

A photograph of a greenhouse structure, showing the metal frame and the glass panes. The sky is visible through the glass, which has a blue tint, suggesting an anti-condens coating. The text "Greenhouse" is overlaid in white.

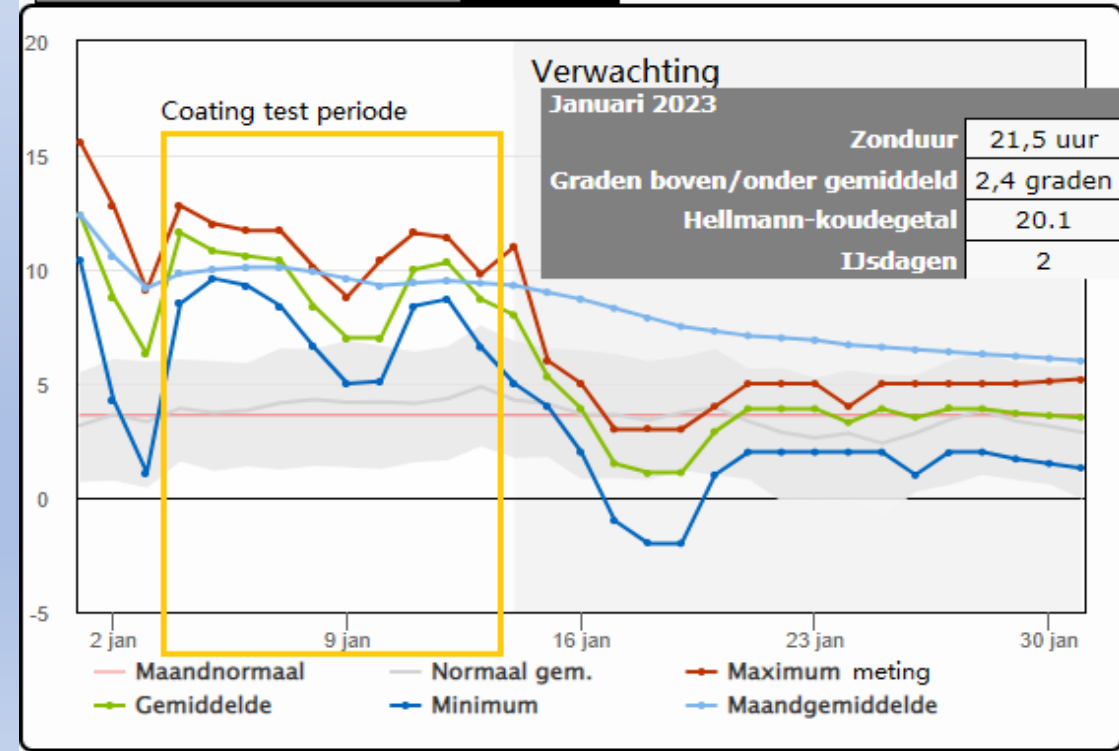
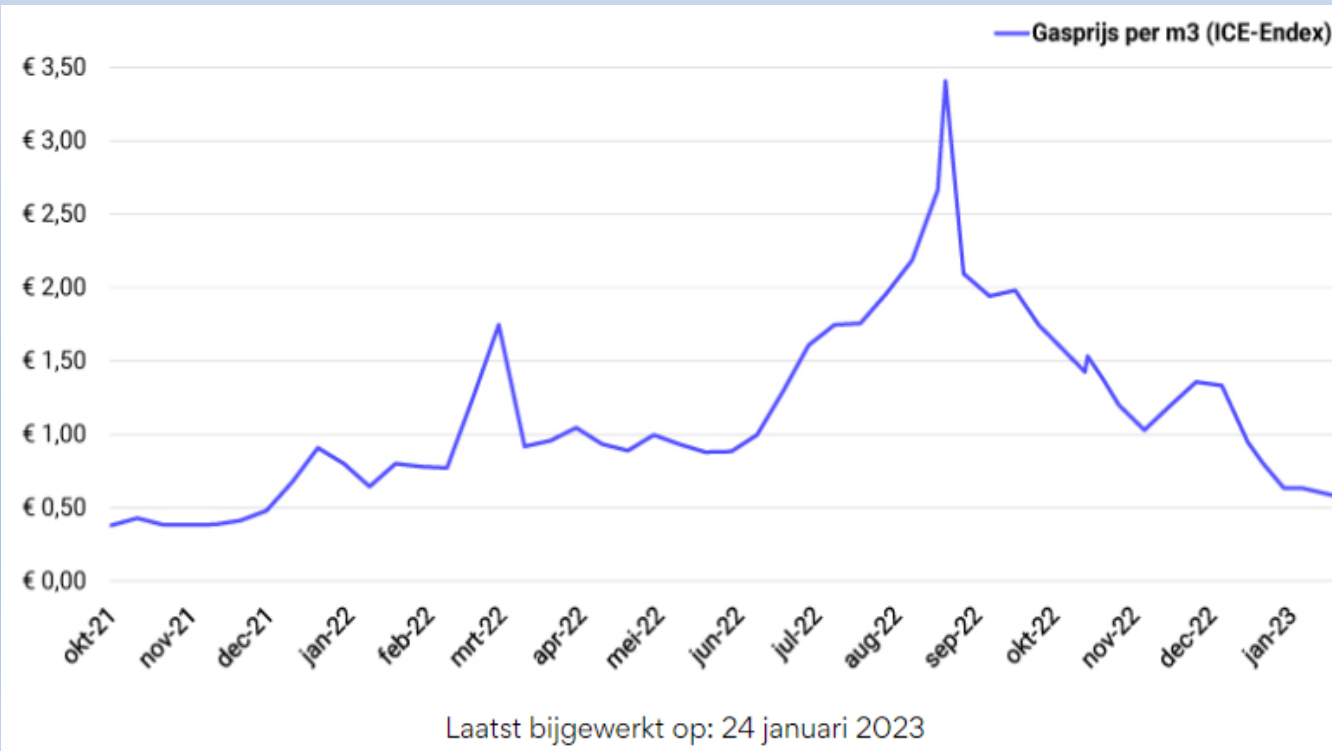
# Greenhouse

