Whitepaper:

Next generation growing

Plant empowerment and plant balances

hoogendoorn growth management

KOPPERT BIOLOGICAL SYSTEMS

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Content

Introduction

Next Generation Growing (NGG) is a new way of growing introduced in the Dutch greenhouse industry by the Dutch Cooperative Grower Association. 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.

The growth processes of a plant are mainly determined by three plant balances: the energy balance, the water balance, and the assimilates balance. These plant balances are interlinked via the stomata; the microscopic little pores in the leaf that let water vapor out and take CO_2 in.
Under all conditions the plant aims to keep its three plant balances in balance. So, 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. Besides that, closing of the stomata obstructs CO_2 uptake, thus slowing down the photosynthesis process which negatively effects the assimilates balance.
That is why increasing one growth factor e.g. PAR light also needs adjustment of other factors such as temperature, CO_2 uptake, Relative Humidity (RH) and water uptake to obtain indeed a higher plant growth rate.

This whitepaper provides in short some backgrounds and applications of Plant Empowerment and explains the three plant balances.

Plant empowerment

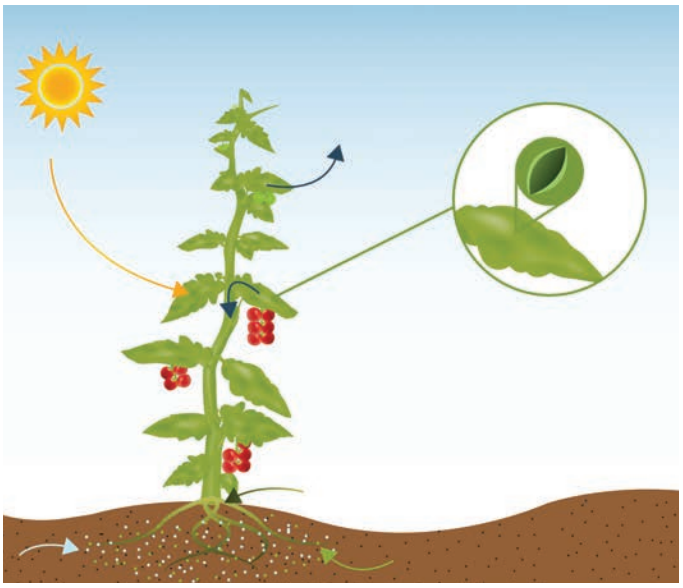
Optimizing growth climate by steering the plant's balances

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.

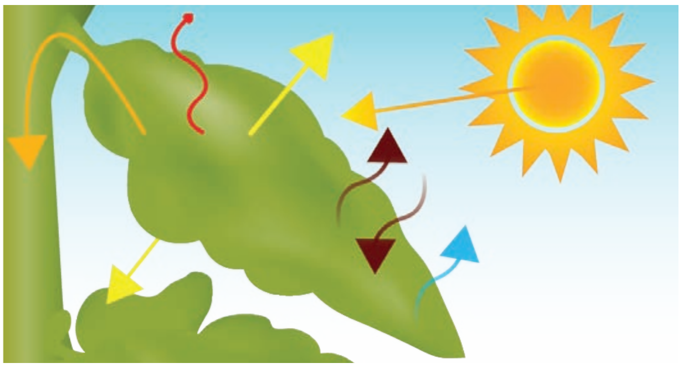
So, as all plant balances are interlinked via the stomata, changing one growth factor e.g. PAR light also involves other factors such as temperature, CO_2 uptake, RH, water uptake and eventually plant growth.

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



Energy balance of the plant

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

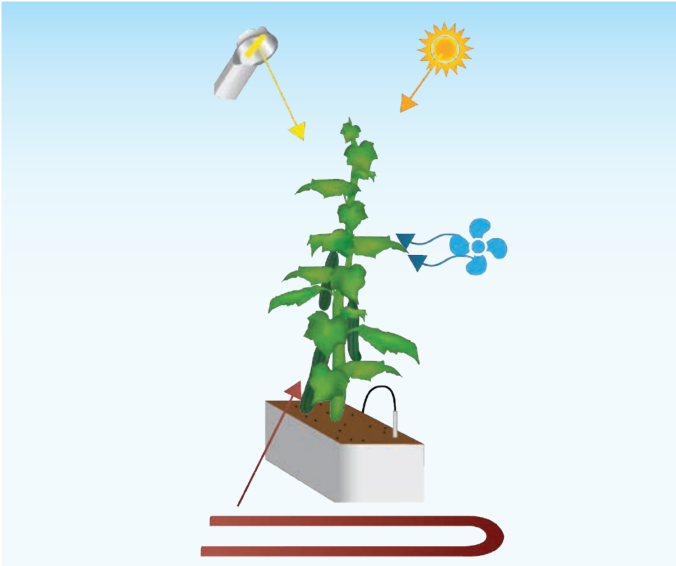
NGG research has revealed at least three important new insights related to the energy balance of plants. Firstly, the fact that plant activity or evaporation can be stimulated by air movement as moving air supplies convective heat input. Air movement also prevents a dull micro climate. Secondly, it has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

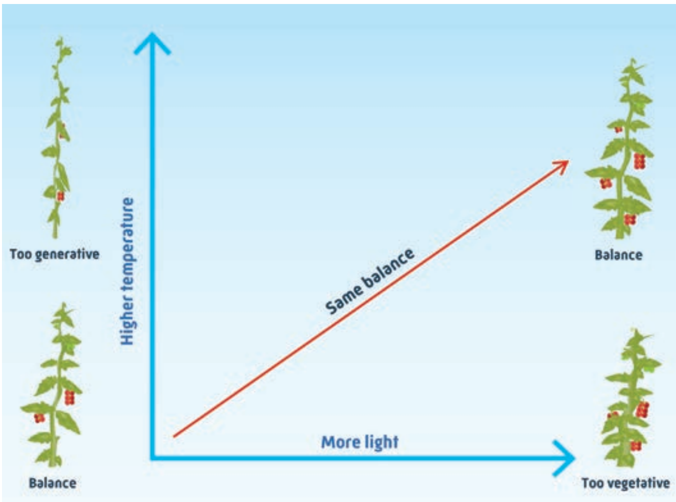
Closed stomato by too high VPD value.

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 conditions. 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 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.

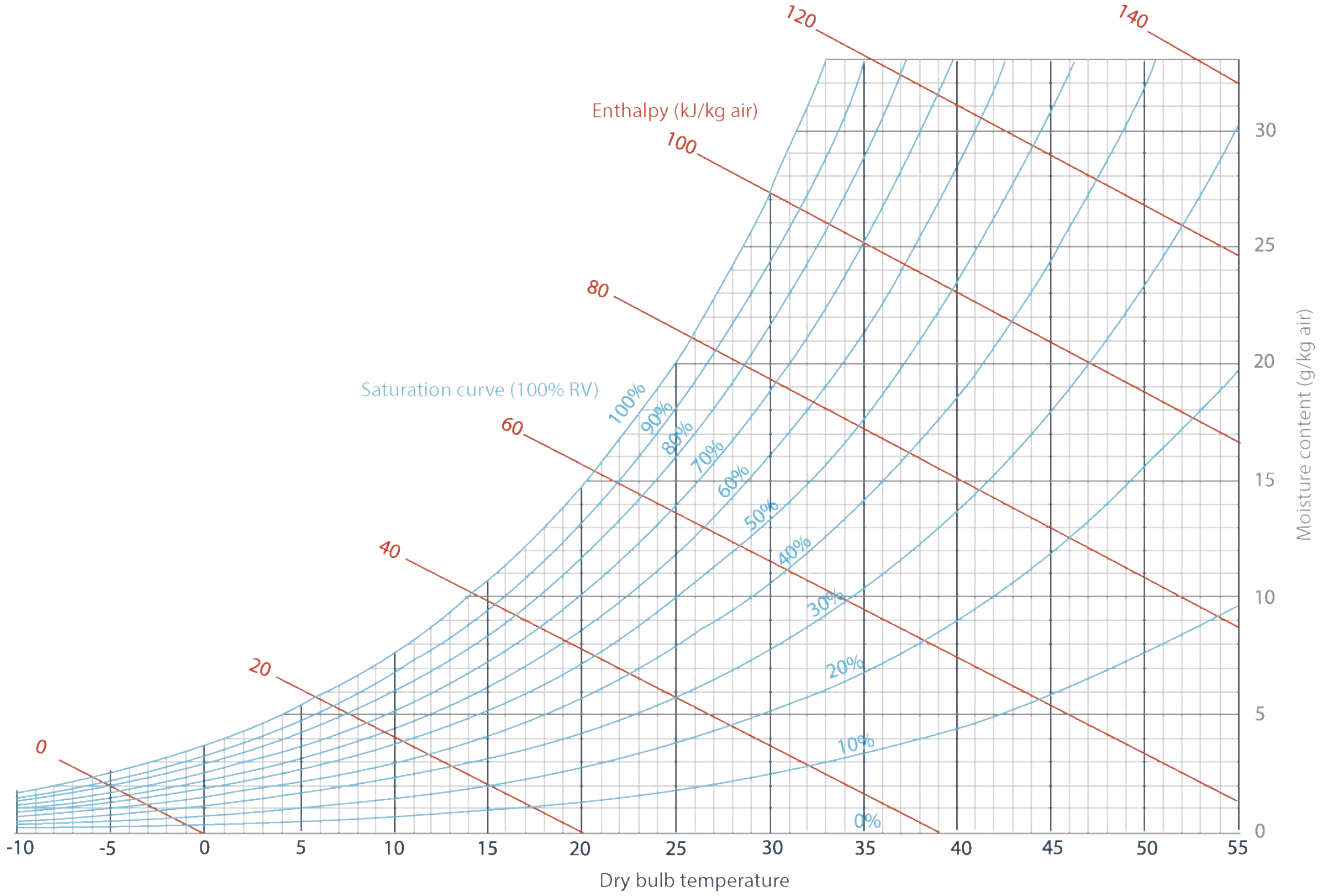
Climate control based on energy balance and water balance

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.

