plant balances are interlinked via the stomata, changing one growth factor e.g. PAR light also involves other factors such as temperature, CO_2 uptake, RH , water uptake and eventually plant growth.

In conclusion it can be said that under all conditions the plant aims to keep its three balances in balance, and that all physiological processes serve the plant to do so. Observing the plant's behavior via the balances reveals many aspects of how plants react to changing circumstances in a relative simple way. It is obvious why the plants are triggered and what the plant eventually tries to achieve: restoring its three balances as much and as quickly as possible. The time horizon of the energy balance and water balance is very short; they react within a few minutes. The time horizon of the assimilates balance is longer, with a reaction time within one or more days depending on the type of crop.

Energy balance

The energy balance is the balance between the energy flow towards (input) and from (output) the plant. We can distinguish four different types of energy flows:

- short wave radiation - this is sunlight or light from lamps or LEDs;
- long wave radiation - also called heat radiation or heat emission;
- convective energy - transferred by moving air around the leafs;
- evaporation energy

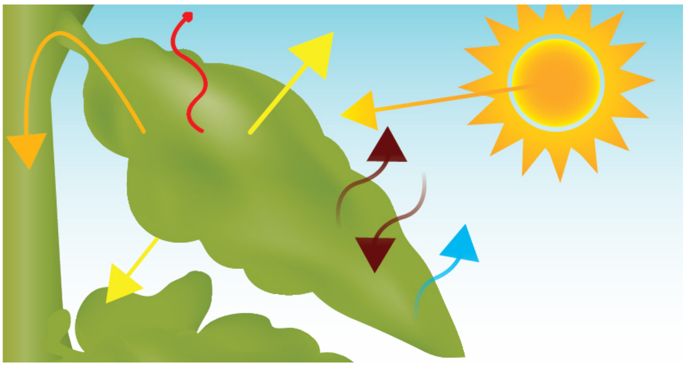
Since plants can't produce heat of their own, the energy balance consists exclusively of external energy flows. If we make up the energy balance all separate flows are counted up and in accordance to the physical law of preservation of energy the result must be zero.

Typically, short wave radiation is only towards the plant and thus always on the input side.
Longwave radiation can be towards the plant, but also from the plant depending on the temperature difference between the plant and the surrounding objects like the soil and greenhouse roof.
Convective heat transfer also depends on the temperature difference between the plant and the air. So it can contribute either positive or negative to the balance.

Evaporation is only possible in case the balance has a surplus of energy. Evaporation is also the link between the energy balance and the water balance, because evaporation is the most important factor for cooling the plant under high radiation conditions.

New insights into energy balance

NGG research has revealed at least three important new insights related to the energy balance of plants. Firstly, the fact that plant activity or evaporation can be stimulated by air movement as moving air supplies convective heat input.



Energy balance of the plant

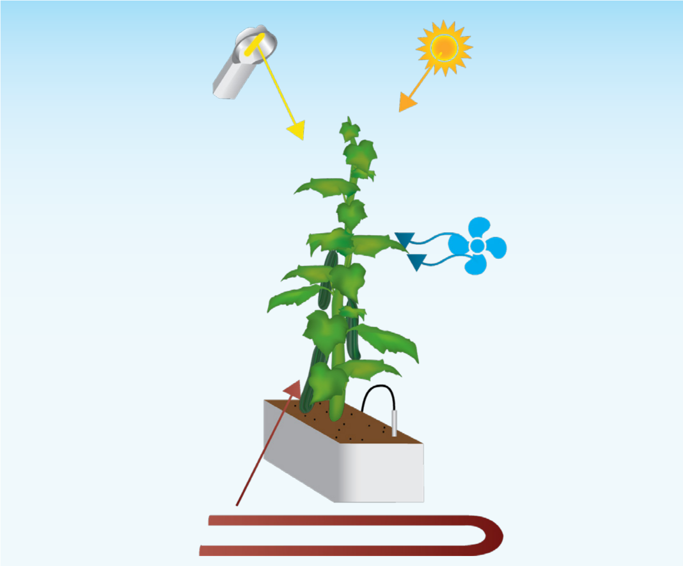
Air movement also prevents a dull micro climate. Secondly, it has been shown that low air humidity or high humidity deficit causes unnecessary extra evaporation under high radiation conditions, thus limiting photosynthesis by stomata closing. Thirdly, it has been found that longwave radiation has a major negative impact on the plant's energy balance during night time, but also at the beginning and end of the day when the roof of the greenhouse is cold compared to plant temperature. In that situation evaporation and thus uptake of vital nutrients, especially Calcium drops under the critical minimum value. This causes many different problems for the plant's growth and development. Therefore it is strongly advisable to keep a good energy screen closed during nighttime to keep the energy balance in the plant top on the positive side and allow evaporation for calcium uptake.