Natural heating contribution and humidity regulation  
with anti condens glass coating

# Energy saving is key for sustainability

Until 2020, 30 to 32 m<sup>3</sup> of gas per m<sup>2</sup> was used in greenhouses for vegetable cultivation. The energy saving obligation now only allows 20 m<sup>3</sup> of gas per m<sup>2</sup> of greenhouse. A 33% reduction!

In January a 10 ha. bell pepper greenhouse uses about 500,000 m<sup>3</sup> of gas and that is ± 125,000 m<sup>3</sup> less per month. Energy saving has the highest priority with the current gas prices.



# Natural improvement for greenhouse climate

We developed: A 100% natural coating that is completely inert (i.e. does not react with other substances) and remains effective for a long time.

The coating does 3 important things:

**1. Forms a super hydrophilic water layer on the glass.**

The water film slides off the glass and the film evaporates before your eyes

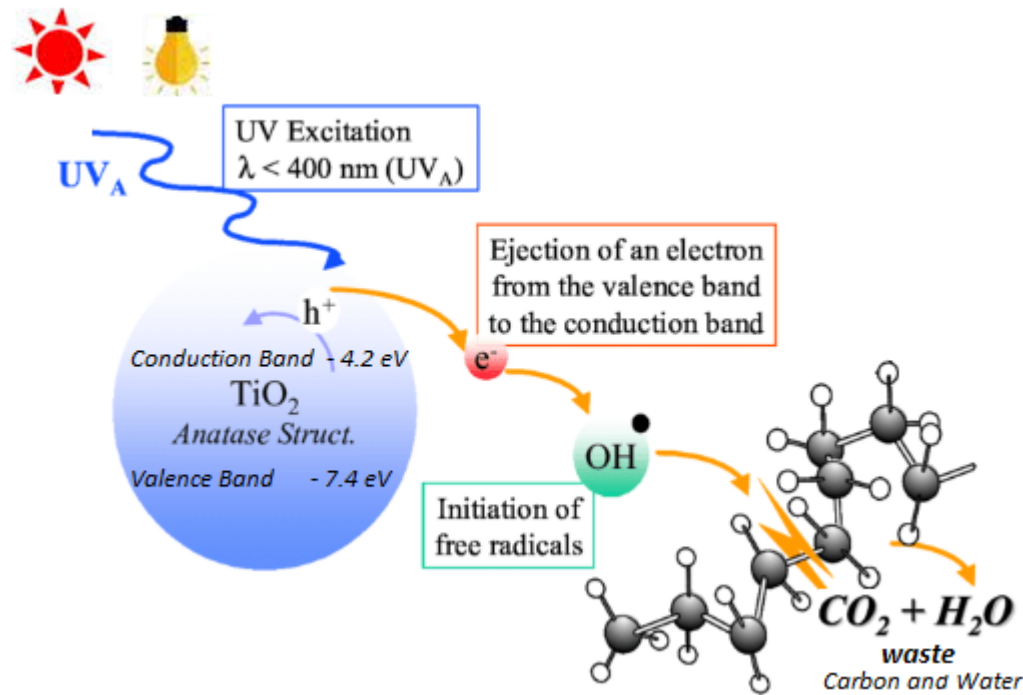
**2. Provides light gain and temperature gain.**

Condensation drops reduce light incidence by up to 8% (WUR) Water droplets evaporate cost a lot of energy and time and evaporation is cooling

**3. The coating works as a catalyst in photocatalysis.**

Photocatalysis makes glass self-cleaning (no algae, dirt, fungi or pathogens)

# Let nature do it's job



- 100% natural treatment
- Solves condensation problems
- Significant energy savings
- Reduced use of chemicals
- Disappearance of algae growth
- Higher production due to light gain
- What remains is CO<sub>2</sub> and H<sub>2</sub>O

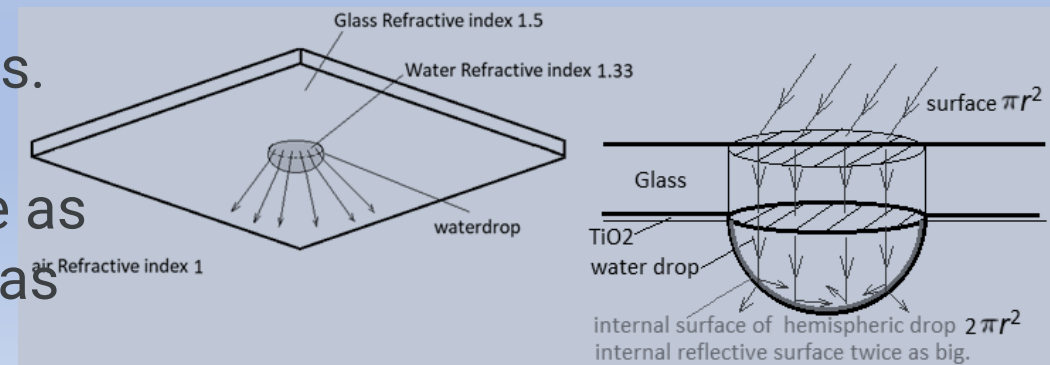
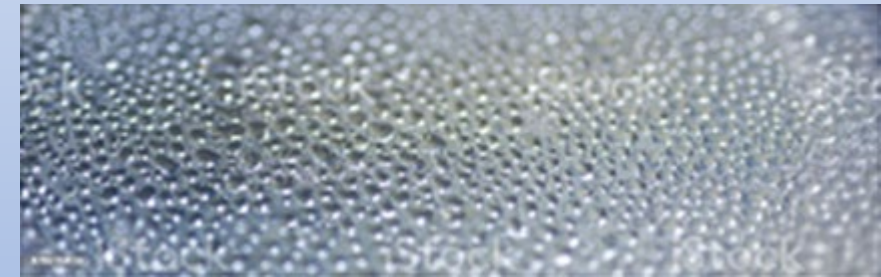
# The big party pooper, condensation in the greenhouse!