Assimilates balance of the plant

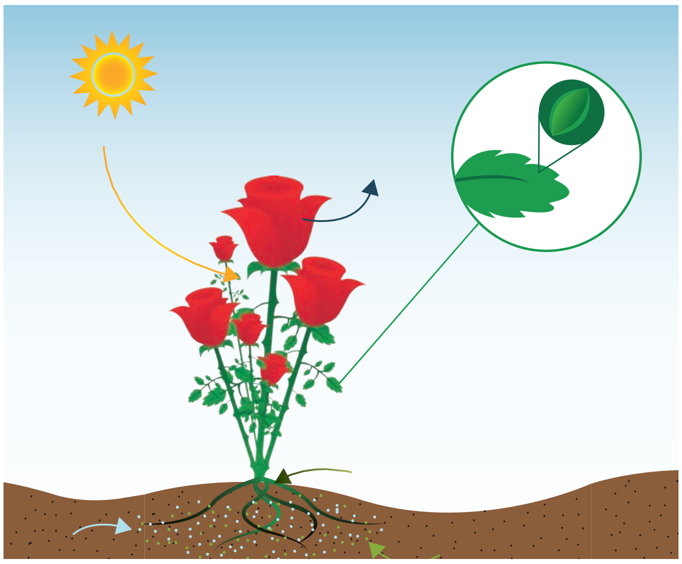
Realize a steady balance between vegetative and generative growth

Assimilates balance

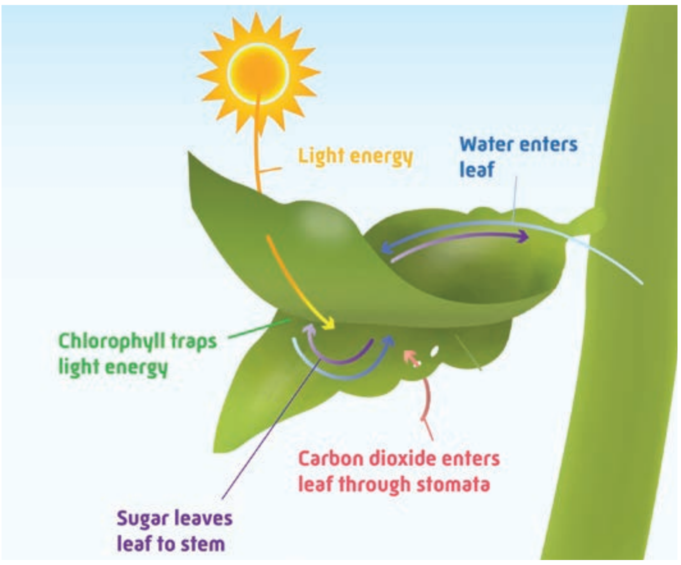
The assimilates balance is the balance between the production and consumption of assimilates (glucose). The photosynthesis process provides the production of assimilates. Photosynthesis means: CO_2 and water are photo chemically synthesized into hydro carbonates (glucose) and oxygen. For the uptake of CO_2 stomata need to be open. So a high CO_2 level and high RH level to keep the stomata open both stimulate the photosynthesis efficiency. 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.

The produced assimilates are used for plant growth. In these processes the available assimilates are "burned" and converted into for example new plant tissues, and CO_2 is released again into the air.

It is important to realize that both photosynthesis and growth depend on temperature. The higher the temperature the faster the process of production and usage of assimilates.



Photosynthesis process. For the uptake of CO_2 stomata need to be open.



Assimilates balance.
Green plant cells contain a pigment called chlorophyll. Chlorophyll absorbs certain wavelengths of light within the visible light spectrum. Green light is not absorbed completely, but is partly reflected, making the plant appear green.

Assimilates balance vs. optimum plant growth

Growth, production and quality start with the production of assimilates, e.g. with photosynthesis. Therefore, the focus should be on the production side of the assimilates balance. In other words, maximization of the production of assimilates and maximum utilization of available PAR light.
But of course this would be in vain if available assimilates are not fully used for growth.

So, for optimum plant growth, it is essential that:

- The production of assimilates is as high as possible by optimization of the photosynthesis process.
- The use of assimilates for the growth of the plant, the fruits and the flowers is stimulated to a maximum.
- The right balance is kept between vegetative and generative development.

Production of assimilates

Crop structure

Optimum utilization of PAR light depends in the first place on the degree of light interception by the plant's leaves. For that an open plant structure and sufficient leaf area are positive factors.

Furthermore, the PAR light should be diffuse in order to better penetrate into the different layers of the crop so more leaves contribute to the total production of assimilates.

Greenhouse climate

The greenhouse climate influences the production of assimilates. The factors which contribute to this production are PAR light from the sun and/or artificial lighting, water availability, CO_2 and humidity. Humidity has an indirect effect on the production of assimilates via the CO_2 uptake capacity of the stomata. A low humidity in combination with high radiation causes a higher evaporation rate, and as a result stomata tend to close earlier to protect the plant against dehydration. In practice this means that water stress can be prevented by maintaining a high RH level in the greenhouse rather than reducing radiation by applying white wash or by closing the shading screens.

But also temperature plays a role here. Under high radiation the optimal temperature for photosynthesis is around 30 °C for most plants.

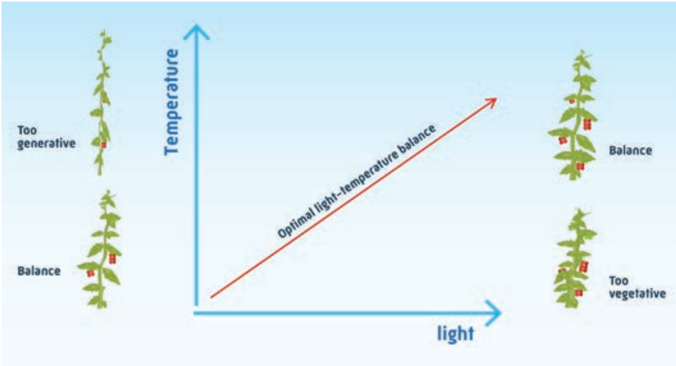
So by simply keeping the ventilation windows more closed on a sunny day three factors for effective photosynthesis shift into a positive direction: less CO_2 loss, higher humidity and higher temperature.

Consumption of assimilates

Greenhouse climate

The growth rate of the plant mainly depends on temperature, that is to say: averaged temperature over a period of one or more days.

As stated above; the consumption of assimilates should keep in pace with the production to maintain the assimilates balance.
To achieve this the PAR sum (production of assimilates) and the average 24-hour temperature (consumption of assimilates) should be kept in a steady ratio. If there is only little PAR light, the average 24-hour temperature should also be low. On the other hand, if there is a lot of PAR light, the average 24-hour temperature should be high.



Visualization of the light-temperature balance. The visualization shows how plants developed at a fixed ratio of temperature and PAR light sum. It also illustrates what goes wrong if temperature and light are not balanced the right way.

Balance between vegetative and generative growth

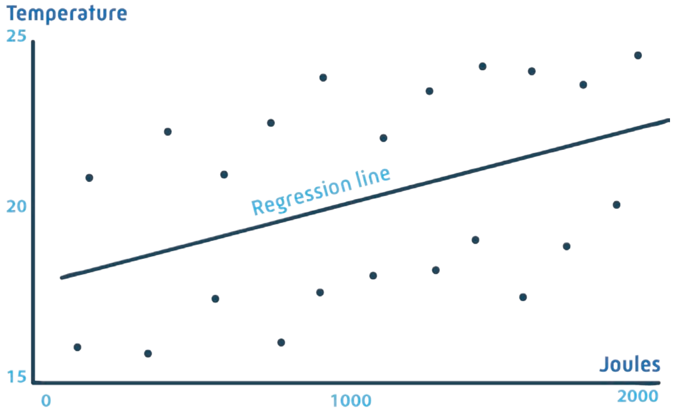
Of course there must be a good balance between vegetative and generative development of the crop. In practice, this is often pursued by observing the plant status and adjusting the climate accordingly. If it is too vegetative, generative actions are executed in order to correct this. On the other hand, a too generative status can be corrected by taking vegetative actions. These vegetative or generative actions may involve adjustments of the temperature strategy, the irrigation strategy, etc.

However, to prevent is always better than to cure. It has been proven in research and practice that keeping a steady ratio between PAR sum and averaged temperature on a daily basis is a strong tool to prevent the plant to become too generative or too vegetative. This way, the crop is always in a good balance and corrective actions are only seldom necessary.

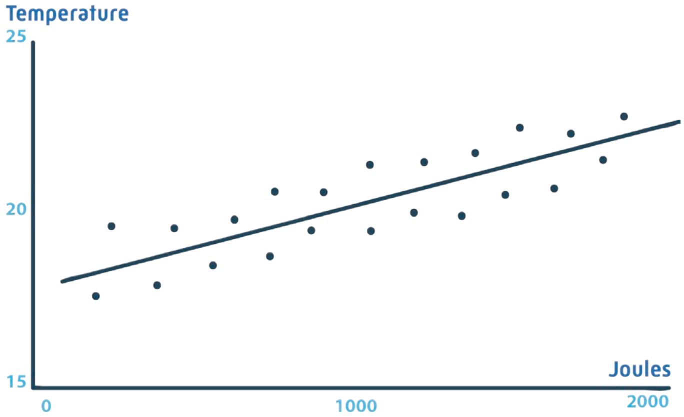
Light-temperature ratio in practice

As described above, to ensure a balanced plant, keeping a steady ratio between PAR sum (production of assimilates) and average temperature (consumption of assimilates) on a daily basis is important. However, in practice, it often occurs that at the same level of assimilates production, there are different values of averaged temperature thus different levels of assimilates consumption. This results in an unbalanced plant.

By daily ensuring the production of assimilates and the consumption of assimilates are inbalance, the plants can be kept in a steady balance. For this, you always have to ensure that at a certain PAR light sum the same average 24-hour temperature is realized.



Scatterplot with a dot for each day to show the light sum (Joule/cm².day) and the average 24-hour temperature (°C). As shown in the scatterplot, at one production level (a certain light sum) there are different consumption levels (average 24-hour temperature). This creates an unbalanced plant.



This scatterplot shows a more balanced relation between light sum and average 24-hour temperature. By spending more attention on the realization of a correct ratio, the dots are closer to one line. This creates a balanced plant.

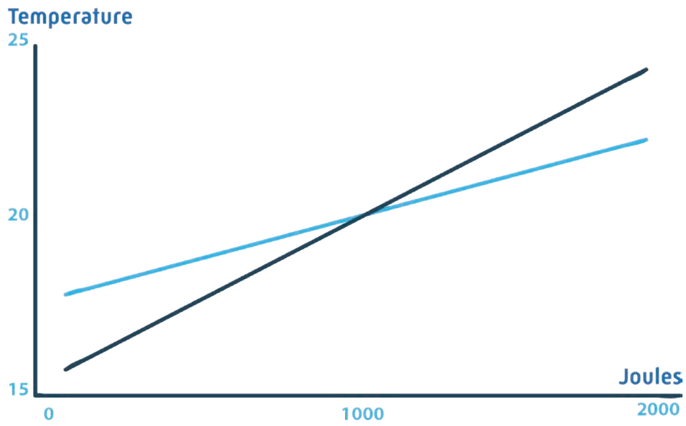
Steps for creating the correct light-temperature ratio

As explained above, usually the unbalance of the plant is 'fixed' afterwards by taking vegetative or generative corrective actions. However, it is better to prevent deviations of the balance by anticipatory control. That is to say by keeping the PAR light sum and average 24-hour temperature in a steady ratio on a daily bases. Anticipatory control on the assimilates balance can be realized in a few steps.

- First visualize the current work method by creating your own graph of daily PAR light sums and associated averaged temperature for example for the last 30 days. This way a scatterplot appears with 30 dots. The so called regression line through this scatterplot forms the basis for anticipatory control.
- The second step is to consciously work on a better light-temperature balance. In terms of climate control, this means that more light during the day should result in a higher 24-

hour averaged temperature. To begin with the vents are kept more closed during the day in favor of higher temperature but also higher humidity and CO_2. If necessary, also the night temperature must be adjusted to achieve the correct 24-hour average temperature.