Water balance

The water balance is the balance between the input to and output of water from the plants. Output of water is mainly caused by evaporation. Only a little portion of the total water uptake is stored in the plant and the fruits. In practice evaporation is mainly driven by radiation from the sun and artificial lighting and also from the heating pipes. If there is no radiation at all, the only source of energy is convective heat transfer by air movement. In that case evaporation also depends on RH (relative humidity) and/or HD (humidity deficit).

The plants need to evaporate and thus take up water from the root zone for three reasons: the uptake of nutrients, for growth and for cooling. In order to keep the water balance in balance, the uptake of water from the root zone must equal at least evaporation rate. So to ensure sufficient water availability, irrigation needs to be aligned with evaporation energy received by the plant.

Growers prefer their plants to be active at all times, with good reason. At least it is very important that evaporation is not interrupted for too long. As stated above evaporation is necessary for uptake of nutrients especially calcium. Calcium is an indispensable building material for young growing cells, and a lack of calcium can cause various types of problems. Furthermore a surplus of calcium at one moment does not mean that it still can be used afterwards. Calcium will soon be implemented in chemical compounds making this element no longer available. This means that evaporation, especially in the top of the plant around the growing tip, should not drop below the critical value depending on the type of crop. And again, protection of the plant against outgoing long wave radiation is a very important measure to prevent calcium related problems.



Water balance of the plant

Monitoring Stomatal behavior

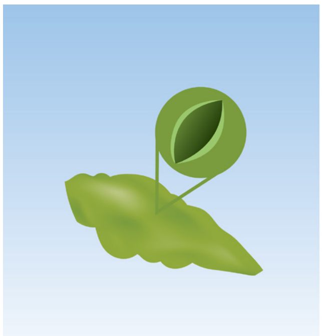
The plant temperature compared to the air temperature is an important indication of the status of the water balance and energy balance of the plant. If the plant temperature is lower than the air temperature, the plant has more than enough water available to evaporate and thus to keep its temperature low. If the plant temperature is higher than the air temperature, this may indicate that the plant has not enough water available for cooling. In this case the plant will partly close its stomata to restrict evaporation rate in order to maintain the water balance.

For the uptake of CO_2 it is very important to keep the stomata open. Stomata are open if the water balance is in balance, so the evaporation rate doesn't exceed the water uptake capacity of the plant. If the evaporation would get too high measures can be taken. The first step is to increase the RH of the air. This way, the convective energy transfer from the air to the plant is decreased and thus total evaporation decreases. If the evaporation rate is still too high, a shading screen or white wash has to be applied to decrease the radiation intensity.

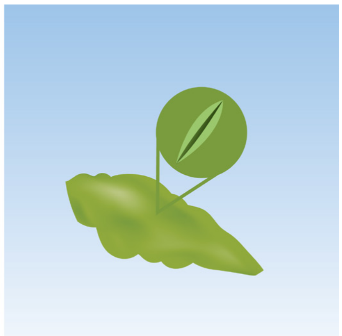
Vapor Pressure Difference (VPD)

If we want to know if the stomata are closed or open, we need to determine the Vapor Pressure Difference (VPD) of the plant. The VPD is the difference between the water vapor pressure in the plant and the water vapor pressure in the air. This can be calculated by measuring plant temperature, air temperature and air humidity.

Typically VPD should be in the range between 0.3 to 1.5 kPa (kilo Pascal) depending on radiation level for most crops. It is a misunderstanding that for high evaporation rates a high VPD and thus a high HD (humidity deficit) is needed. Plants such as tomatoes and cucumbers can evaporate a lot of water at low VPD values if stomata are wide open, even if the RH (relative humidity) of the air is high.



Open stomato by low VPD value.