In winter, the greenhouse roof is condensed on the inside for 80% of the time. Condensation droplets affect the incidence of light and temperature in the greenhouse. A greenhouse evaporates 100 to 200 liters of water/m<sup>2</sup>/year. The hydrophilic properties of the coating prevent droplets resulting in more light and heat in the greenhouse because evaporation is cooling.

In 2023, the temperature gain of the coating was investigated at 3 greenhouse locations. In a greenhouse, WUR also investigated the incidence of light under coated and uncoated windows. Captured light does not easily escape from glass. Think of fiber optic cables. Water droplets have almost the same refractive index as glass. Water droplets under the glass increase the total surface area from which the light must escape to twice as large. With a water film, the surface remains the same as that of the glass.



**Condensation inside the window**



no coating

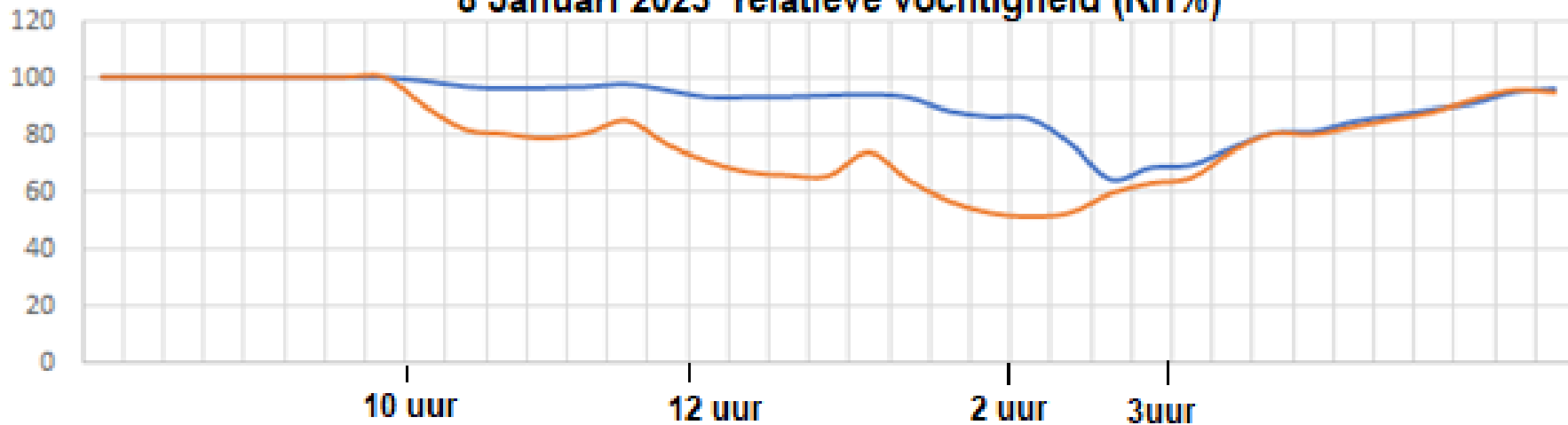
anti-condens coating

Let nature do it's job

Clouded day with some sunny moments

The coated window dries in a few minutes

8 Januari 2023 relatieve vochtigheid (RH%)



Ventilation is CO2 and heat loss

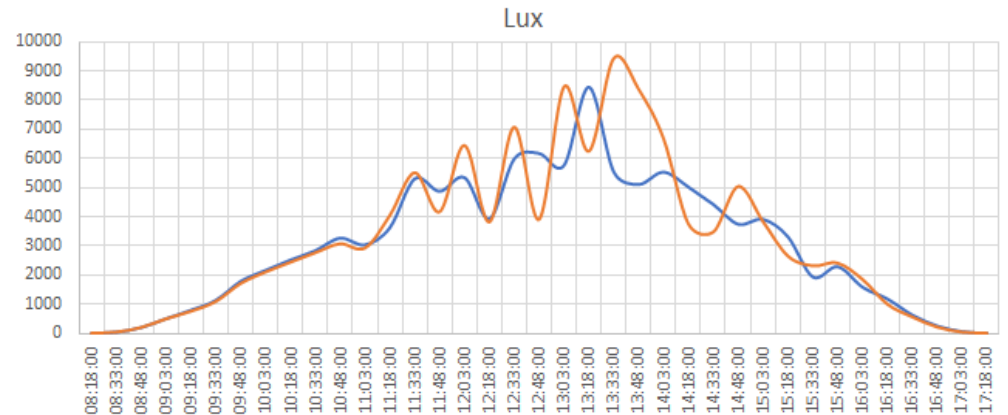