- The third step is gradually adjusting the PAR light-temperature ratio to find the best balance for the crop, also depending on the environmental circumstances. If for example outdoor temperature is often high on sunny days, it is advisory to choose a steep line for the light-temperature ratio. This allows keeping the vents more closed in favor of higher humidity and CO_2 under high radiation conditions.
- The fourth step is to better control the plant load to the available PAR light sum, depending on the season.



This graphs shows growing according to the environmental circumstances (steep line). Now at higher radiation levels, a higher 24-hour average temperature is realized and at lower light sums a lower 24-hour average temperature. This results in a different plant balance.

The role of plant load

The consumption of assimilates is highly determined by plant load. For vegetable crops, plant load corresponds to the number of fruits per square meter greenhouse area. For flower crops or plants, plant load is related to the number of flowers / plant per m².

The total demand for assimilates is determined by the combination of plant load and temperature. So a higher plant load needs a lower temperature. A high plant load provides many fruits and therefore a high demand for assimilates. With cloudy weather, when there is hardly any or no radiation, there is low production of assimilates.

High plant load makes it necessary to have a lower temperature. Otherwise the demand for assimilates would exceed the available amount, and the plant would suffer an assimilates shortage.

Recent research has shown a preference for maintaining a lower plant load combined with a high temperature regime. This approach, in comparison to a high plant load and low temperature, offers more possibilities to realize a steady, vital and healthy crop. At a lower plant load, the demand for assimilates is lower, which makes it easier to steer.

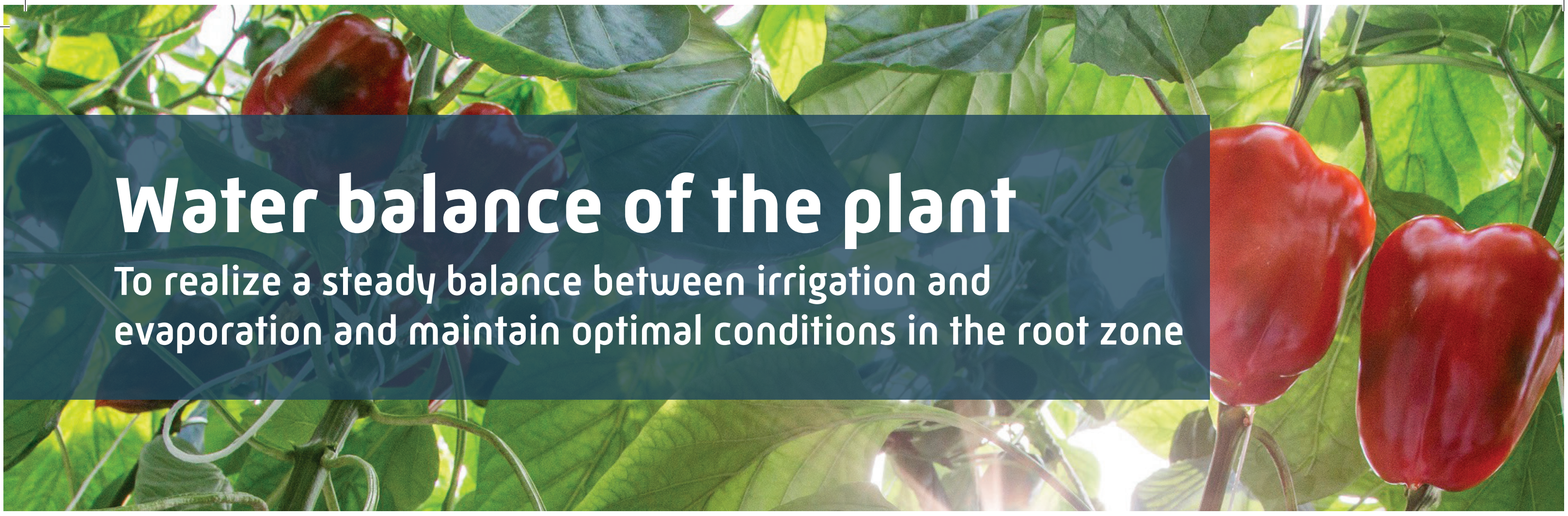
Growing at higher temperatures makes it easier to correctly steer on the plant balances. Furthermore, it is possible to realize an improved PAR light efficiency and CO_2 uptake.

Improved CO_2 uptake by growing at a high temperature

Growing at a higher temperature under high radiation allows for smaller vent positions. The photosynthesis rate is increased by improving three growth factors: temperature, humidity and CO_2, because less CO_2 is lost in comparison with wide vent positions. Thanks to the higher humidity in the greenhouse, CO_2 is better taken in via the stomata of the plant.

Conclusion

Research has given us more insights into how to support and maintain the assimilates balance of the plants. Combining these new insights with advanced climate control techniques to create the correct light-temperature ratio, a good balance between vegetative and generative growth of the crop can be accomplished. Anticipatory control instead of taking corrective actions afterwards ensures a more steady plant balance which results in a healthy, more resilient crop and an optimized production and quality. Besides that it ensures better utilization of PAR light and CO_2 and last but not least energy savings.

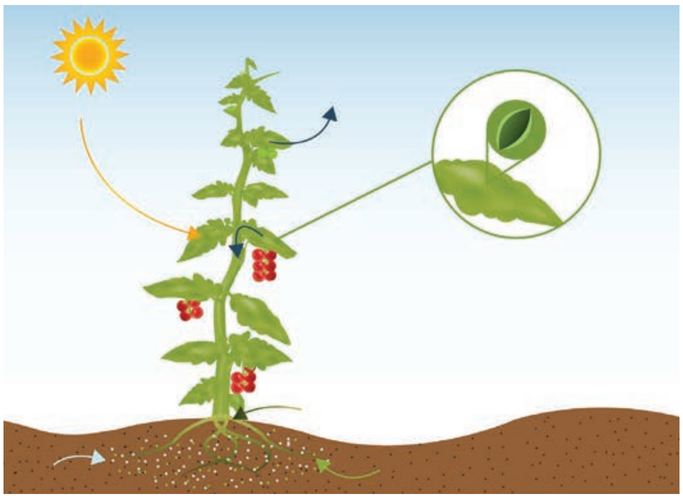


Water balance of the plant

To realize a steady balance between irrigation and evaporation and maintain optimal conditions in the root zone

The plant's water balance

The water balance of the plant is the balance between the water uptake and the evaporation. If evaporation exceeds the uptake, the plant turgor (the internal water tension) decreases. On the short term some water can be extracted from the leaves and fruits. As a result these leaves and fruits shrink a little. This is normal and causes no problems. If water availability is restored, the leaves and fruits are re-hydrated again. But if water uptake by the roots cannot keep up with the high evaporation rate for a longer period of time, stomata tend to close in order to reduce evaporation and thus prevent the plant from drying out. This may hamper the CO_2 uptake and thus slows down the photosynthesis at the cost of growth.

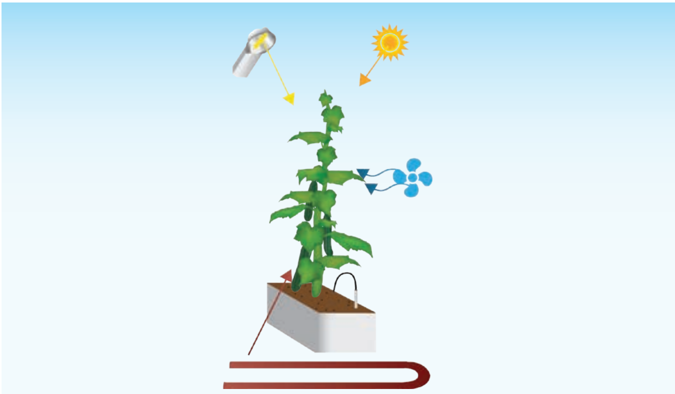


It is important to realize a good balance between evaporation and water uptake to allow the plant to keep stomata open for CO_2 uptake.

The driving force of evaporation

It is often thought that evaporation rate is mainly determined by the conditions of the greenhouse air, especially humidity deficit (HD) expressed in gram/m^3. However, this is a misunderstanding. The driving force of evaporation is always energy. Since evaporation of water takes a lot of energy, about 2,5 Mega Joules per kilo, evaporation rate is basically proportional to energy input and nothing else.

Plants can receive energy from the environment in different ways. First is by visible radiation from the sun and lamps. This is called short wave radiation. Second is long wave heat radiation, also from the sun and lamps, but from heating pipes as well. Third is by convection from the surrounding air. This convective heat transfer can only take place if two requirements are fulfilled: the plant leaves must have a lower temperature than the air, and there has to be air movement.



Plants receive energy from different sources by short wave radiation and long wave radiation and also by convection via air movement.

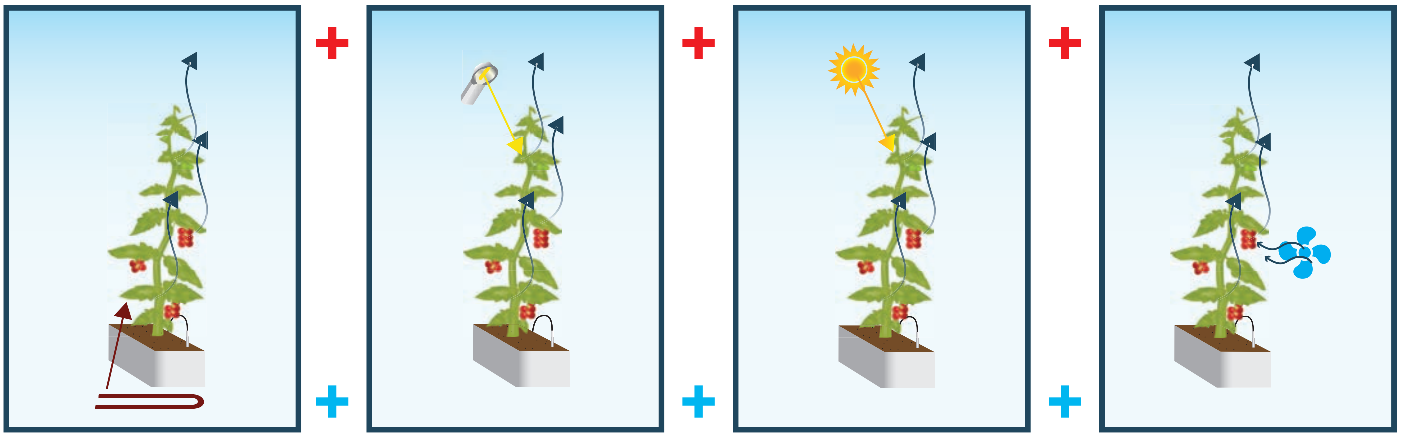
This first requirement links evaporation rate to the humidity deficit of the air (HD), mentioned before. The temperature difference between the leaves and the greenhouse air depends on this HD because it is related to the so called wet-bulb temperature. If HD is too small, then the wet-bulb temperature almost equals dry bulb temperature and thus convective energy transfer is very low. As a result there is little or no convective evaporation. So it is important to maintain sufficient HD, especially during the night as there is no incoming radiation to promote the evaporation.