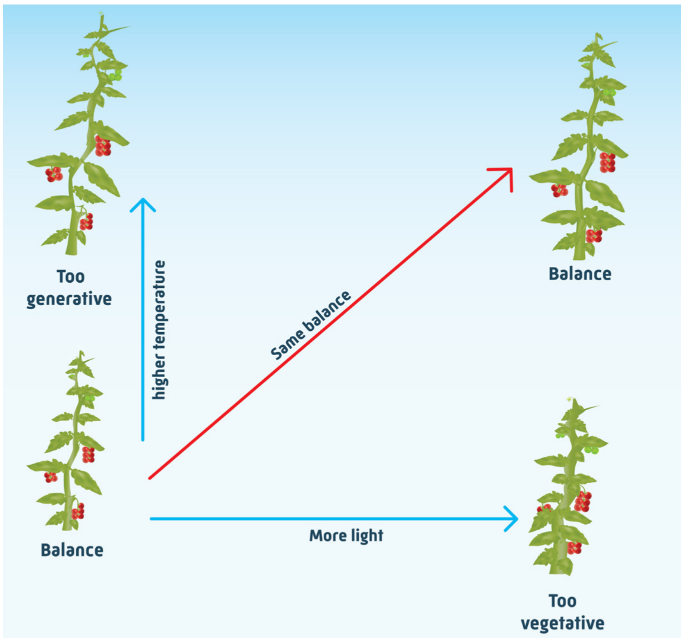
closed stomato by too high VPD value.

A too high VPD value (from 1.5 kPa and up) indicates beginning of water stress and closed stomata. A too low VPD value (below 0.2 kPa) means there is only a little vapor pressure difference to drive water vapor out of the stomata, or even that leaf temperature is around or under dew point. This can occur during nighttime at very high RH values (above 95%) in combination with long wave outgoing radiation. This means there is nearly no evaporation and consequently no Calcium uptake.

Assimilates balance

The assimilates balance is the balance between the production and consumption of assimilates. To optimize growth it is essential that the production of assimilates is as high as possible and that the use of assimilates is stimulated to a maximum. In general a higher PAR sum results in a higher assimilates production, under assumption that sufficient CO_2 is available and stomata are open. The processing rate of assimilates within the plant depends mainly on average temperature.

To keep production and usage in balance there must be a good ratio between PAR light sum (production of assimilates) and the average temperature (usage of assimilates), preferably on a daily basis.



Assimilates balance of the plant

Plant related control factors

Plant processes are influenced by the conditions of the environment. What we want to achieve is that plants can grow and develop under optimal condition. According to the NGG philosophy climate control in greenhouses must focus on supporting the three plant balances. The following five control factors have a large influence on these balances.

1. Relative humidity(RH) and absolute humidity(AH)

RH is recognized as an important growth factor besides PAR, CO_2 and temperature. The combination of high radiation and low RH causes the stomata to close, thus decreasing photosynthesis. Therefore, the RH level needs to be kept high at a high level radiation for that type of plant. This can be controlled by minimizing the opening of the ventilation windows, sometimes in combination with additional misting.

Next to RH, AH should also be a factor in humidity control. Measured RH and HD (humidity deficit) don't illustrate a correct increase or decrease of humidity. For example, it is well possible that RH decreases while the value of AH increases. One could be reassured with the thought that the humidity is under control while in reality the risk of condensation has increased.

2. Measuring plant temperature and VPD

This is an important instrument to recognize and prevent plant stress. A too high VPD indicates water stress. This could be caused by too much light, but also by a too low RH level.
If water stress occurs, it is important to take the right measures. First of all, provide enough water in the root zone. Secondly, keep a higher RH to lower evaporation caused by convection energy. Also, you can apply whitewash or a shading screen to decrease solar radiation.

3. Air movement

Air movement around the plant is necessary to keep the evaporation, and therewith plant activity, on a sufficient level. Especially under low radiation conditions and during nighttime. Furthermore, air movement improves the micro climate near the plant and contributes to a homogeneous temperature distribution throughout the greenhouse. To stimulate air movement, vertical ventilators can be used instead of heating up the pipes.

4. A good (energy saving) screen reduces outgoing long wave radiation

Outgoing long wave radiation caused by a cold greenhouse roof for example, has a big negative influence on the growth process. Too much outgoing radiation causes lower evaporation and lower nutrient uptake in the top of the plants. It also causes a decrease in growth rate (speed of growth) which is temperature related.