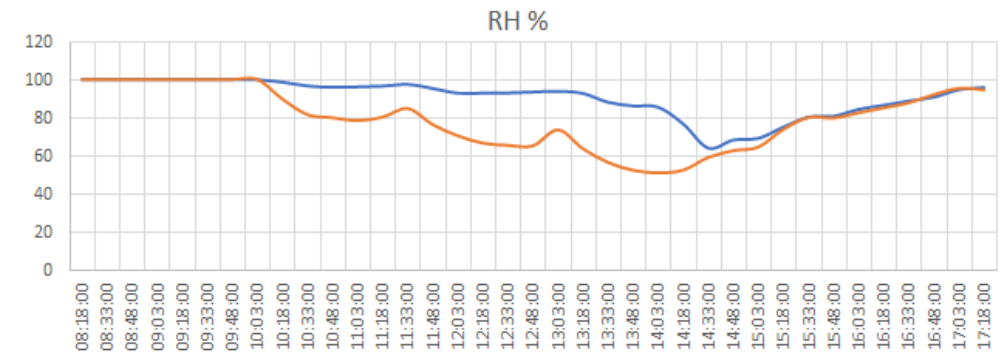
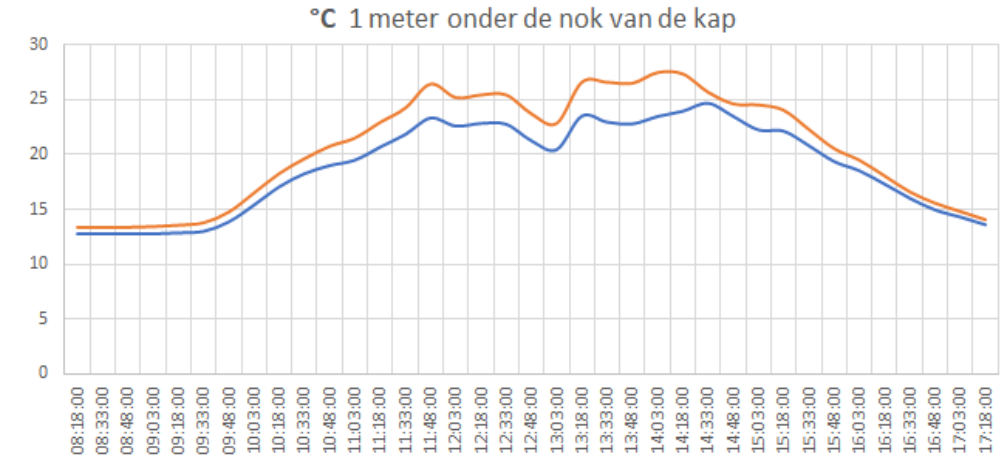
Evaporation is cooling !

# Het effect van condens op temperatuur en licht , 8 januari 2023

**Red is coated glass. Blue is not coated glass**

The coating forms a water film like a drop of oil on water. There are no drops. The water film flows down and dries in a few minutes, so that no more heat is extracted from the greenhouse (evaporation/cooling). The evaporation of large droplets by sunlight and greenhouse heating takes a lot of time and energy.

Results measured under coated and uncoated pane  
Temperature from 11:00 a.m. to 3:30 p.m. 2 C to 5 C higher.  
The screens are closed at night. Daytime humidity on average 25% lower. Light increase 4% more.



# Measuring °C, Relative Humidity (RH%) and light intensity (Lux)



The temperature, humidity and light sensors are placed 3 meters apart under one hood. 1 sensor under the coated window and 1 sensor under the uncoated window.

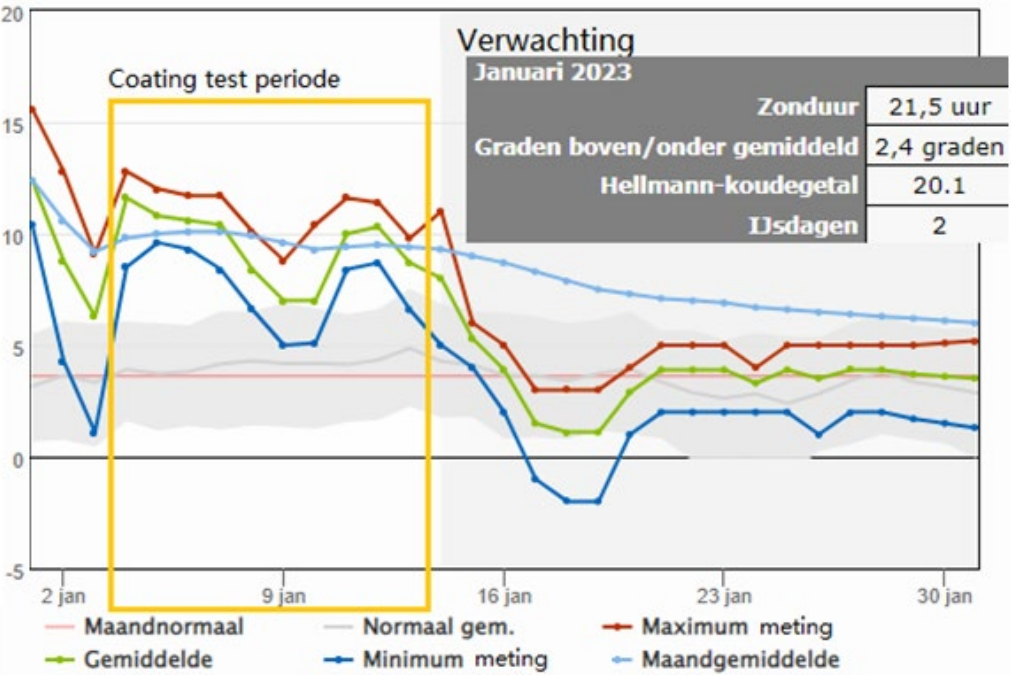


The temperature difference between the sensors is limited because there is only one coated (warm) window, next to the still evaporating (cooling) adjacent uncoated windows.