For the sake of completeness it has to be remarked that protecting the crop against heat emission to a cold greenhouse roof is also important during the night. This heat emission means a loss of energy for the plant and therefore decreases evaporation at the cost of nutrient uptake. So, closing of the energy screens during the night is an effective measure to stimulate crop activity and plant health.

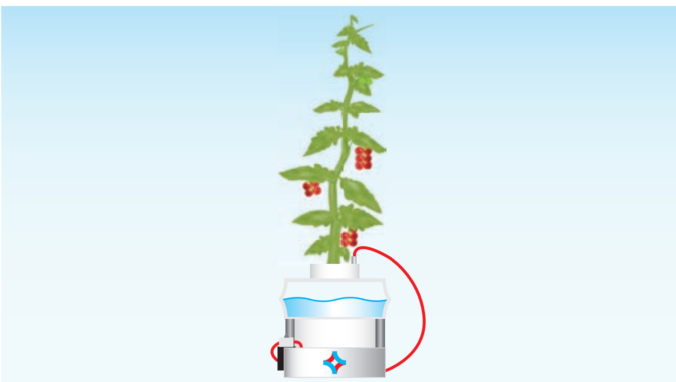
How to align irrigation to evaporation?

For an accurate alignment of the irrigation to the plant needs we need to add up the different energy inputs to a total evaporation energy flow expressed in W/m^2. In the Hoogendoorn iSii irrigation control software this flow can be calculated and be summarized over time to an energy sum in $Joules/cm^2$. Every time a certain sum is reached, the next drip cycle can be triggered. This looks quite comparable to the normal irrigation strategy bases on solar radiation, but with several important improvements:

- The energy inputs are not only taken from the sun, but also from other relevant sources like lamps, heating pipes and air movement.
- The total sum is calculated based on the inside situation rather than outside situation, so the influences of retractable shading screens and/or whitewash can be taken into account.



The irrigation controller should take the various energy sources into account to calculate the total evaporation energy sum.



An example of a slab weighing system; the Hoogendoorn Aquabalance.

In addition different sensors can be used in order to keep track of the real slab conditions, and thus provide feedback to the control system.

One of these sensors can be a system that weighs the slab and provides insight in the water content of the slab from minute to minute. The weighing system can also include measurements of drain volume and EC and pH values.

Root zone water and nutrient management

In order to optimize and maintain the water balance of the crop a well designed substrate system is required. The basics of such a system are discussed below, subdivided in four subjects:

1. **The Function of the substrate system**
   What does it have to achieve?
2. **Design of the substrate system layout**
   What layout helps to optimize this function?
3. **Control over the substrate system**
   How do we make best use of the control potential?
4. **Target Levels**
   Setting basic target levels for the different crop stages and climate

The Function of the substrate system

Water content

The water content of the substrate provides the reservoir of the water that the plant needs to match the evaporation requirements of the plant. Control over the water content is a tool to maintain and control uptake and plant balance. Target levels should be used for each of the crop periods to help react to the changing evaporative demands.

A target range of water contents would be from 45% to 70%. for most crops.

- In long periods of low light levels it is better to run lower water content as the plant is less active. This makes the slab more reactive and dry back faster to allow more oxygen into the slab and also give a generative action;
- In high light levels with high evaporation levels it is best to run a higher water content to give more water availability for the higher evaporation by the plant and maintain the water balance.

EC; electrical conductivity

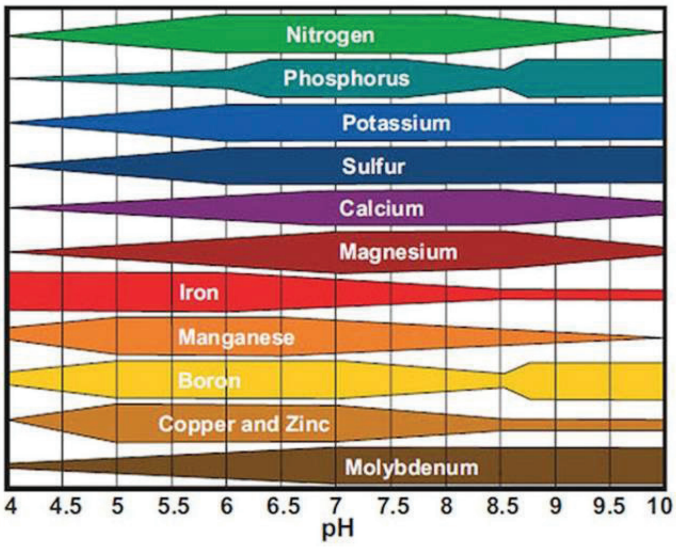
The distribution of the nutrients in the substrate is important to get even root distribution. Good nutrient availability for the roots is vital to get optimal quality and yield. Using the EC to control nutrient uptake is also a useful tool for controlling the plant balance.
Target levels should be used for each of the crop periods to help react to the changing demands of the crop and maintain the water balance.

- In long periods of low light levels it is better to run a higher EC to steer the plant in a generative way;
- In high light levels with high evaporation levels it is best to run a lower EC to help uptake for evaporation.

pH ; acidity

The ability of the plant to take up the nutrients it requires is affected by the pH of the nutrient solution around the roots. It is therefore very important to have the correct pH around the root system.

The optimal pH for most plants is between 5.5 and 6.5 and this should be the target level. The pH in slabs can change because of selective root uptake. When Ammonium (NH_4) is transported into the roots, the pH will drop. When Nitrate (NO_3) is transported into the roots, pH will rise. Also NH_4 and NO_3 can be used by micro-organisms, which will also influence the pH in the substrate. The change of concentration of the fertilizers NH_4 and NO_3 can influence the pH in the substrate.



This picture shows the uptake of different elements at different pH levels. For example : for good Calcium uptake pH should be above pH 5.5 – 6.

Thus, it is important that the pH of the source water is corrected to the right pH at the irrigation unit.

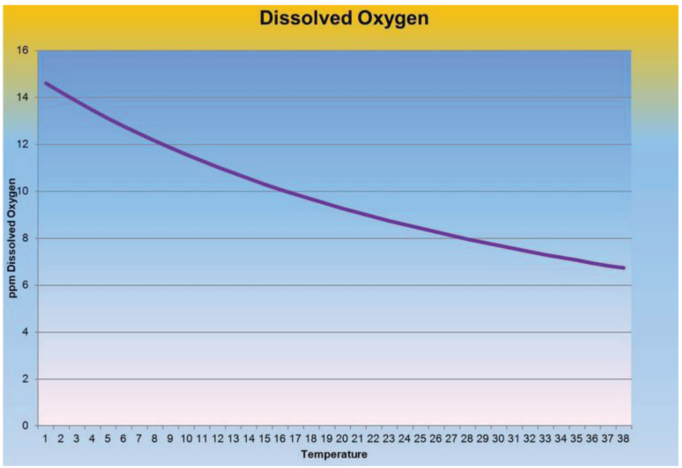
Attention should be paid to the following issues:

- If the bicarbonate levels are very low (no buffer) in the source water it may be necessary to add bicarbonate to give some buffer;
- With low bicarbonate levels it may be necessary to dilute the acid used for pH correction to avoid a sudden decrease in pH to below 5.0;
- Ammonium especially with low bicarbonatelevels can cause a sudden decrease in the pH.

Always check the pH of the source water in the storage tank, at the irrigation unit and at the drippers. pH levels of below 5.0 will damage the roots. Remember the plant gets the water that is coming out of the dripper so that has to be right.

O_2 Oxygen content

All parts of the plant need oxygen: leaves, stems and roots. In the slab, roots need oxygen for cell respiration. When there is enough oxygen at the roots, the root system can function optimally.



This picture shows that oxygen content decreases with rising temperature of the slab.

Oxygen is also used by micro-organisms, fungi and bacteria. In stonewool, bacteria are present in large numbers very quickly after the initial wetting up. When there are circumstances with low oxygen levels, the micro-organisms can compete with the roots for the use of oxygen.

Oxygen supply in the substrate is vital for good healthy roots. When there is 85% water content at the bottom layer of a slab, the air canals make sure that oxygen can get to the water and plant roots (diffusion). At high temperatures (over 25 °C), less oxygen can dissolve in the water, and roots at the wetter parts of the substrate can have problems with too low oxygen levels in the irrigation.

Temperature

The temperature of the root zone is not always measured or controllable. It is however critical, and root temperatures should be kept between 18 °C and 25 °C.

As the temperature of the root zone increases, the availability of oxygen from the irrigation water decreases. Root temperatures of over 25 °C, especially if root distribution is poor, combined with competition between roots, can lead to root death. This opens up the possibility of secondary infection by root pathogens such as Pythium.

The design of the substrate system layout

The conditions around the root system are just as important as the conditions around the plant itself. The roots need to be able to adapt to the changing conditions in the glasshouse (light, humidity, etc.) and the demands of the plant evaporation. To do this, the substrate system should be designed properly.

Volume of substrate

The roots need enough volume in which to grow and develop.
We recommend a substrate volume between 7 and 9 litres per square meter of the cropped area of the glasshouse (stonewool). The objective for each root system and dripper is to have the same volume of substrate to reduce the variation and so increase the control over the root zone to match the evaporative demands of the plant. It is important that the substrate volume you choose matches the capacity of your irrigation system, accuracy of your drippers and your objectives.

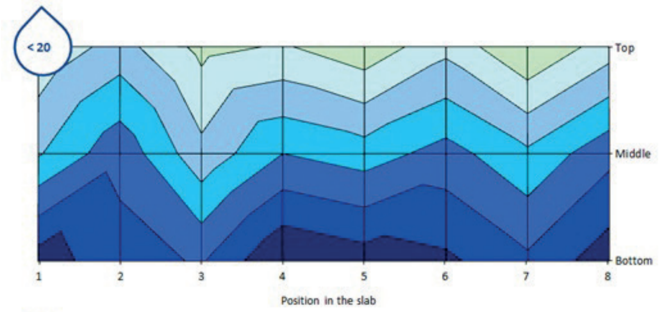
Control over the substrate system

Dose size and root distribution

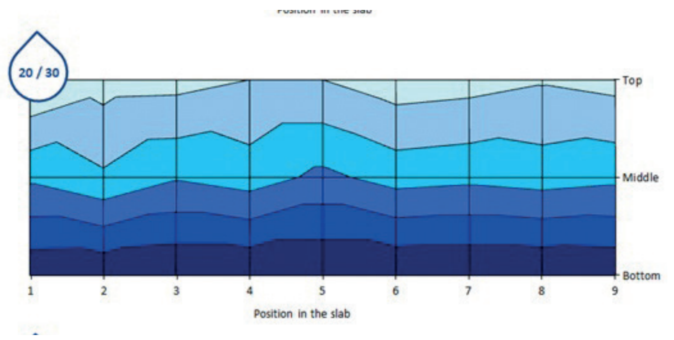
The position of the root development in the slab will be dictated by the conditions in different parts of the substrate. The amount and frequency of water applied at each watering influences the distribution of water and nutrients. This is the dose size and this should be related to the volume of substrate that each dripper supplies. It is vital to maintain the water balance in the plant so that the roots can take the water and nutrients that they require at the time they need them.