5. A steady balance of PAR light sum and average temperature

For a healthy crop as well as a controlled plant load it is important to maintain a steady balance of PAR light sum and average temperature, preferably on a day to day basis.

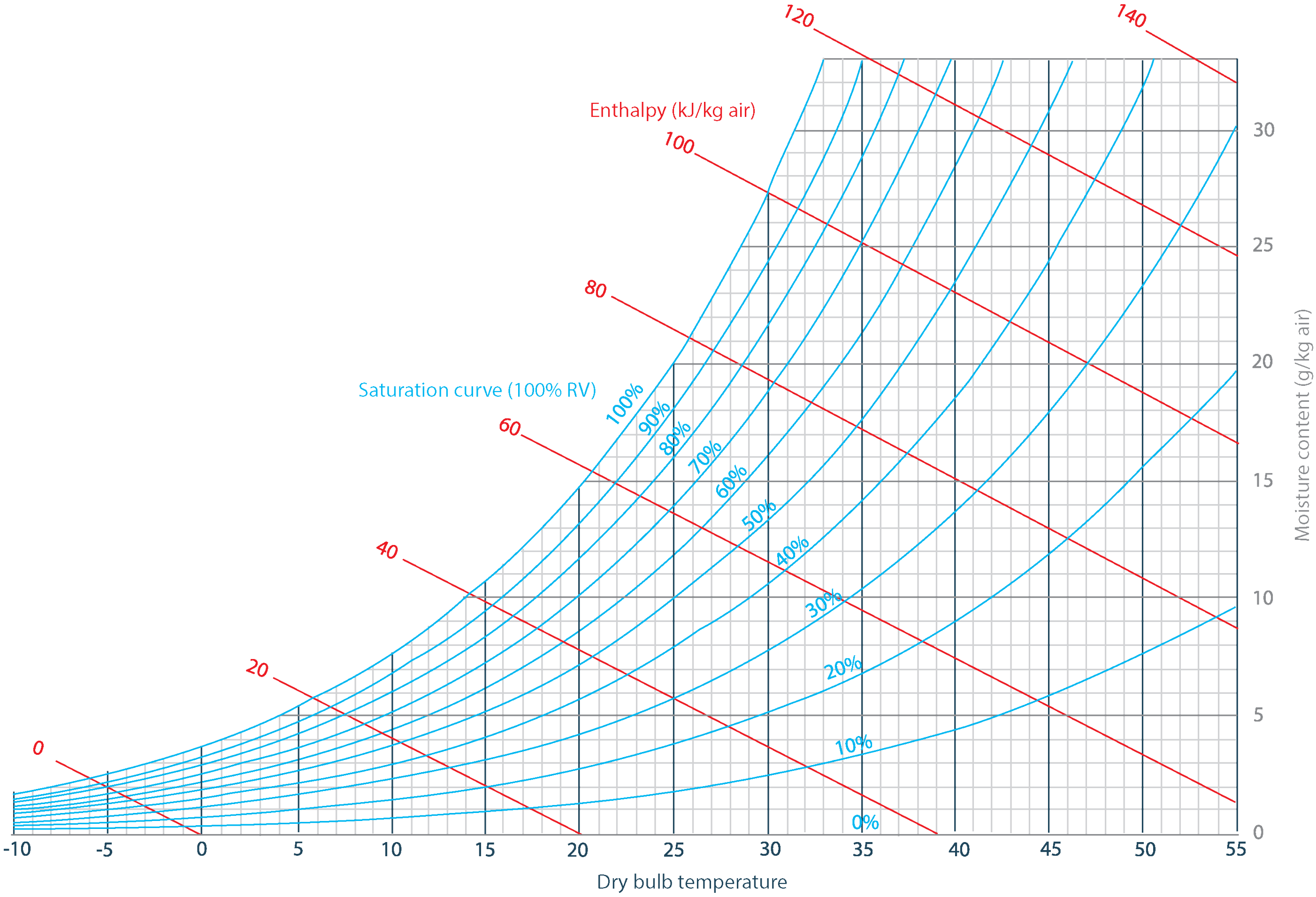
Climate control based on energy balance and water balance

Most climate control systems react on the greenhouse temperature and RH values. However, it is much more obvious to focus on the energy balance and the water balance of the greenhouse. This means also that the focus is on the cause of changes in greenhouse temperature and RH values instead of the consequences.