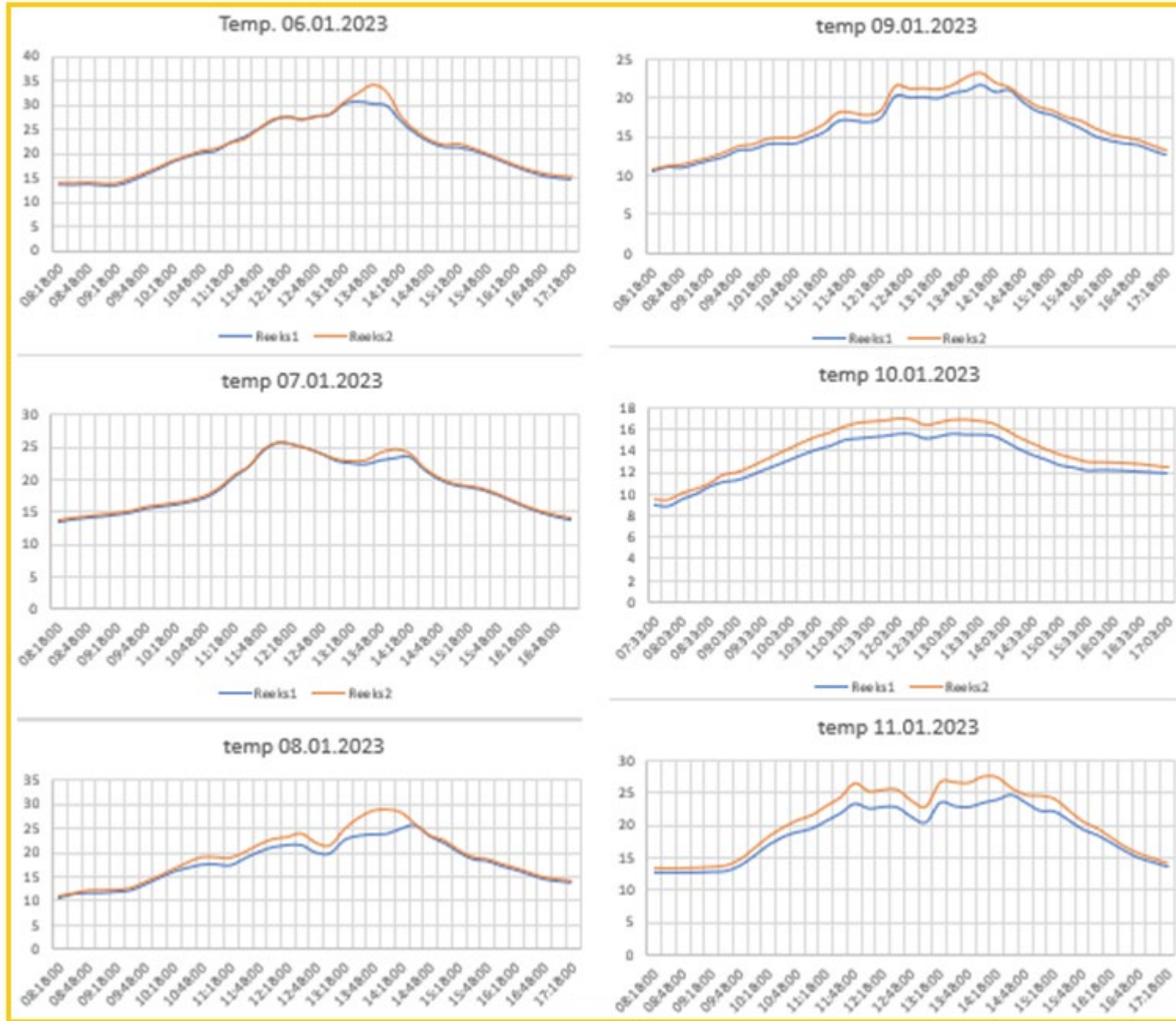
## 2. Light gain and temperature gain



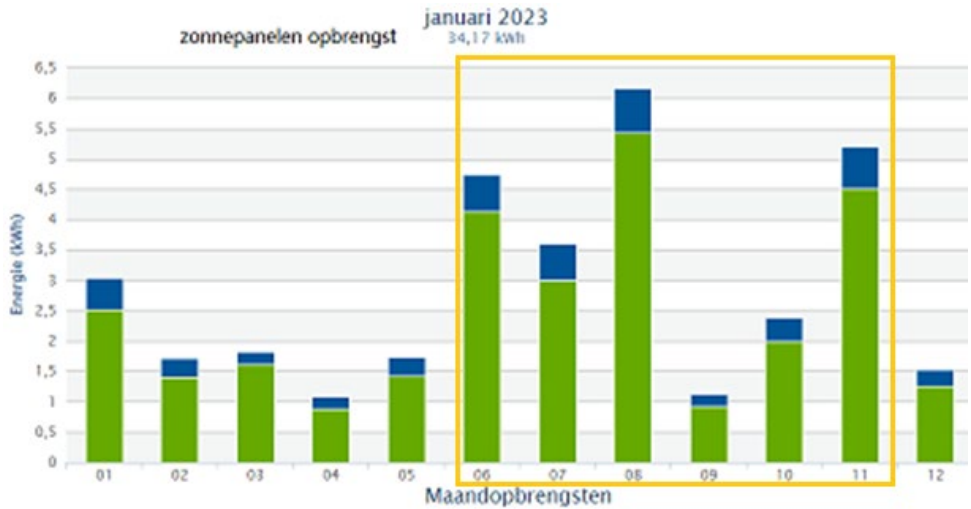
# January 6 days in a row



Early January 2023 was unusual warm with limited condensation.