It is therefore important to:

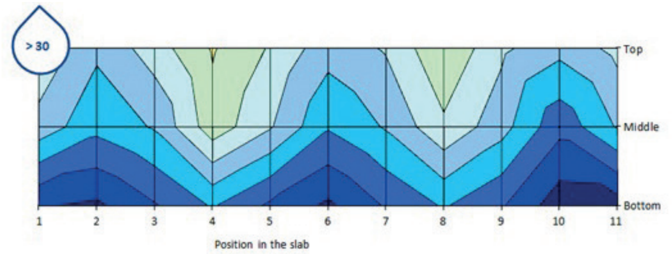
- Keep the number of roots growing at the bottom of the slab to a minimum;
- Avoid competition between roots for nutrients and oxygen;
- Maximize the use of the total volume of the slab;
- Get even dry back and control over the water content and EC to balance the plant;
- Maximize water and fertilizer use.



Dose size too small giving poor flushing of nutrient build ups



Optimal dose size giving good water and EC balance, so good root distribution



Dose size too big giving poor water & EC distribution, so poor root distribution.

The correct dose size is related to the total volume of substrate that each dripper supplies. This dose size also affects the frequency of application.
The smaller the dose, the more frequent the application.

The optimal dose size for our slabs can be calculated using the Dose size Calculator or manually as shown below.

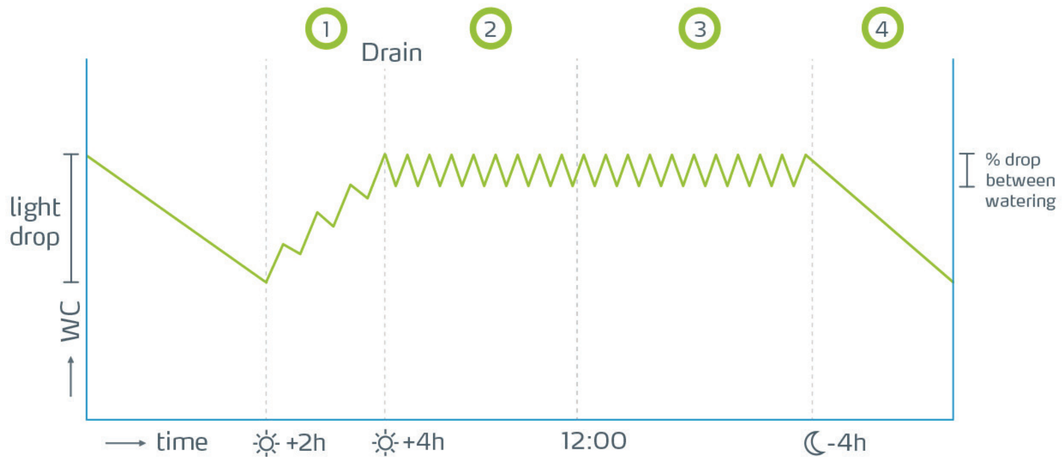
Dose Size Factor	<15	20	25	30	>35
Valuation		SMALL	OPTIMAL	BIG	

Example:
Slab with volume = 100 x 15 x 7.5 cm = 11.25 litres
3 cubes volume = 3 x (10 x 10 x 6.5 cm) = 3 x 0.65 liter = 1.95 litres

Total stone wool volume = 13.2 litres

Dose size:
- 3 drippers / slab = 13.2 / 3 = 4.4 litres / dripper
- Dose size = 25 x 4.4 = 110 cc

This is the total volume of substrate (cube and slab) supplied per dripper multiplied by the DSF (Dose Size Factor). So the larger the volume of substrate per dripper the larger the dose size



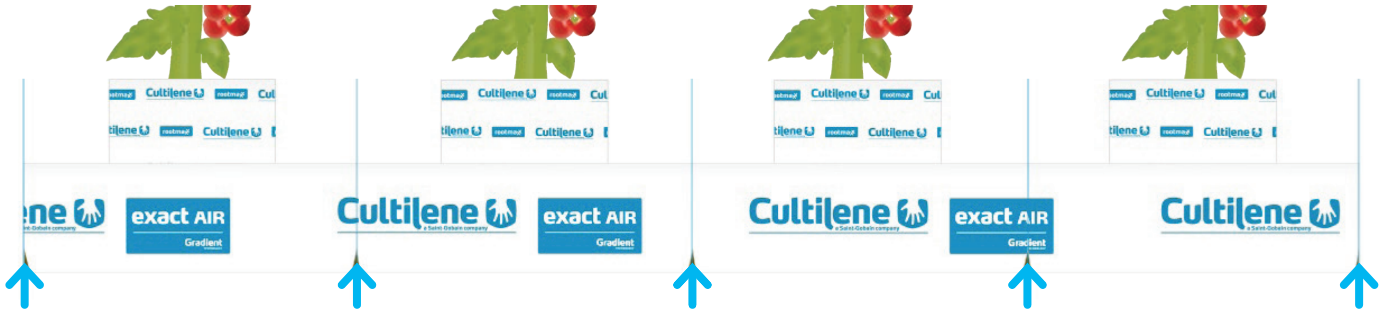
Different dose sizes should be used during the day according to the objective of each of the periods.

Period 1	Objective	To re-fill the slab from the night decrease in water content and to achieve drain by the end of the period - small dose size within the calculated range.
Period 2	Objective	To maintain the water content and EC levels at the target levels for the crop to maintain the water balance - medium dose size within the calculated range.
Period 3	Objective	To maintain water content and control the EC rise to maintain the water balance especially in high light and low humidity conditions - dose size can be increased within the calculated range.
Period 4	Objective	To allow the water content to drop overnight to the target level required by the crop balance.

Drainage of the slabs

For good drainage control attention should be paid to the following aspects:

- Make drainage slits at both ends of the slabs at the lowest points.
- Make additional drainage slits exactly between the cubes as shown in the picture below. This creates the same "cone" or drainage pattern for every dripper reducing the standard deviation of EC and more efficient flushing and water efficiency.
- This can also be done on both sides of the slab on hanging gutters to make sure that all the slabs drain evenly when the gutters are not quite level.
- Make sure that all the drainage slits are right to the bottom of the slab and wide enough to prevent the roots slowing down the drain water (3 to 4 cm).
- Drain the slabs 24 hours before planting.
- Do not make additional drainage slits during the crop as this will change the drainage pattern in the slab and can cause root death.
- Never make drainage slits under a dripper as this can give "false drain".
- Make sure the job is done correctly as it has to last the whole crop so staff training and monitoring is critical.



The picture above shows where to make the drainage slits.

Season watering objectives and targets

Setting target levels for each of the critical periods during the life of the crop will help to prepare the substrate and make it easier to maintain the water balance within the crop. When the demand for water is high a large water buffer is required and this can be done by controlling the water content. In low water demand conditions the buffer should be smaller to keep the substrate more responsive and to maintain oxygen levels.
The setting of these target levels and the measuring of achieved levels is critical in the control of the substrate and achieving optimal water balance. The table on the next page shows an example.

Season Dynamics - Short Day Planting Tomatoes

	Crop stage	Objective V/G	WC cube	WC slab day	WC drop waterings	WC Drop night		EC roots	Delta EC
1	Pre planting before fruit set	VG	60%	-	30%	-	-	5 to 8	< 3.0
2	Pre planting after fruit set	G	60%	-	20%	-	-	< 5	< 2.0
3	Planting until roots established	V	60%	85%	< 5%	2%	5%	3.5	< 1.0
4	After planting and rooted out	G	50%	45 - 60%	1 to 3%	2%	5%	5 to 7	< 2.0
5	Harvest preparation	N/V	-	65 - 70%	1 to 2%	2%	5%	< 5	< 2.0
6	Balanced production	N	-	65 - 70%	1 to 2%	5%	12%	4 to 5	< 2.0
7	Decreasing day length	N/G	-	50%	2 to 4%	10%	20%	5 to 7	< 2.0
8	Heads out	V	-	40%	1%	5%	10%	5 to 6	< 1.5

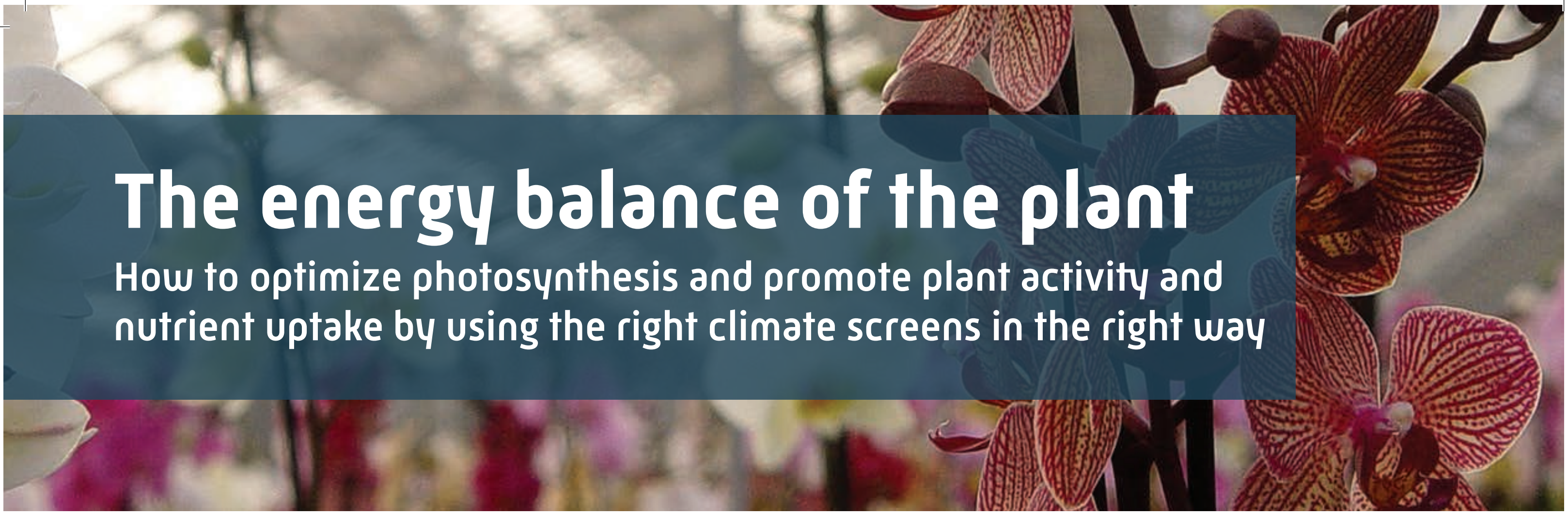
Target levels should be used for each of the crop periods to help react to the changing demands of the crop and maintain the water balance.

Conclusion

Research has given us more insights into how to support and maintain the water balance of the plants. When combining these new insights with advanced irrigation control techniques a good balance between evaporation and water availability for the plant can be achieved.

Special attention has to be paid to the root zone. By matching the needs of the plant to the characteristics of the slab in a smart way, a strong and high productive crop can be grown without wasting water and nutrients.