A steady balance of the energy and water input and output will result in a good growing climate for the crop, without strong fluctuations in temperature and humidity. These are influenced by outside conditions: solar radiation, temperature, humidity, wind speed, outgoing long wave radiation, rain, etc. Therefore, the Hoogendoorn climate control systems are developed to maintain the energy and water balance by anticipating (pre control) on changing outside conditions. This is more effective than reacting on temperature and humidity changes in the greenhouse by corrections afterwards.

Climate control based on psychrometric chart

To efficiently control greenhouse climate knowledge of the Psychrometric chart is indispensable. The Psychrometric chart shows all characteristics of humid air inside and outside the greenhouse. With this information, you know which measures, e.g. heating, ventilation, humidification or shading, to take for a good water and energy balance of the greenhouse and for the plants.



Psychrometric chart

Greenhouse climate related factors

In this paragraph some practical tips are given to optimize the greenhouse climate, based on insights provided by NGG research.

1. Avoid energy loss by long wave radiation by closing the screen(s)

When the greenhouse roof is colder than the plants, plants radiate heat towards the cold greenhouse roof, losing much energy. This decreases plant growth and uptake of nutrients. When screens are closed at the right time outgoing long wave radiation is (largely) prevented.

The temperature of the greenhouse roof is determined by outside temperature, but also by long wave heat radiation to the sky. This can be measured by a Pyrgeo sensor. In case of high outgoing radiation outside, the greenhouse roof temperature will be cooled down under outside air temperature. Therefore keeping the energy screens closed is even more important.

2. Screening without moisture gaps for a homogeneous climate

Gaps in the screens cause temperature differences in the greenhouse if the cold air from above the screen drops into the greenhouse. The temperature differences will cause cold heads of the plant and possibly condensation on the crop. To realize a more homogeneous climate, screening without moisture gaps (as much as possible) is advised.

3. Ventilation above a closed screen for better humidity control

NGG research shows that ventilation above a closed screen can realize a better humidity control than increasing the minimum tube temperature. If the RH rises it is better to increase the transport of water vapor through the screens than to increase the evaporation of the plants. This requires a screen with good humidity transfer properties.

4. Ventilation with lee and wind side vents for a more homogeneous climate

When the wind and lee side of the ventilation system are both used for ventilation, the vents do not need to open that much. With this, ventilation is more equally and controllable. Also, blowing outside air into the greenhouse is more effective than sucking out greenhouse air. Accordingly, ventilation with both lee and wind side vents ensures a more homogeneous climate.

Conclusion

By adaption of the NGG insights and by using the NGG climate control techniques hundreds of Dutch growers with many different cultivations report that they achieve positive results. Especially, NGG has led to a real revolution in screen management. By using the right screens in the right way it is possible to improve growing conditions for the plant and save energy at the same time.

Applying the NGG principles and insights results in a number of advantages.

- Water stress under high radiation conditions is detected and prevented.
- Natural and artificial lighting is used more effectively so the photosynthesis is higher.
- With the right plant balance, more assimilates are produced resulting in higher production and quality.
- A balanced plant is healthy and less vulnerable to pests and diseases.
- An effective use of energy screens without gaps and by the use of vertical fans to activate the crop instead of heating up the pipes, large energy savings can be achieved.

In short, with NGG, you realize a more homogeneous climate, better growth, a healthier crop with less pests and diseases and large energy savings.

Epilogue

Since 2006 Hoogendoorn Growth Management has been closely involved in the NGG research program in cooperation with Wageningen University and Research (WUR). As one of the founder fathers, one of our colleagues is co-writer of the book “De Basisprincipes van het Nieuwe Telen” (“the basic principles of the Next Generation Growing”).

Hoogendoorn has step by step upgraded its climate control systems based on new insights and results of the NGG research. For this, not only the standard software has been updated, but also several special modules have been developed. An example is the special module “PlantVoice”, a monitoring and control system to adjust the irrigation cycle based on the needs of the plant and to realize the ideal greenhouse climate for your crops. Another example is “Connected Screening”, a software module which connects the advanced software of the Hoogendoorn iSii process computer with the wide range of Svensson climate screens. Firstly, the grower gains more insight into the effect of screening on ventilation, humidity transfer, energy savings and transmission of light and outgoing longwave radiation. Secondly, by integrating these specific properties of each screen in the climate controls a much more predictable and stable climate can be realized.

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