Average temp in measured period 10°C i.p.v. 4°C



# February at pepper grower

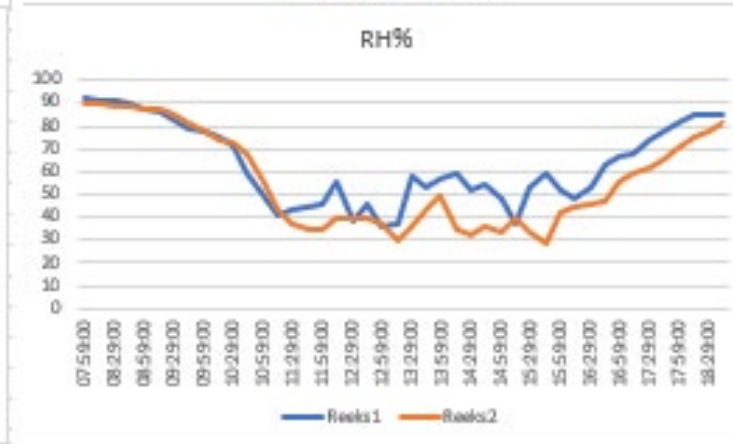
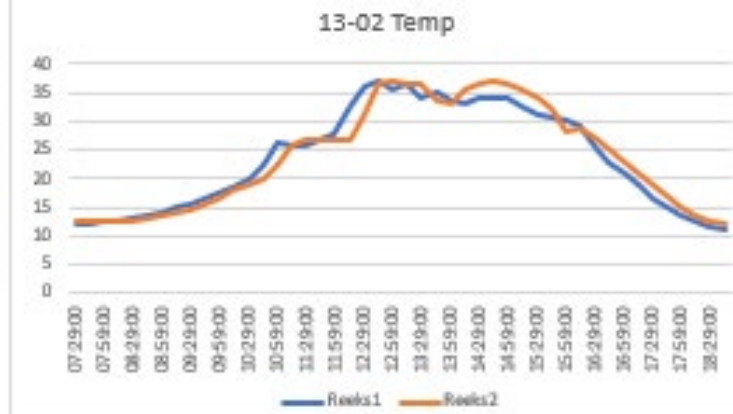
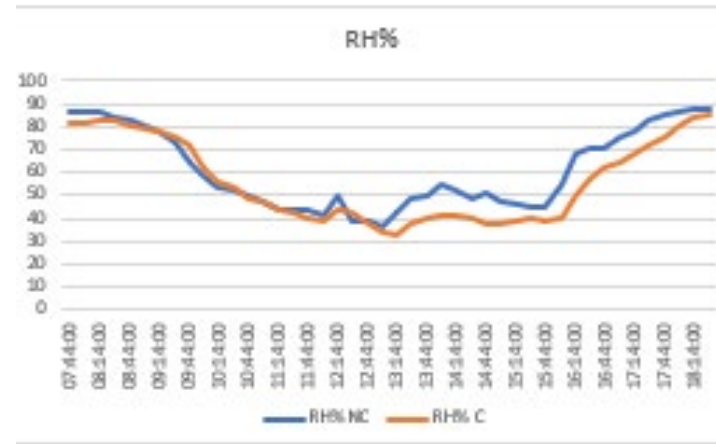
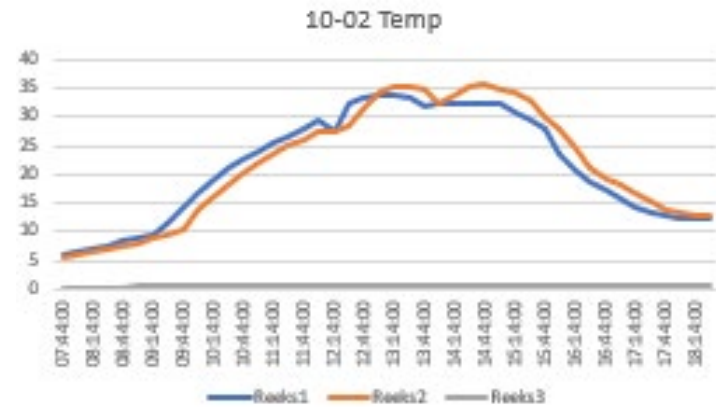
Sensors 25 meter apart from each other in the same hood.

**10/2** Sum Temp 943 953 =10 °C  
Van 8:00 hr. tot 18:00 hr. =10 u  
Avrg. Temp. non coated 20,57 °C  
Avrg. Temp. coated 21,67 °C  
Avrg. RH% non coated 61,5 %  
Avrg. RH% coated 56,0 %  
Avrg. Lux non coated 7254 lux  
Avrg. Lux coated 7998 lux

To determine °C, RH% and Lux gain, the averages of each day were taken from 8:00 am to 18:00 pm.  
The average temperature gain in January en February was between 1 °C en 3 °C. (5%)  
The measured light gain was between 3 en 10%