Anticipatory control instead of taking corrective actions afterwards ensures a more steady water balance which results in a healthy, more resilient crop and an optimized production and quality.

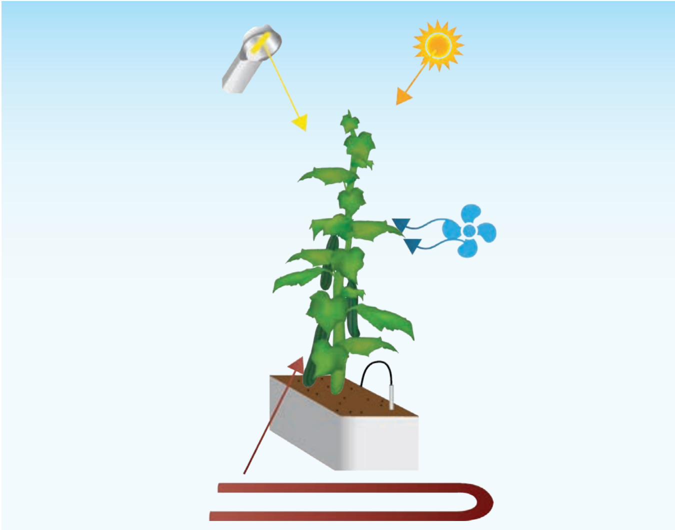


The energy balance of the plant

How to optimize photosynthesis and promote plant activity and nutrient uptake by using the right climate screens in the right way

The plant's energy balance

The energy balance of the plant is the balance between the energy input and the energy output. Without energy input or output plant leaf temperature equals the temperature of the air. If more energy is supplied than dissipated, the plant leaf temperature will rise above air temperature. The other way round, if more energy is being lost than received, plant leaf temperature will drop below the air temperature. So the difference between plant leaf temperature and air temperature is strongly related to this energy balance.



Plants receive energy from different sources by short wave radiation and long wave radiation and also by convection via air movement.

Plant activity and nutrient uptake

To grow and prosper a plant needs to take up water and nutrients from the soil. However, this is only possible if water is being evaporated from the leafs. A continuous evaporation causes a continuous uptake and transportation of nutrients inside the plant. If the evaporation stops for whatever reason, growing parts, especially in the top of the plant will suffer shortage of nutrients, among which calcium is a very crucial element for the development of strong cells. A lack of calcium always means trouble like tip burn, tip rot, glassiness, etc.

This is why experienced growers like their plants to be active at all times, which means that there is always some evaporation going. At the least, evaporation must not be interrupted for too long a period. This is all about the energy balance as will be explained hereunder.

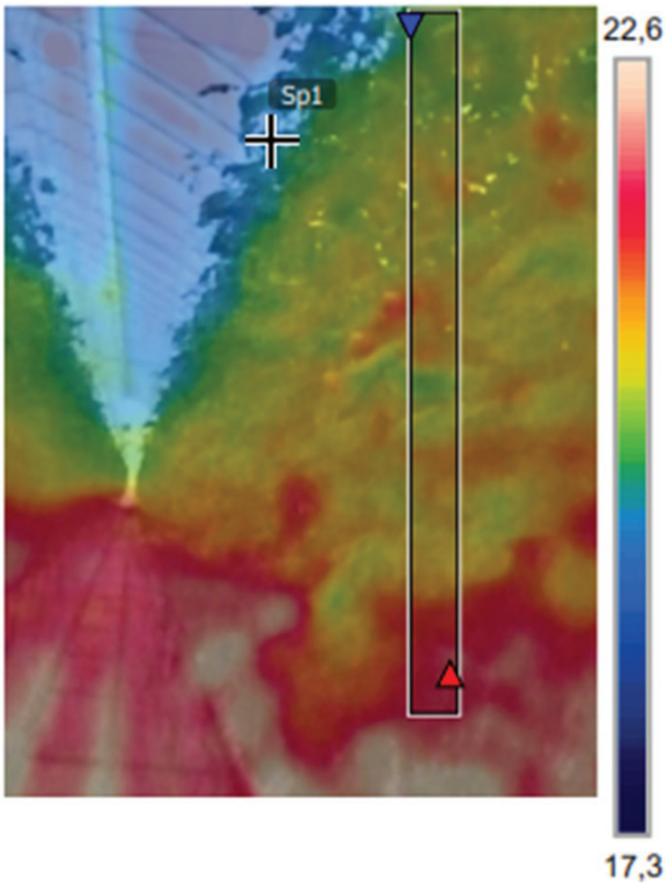
The driving force of evaporation

It is often thought that evaporation rate is mainly determined by the conditions of the greenhouse air, especially the humidity deficit (HD) expressed in gram/m^3. However, this is a misunderstanding. The driving force of evaporation is always energy. Since evaporation of water takes a lot of energy, about 2,5 Mega Joules per kilo, evaporation rate is basically proportional to energy input and nothing else.
This means that evaporation can only occur if the energy balance of the plant is positive and there is a surplus of energy which is available to drive the evaporation process.

Plants can receive energy from the environment in different ways. First is by visible radiation from the sun and lamps. This is called short wave radiation. Second is long wave heat radiation, also from the sun and lamps, but from heating pipes as well. Third is by convection from the surrounding air. This convective heat transfer can only take place if two requirements are fulfilled: the plant leaves must have a lower temperature than the air, and there has to be air movement.
This first requirement links evaporation rate to the humidity deficit of the air (HD), mentioned before. The temperature difference between the leaves and the greenhouse air depends on this HD because it is related to the so called wet-bulb temperature. If HD is too small, then the wet-bulb temperature almost equals dry bulb temperature and thus convective energy transfer is very low. As a result there is little or no convective evaporation. So it is important to maintain sufficient HD, especially during the night as there is no incoming radiation to promote the evaporation.

The important role of heat emission

It is commonly known that all physical bodies exchange energy with their environment by long wave radiation. This is also referred to as heat emission. But the effect of heat emission on plants was neglected and underestimated for a long time. Only in the recent years it has been discovered as one of the main causes of plant in-activity, grow problems and the initiation of diseases like botrytis.
It has been proven that warm plants lose a lot of energy towards a cold greenhouse roof or even a cold (single) climate screen above them. This energy loss is at the cost of evaporation and thus nutrient uptake.



This thermographic picture of a tomato crop shows that the temperature of the greenhouse coverage is more than 5 degrees colder than the average crop temperature. As a result the heads of the plant cool down by heat emission to the colder roof. So evaporation and nutrient up take are decreased here. Depending on relative humidity, even condensation on the top leaves may occur.
So, closing of the climate screen(s) during the night is an effective measure to stimulate crop activity and plant health.

How climate screens can be used to improve growing conditions

Traditionally, energy saving screens are considered a necessary evil to save energy, but at a cost of plant activity and a good climate.

However, thanks to the new insights into the plant balances we have learned that climate screens can substantially contribute to improve growing conditions for the crop if the right climate screens are applied in the right way.

Hereunder different positive effects of climate screens are discussed:

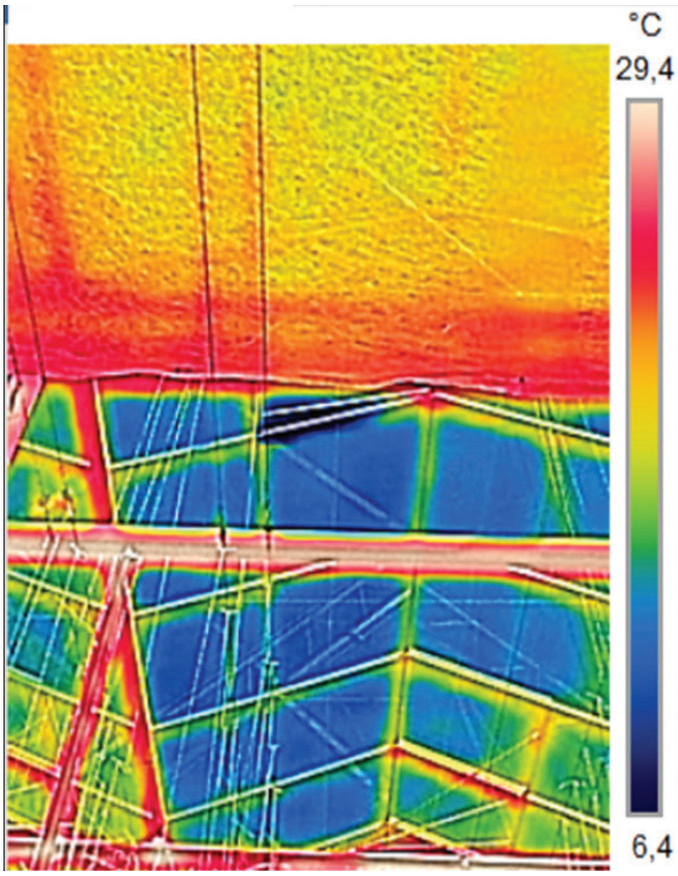
- Blocking of heat emission
- Tempering and diffusing of direct sun light
- Improving humidity control without screen gaps
- Optimizing growth climate and saving energy

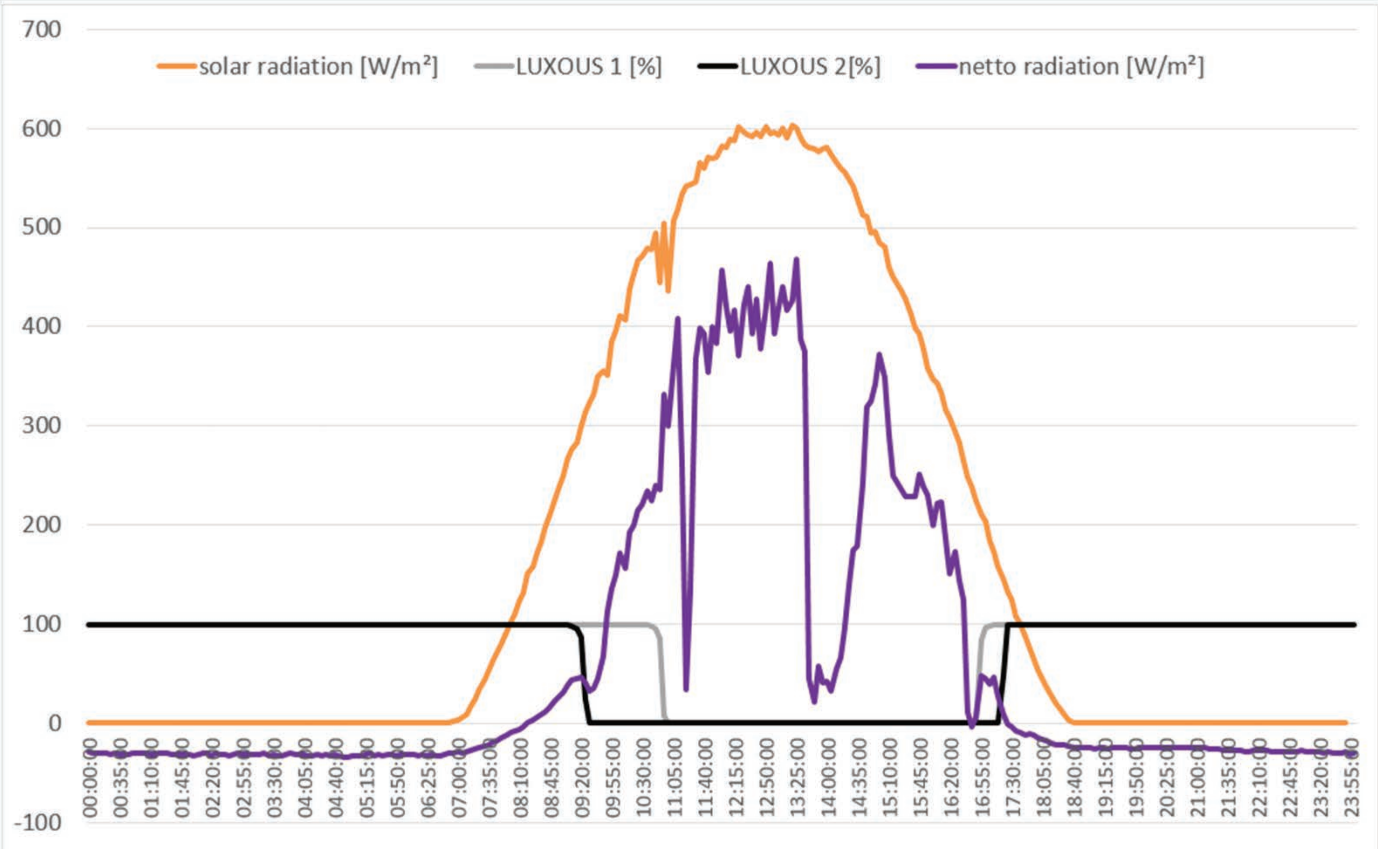
Blocking of heat emission

This thermographic picture illustrates the positive effect of a climate screen on blocking outgoing long wave radiation.

It shows that the temperature of the partly closed climate screen is substantially higher than the greenhouse coverage. As a result the heat emission from the crop under a (largely) closed climate screen is much less than under a fully opened climate screen.

This can be verified by a new type of sensor that has been introduced in the greenhouse industry, the net radiation sensor.
This net radiation sensor is installed above the crop and measures the incoming radiation from the sun (upper side of the sensor) and the outgoing radiation consisting of reflected sunlight plus the long wave radiation from the crop (bottom side of the sensor). The difference of these two measurements is the output of the net radiation sensor. An example of a net radiation measurement in a sweet pepper (paprika) greenhouse with two highly transparent LUXOUS energy saving climate screens is presented in the graph below.





Measured net radiation at a clear night and day

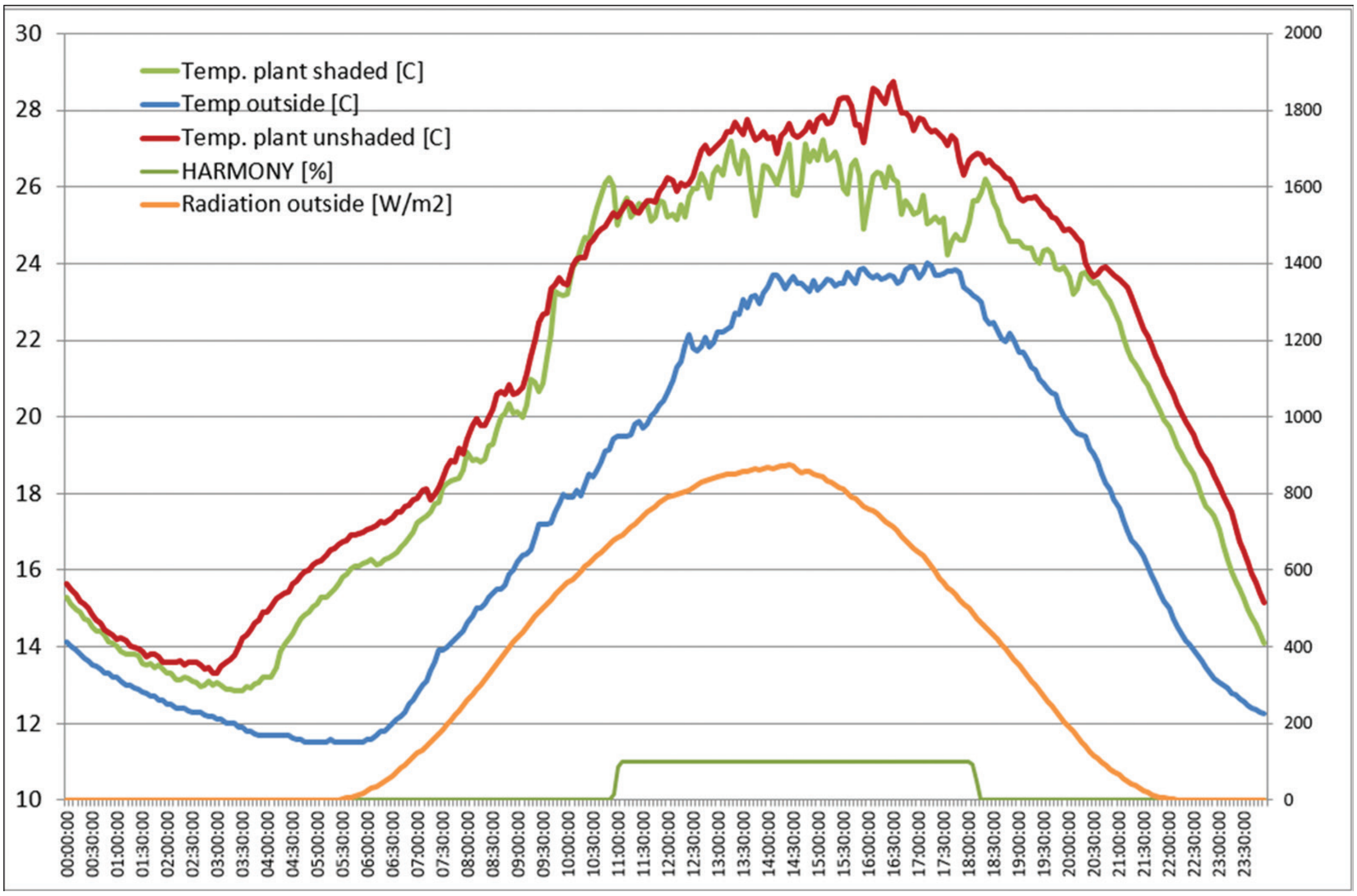
Because two energy saving climate screens (grey and black lines) are in closed position at night, the net radiation (purple line) at this clear and cold night is just -30 W/m². A negative value means more upwards energy radiation than incoming radiation, resulting in an energy loss from the crop. After sun-rise the net radiation increases because of solar radiation (orange line). In despite more light is entering the greenhouse when the first climate screen is opened at 09.30 hours (black line), the net radiation decreases a bit. Therefore, it could be considered to open the first climate screen a bit later in time. In the evening, when the first climate screen closes at 17.00 hours (grey line), the net radiation increases from 0 to 45 W/m². From 150 W/m² solar radiation in the morning with two climate screens in closed position, the net radiation is positive, in the afternoon at 240 W/m², the net radiation becomes negative with the climate screens opened.
Thus, the net radiation sensor shows that the climate screen or screens should be used longer in the morning and earlier in the afternoon.
Note: the drops in net radiation measurement during the day are caused by shadow of the greenhouse structure on the sensor.

High grade light diffusing climate screen to improve photosynthesis

During summertime the greenhouse climate can become too extreme (too much solar radiation, too high (plant)temperature and a too low RH) resulting in a crop that does not grow as efficient as possible. Typically, for a tomato crop for instance, the photosynthesis decreases when the temperature is above 28 °C and the sun radiation over 800 W/m².
Note: If a high RH level can be maintained (over 70%), higher temperature can be allowed.

The picture on the right and climate graphs on the next pages present a tomato crop in summer in two different situations. Situation A: no shading by a climate screen, versus situation B: with a HARMONY high grade light diffusing shading screen (23% shade).

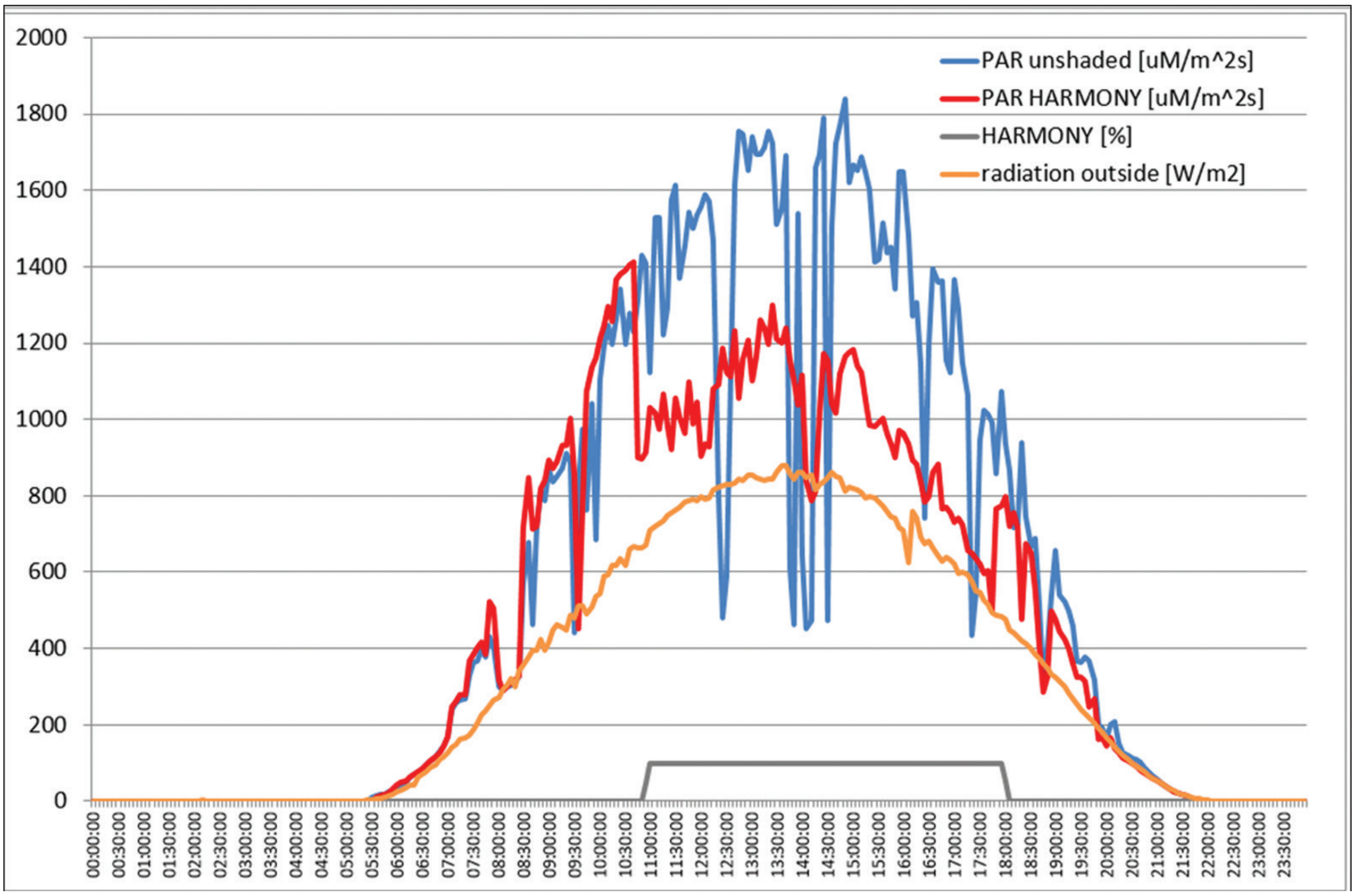
Situation A: no shading in the front of the greenhouse versus situation B: shading with high grade light diffusing HARMONY climate screen greenhouse at the back.