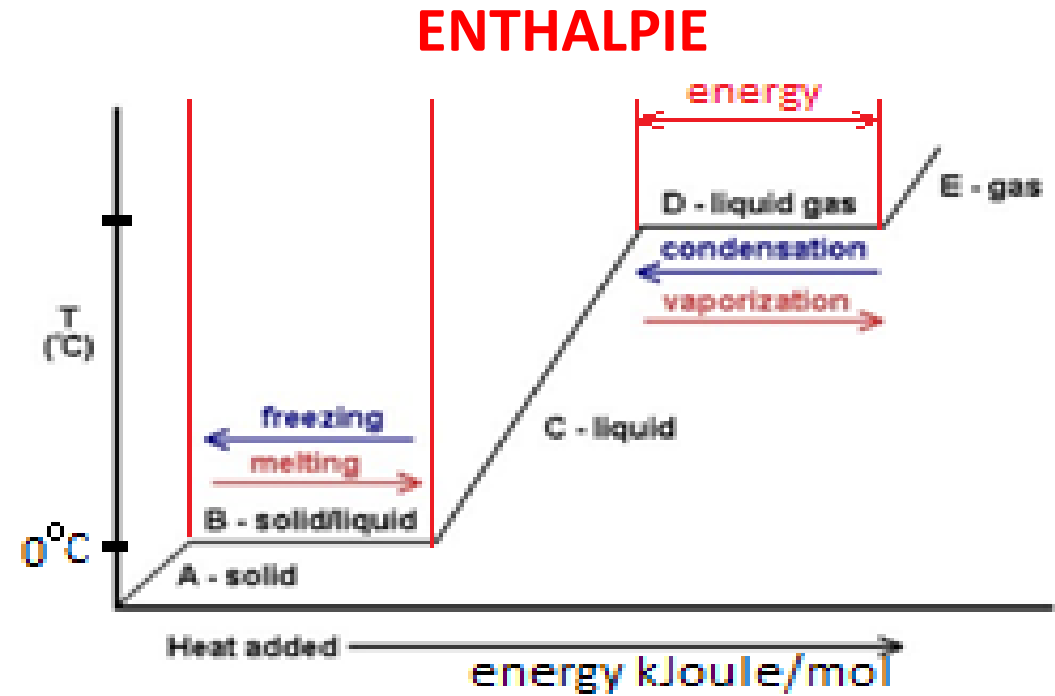
**Attention!:** The measured results are only there when there is sufficient daylight.

## Februari 2023

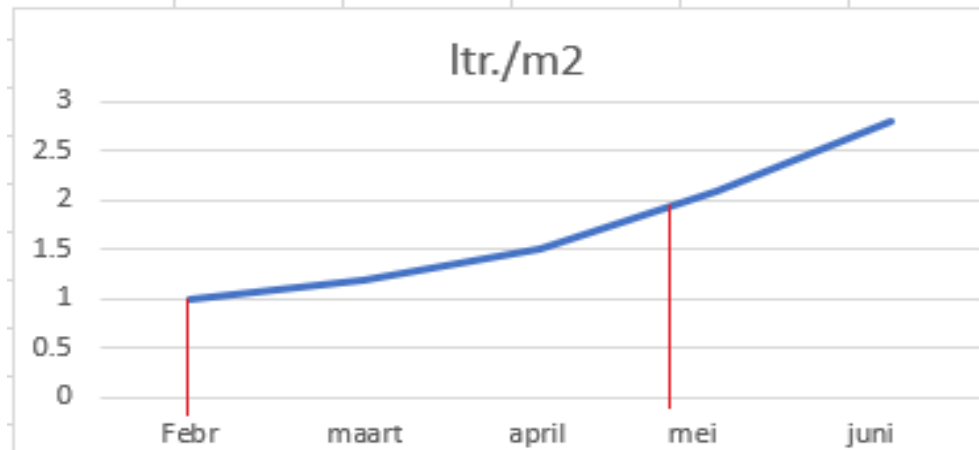


# Heat loss due to evaporation condensation

Evaporating water costs a lot of energy. Condensation disappears through evaporation and ventilation. Ventilation in the winter costs heat. Changing from ice to water, or from liquid to water vapour is a phase change and requires a huge amount of energy. The enthalpy graph shows that the temperature remains the same while a lot of energy is absorbed or released in the reverse process.



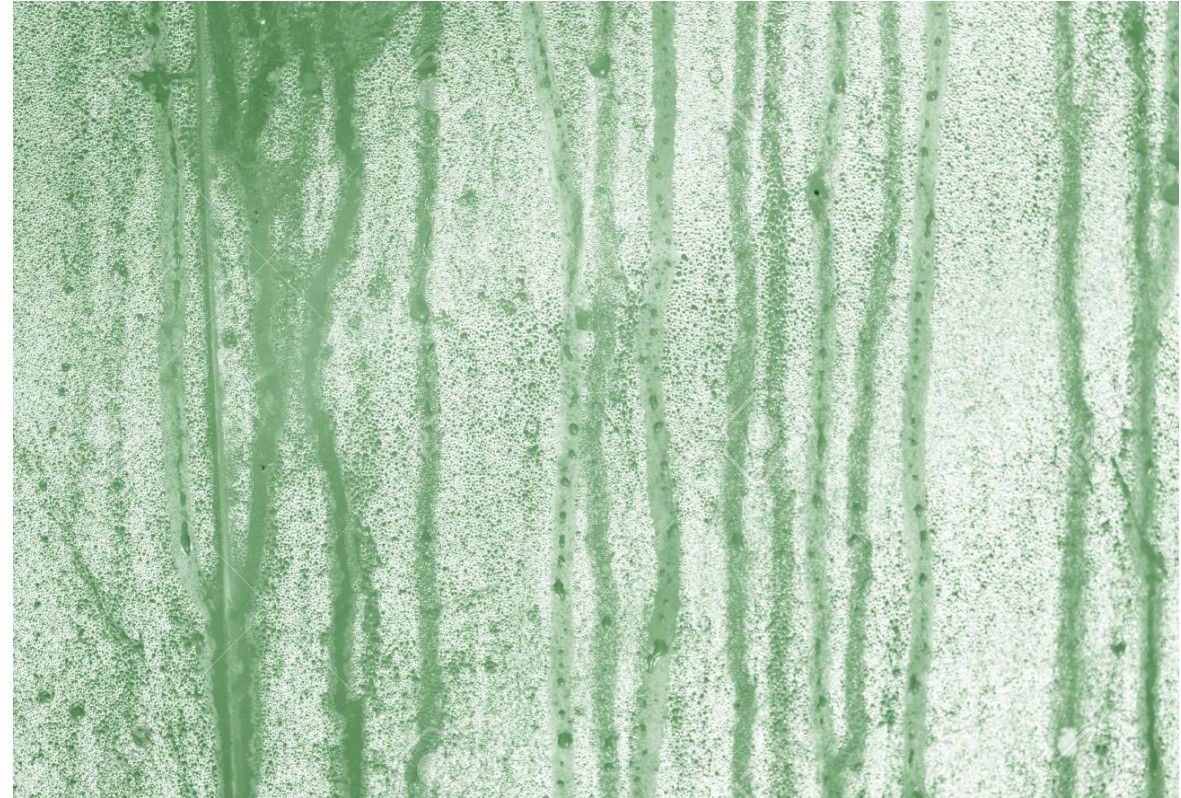
per dag	Febr	maart	april	mei	juni
ltr./m2	1	1.2	1.5	2.1	2.8