Situation A: no shading in the front of the greenhouse (red line) versus situation B: shading with high grade light diffusing HARMONY climate screen greenhouse at the back (green line).

The graph above shows the different leaf temperatures of the tomato crop. In the greenhouse without a climate screen (situation A) plant temperature is up to 2 °C higher versus plant temperature below the HARMONY high grade light diffusing climate screen (situation B).

It has been proven in research and practice that diffused light gives better growing results than direct light for most crops because of better light distribution and less water stress in the top of the plants.



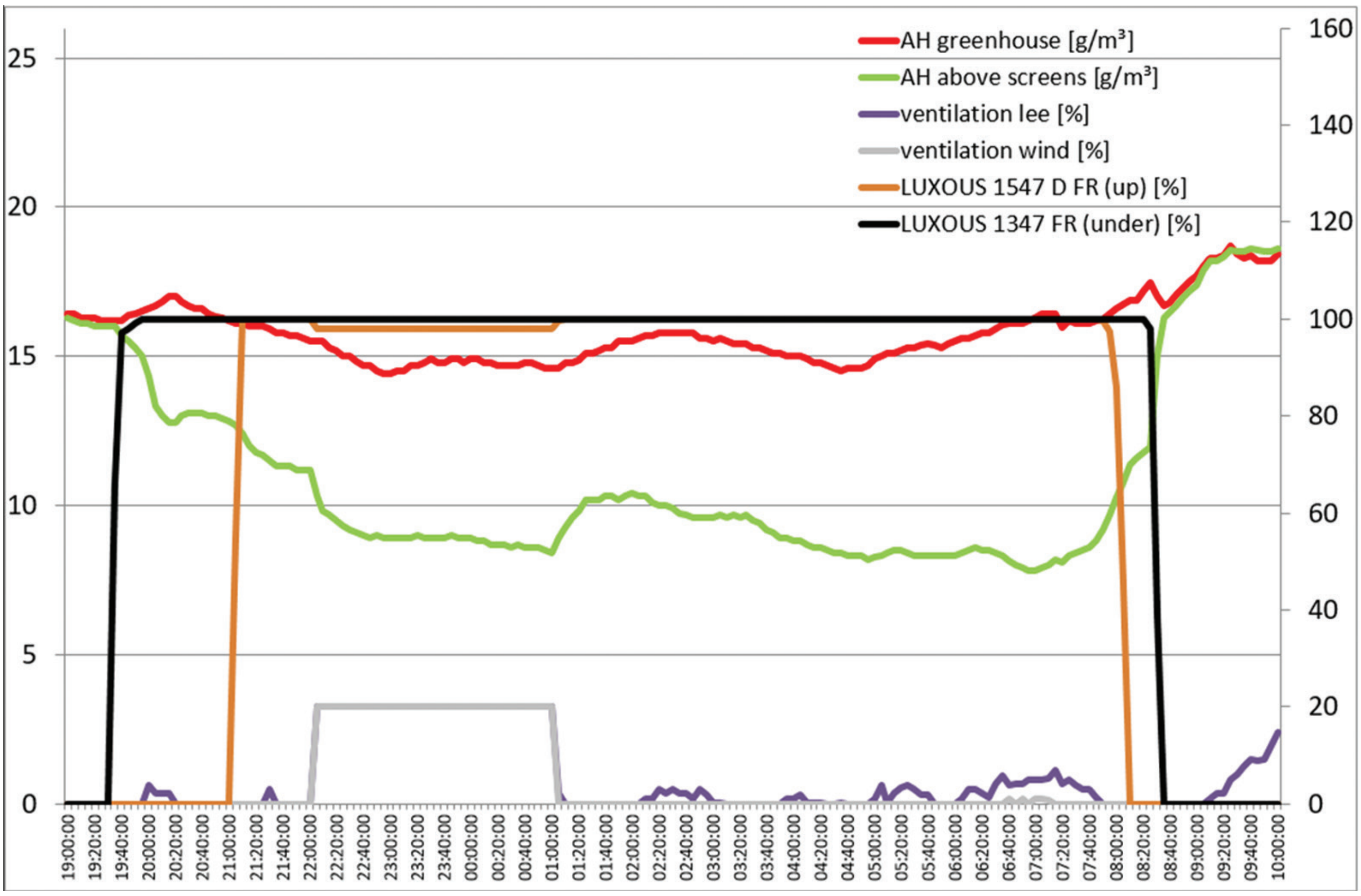
Measured plant temperatures at sunny summer day

The graph above shows a peak solar radiation outside of 880 W/m². The PAR light measured inside the greenhouse without a shading climate screen (situation A) , peaks up to 1840 µmol/m².s. The PAR level in the greenhouse with the high grade light diffusing climate screen (situation B) drops at the moment of closing the climate screen and rises when the climate screen opens again. The inside PAR light measurement in the unshaded greenhouse is showing big peaks and drops because of the shade of the greenhouse constructions. The PAR light measurement under the HARMONY high grade light diffusing climate screen shows a much more smooth pattern, which is a result of the high grade diffused light.

Homogeneous horizontal climate and improved humidity control

When the humidity in the greenhouse below the climate screen rises to a too high level, the most common way to discharge the moist is to set a small screen-gap. This results in fall of cold air locally and in an unhomogeneous horizontal climate (temperature and RH) in the greenhouse. As a result, the climate has to be controlled at a lower humidity level (for instance a humidity deficit of 2 g/m³) to be on the safe side for preventing diseases like botrytis.

By not setting a screen-gap, the horizontal climate in the greenhouse is much more even. So the climate can be controlled at a lower HD level (for instance 1 g/m³) without risk for plant diseases. A good moist transfer capability of the climate screen enables moist discharge from the greenhouse to the greenhouse rooftop without a screen gap. To stimulate this process even more, the roof ventilation windows can be opened. In the graph below this principle is demonstrated.



Moist discharge through the climate screens

The graph shows the moist transfer capabilities of a double maximum light transmitting LUXOUS energy saving climate screen installation. At 19.20 hours the lower climate screen is closed. At first the absolute humidity (AH) in the greenhouse (red line) increases. But after a while it decreases again because of the decreased AH above the climate screen (green line). This can be explained as follows: by closing the climate screen, the temperature of the greenhouse coverage drops, thus stimulating condensation. Typically, if the outdoor temperature is lower than the dew point temperature in the greenhouse, crop evaporation can be absorbed by this condensation.

At 21.00 hours the upper climate screen is closed as well, but this hardly hampers the moist exhaust, which is shown by an ever decreasing AH in the greenhouse. At 22.00 hours, a 2% screen-gap is adjusted in the upper climate screen, and at the same moment the ventilation window at the wind-side is opened for 20% to promote moist exhaust by ventilation. The absolute humidity (AH) above the climate screens (green line) is now reduced from 12 to 9 g/m³. In the same period the AH in the greenhouse, decreases with more than 1 g/m³, showing that the moist is effectively carried off through the closed lower climate screen.

Optimizing growth climate and saving energy

The highly transparent LUXOUS energy saving climate screen types make it possible to close the climate screen not only during the night but also during part of the winter-days with only a little loss of sun light. This way energy is saved and an optimal growth climate is realized. In the morning after sunrise it is the coldest moment of the day; by keeping the climate screen in closed position, there is no need for extreme hot heating tubes in the greenhouse to keep the temperature at its set point. So a dry microclimate in the vicinity of the tubes and plants, is prevented.

Transparent energy saving saving climate screen type LUXOUS 1147 FR

The best moment for opening the energy saving climate screen in the morning, is when the sun has heated up the greenhouse space above the climate screen up to a value of about 5-7 °C difference from the greenhouse temperature. Opening the climate screen at this moment does not result in an extreme fall of cold air upon the crop. Secondly the heating climate tubes do not need an extreme rise in temperature. If solar radiation intensity is not sufficient to heat up the air above the climate screen, it is better to keep the climate screen closed.

It goes without saying that blocking of heat emission and screening without gaps result in substantial energy savings. In research and practice it has been proven that 10 – 40 % energy saving can be achieved in many crops. However, it has to be underlined that improving the grow climate for the crop must always be the first concern. Energy savings will then be the bonus.
The other way round; by focusing on energy saving as the primary goal, in many cases this is at the cost of plant growth and health.

Conclusion

Research has given us more insights into how to support and maintain the energy balance of the plants. Combining these new insights with the right climate screens and advanced screen control techniques a good balance between plant activity and the usage of fossil energy can be achieved.

Anticipatory control instead of taking corrective actions afterwards ensures a better energy balance, which results in a healthy, more resilient crop and an optimized production and quality.

Epilogue

Since 2006 Hoogendoorn Growth Management has been closely involved in the Next Generation Growing research program in cooperation with Wageningen University and Research (WUR). This research has provided us with new insights into the plant balances. Over the years, Hoogendoorn has step by step upgraded its climate and irrigation control systems based on these new insights and results. For this, not only the standard software has been updated, but also several special modules have been developed.

Koppert Biological Systems produces sustainable cultivation solutions for food crops and ornamental plants. Together with growers and in partnership with nature, we work to make agriculture and horticulture healthier, safer, more productive and resilient. We achieve this by using natural enemies to combat pest infestations, bumblebees for natural pollination, and biostimulants that support and strengthen the crops both above and underground. Restoring and protecting vital ecosystems in a natural way is the basis for healthy crops and a balanced environment.
Add our quality know-how and consultancy services to this and you will understand why an increasing number of growers regards us as a partner with whom they can realize their ambitions.

Cultilene is one of the leading manufacturers of slabs for hydroponic cultivation worldwide, and is known for its high added value in terms of specialized consultancy and knowledge sharing with the end users. Cultilene has introduced an App for Smart Root Zone Management. This App is available for mobile devices as CULTILENE SRZM. Download the App for Android or iOS, or visit app.cultilene.com.

Svensson is the leading manufacturer of climate screens and is known for its added value in terms of specialized consultancy and knowledge sharing with the end users. The Svensson climate screens give the grower more effective climate control: from solar reflection and high grade light diffusion to shading and cooling.

Hoogendoorn, Koppert, Cultilene and Svensson all strongly believe in cooperation and knowledge sharing to provide the best possible support for their clients.

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