An unscreened greenhouse has, during the heating period, 1 to 2 litres/m<sup>2</sup> per day condensation drainage for cucumber spring cultivation on substrate. Evaporation of condensation extracts a huge amount of energy from the greenhouse. If condensation has already drained off the glass into tanks, that heat is no longer extracted for evaporation.

# Scientific discovery! Light evaporates water without heat

Water also evaporates under the influence of light, MIT researchers published in the scientific journal PNAS. Exposure to light results in evaporation at the surface of water even at 0°C. Under certain conditions, even more than when water is heated. Photons are able to break the bonds between water molecules. If these bonds are broken at the water surface by photons, nothing stands in the way of the H<sub>2</sub>O molecules evaporating. The mystery that water evaporated much faster than just by the effect of heat was solved with this discovery. Adding heat makes water molecules move faster, allowing them to escape more easily, i.e. evaporate. The combined effect of light and heat explains the 'extra', unexpected evaporation. onverwachte verdamping.

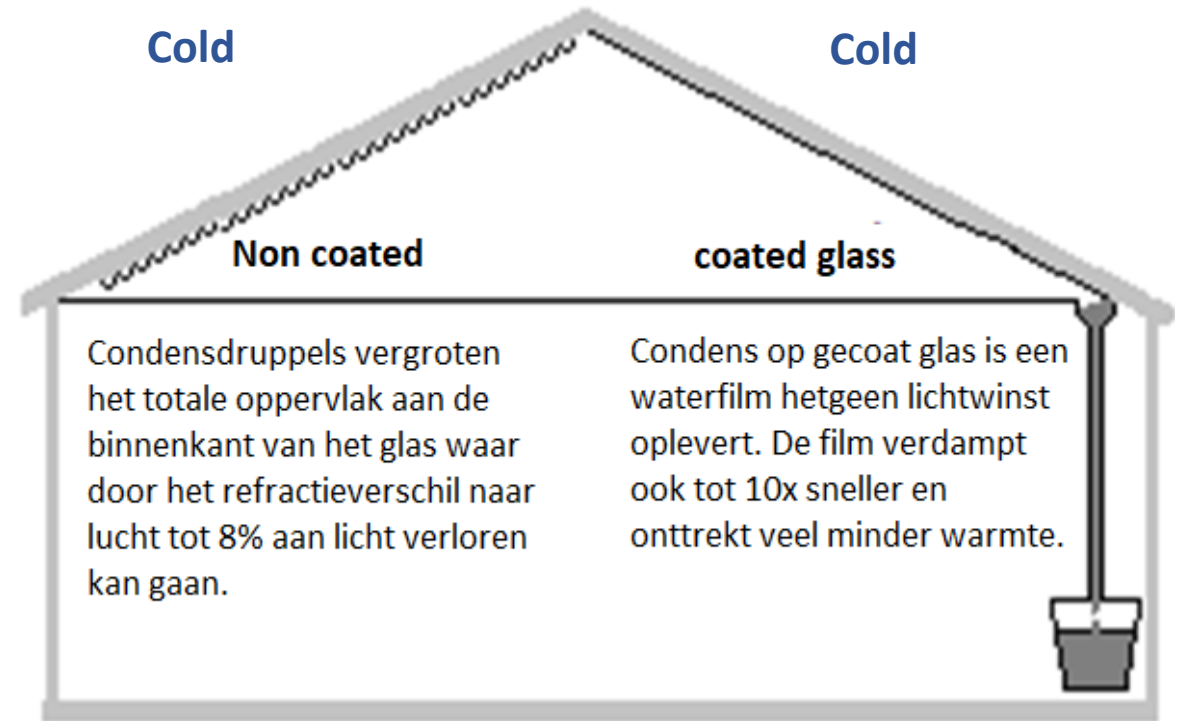


**PCO glass coating prevents light loss due to condensation and algae growth Evaporation is cooling, in other words, we have to supply a lot of heat to get rid of condensation. That costs a lot of energy (gas!)**

# Nature does its work with super-hydrophilic coating

With coated glass, the condensation water runs in a thin water film to the water gutters. With condensation of 1 to 2 liters/m<sup>2</sup> per day, 50% of the condensation water is drained away by runoff. A 23° roof slope is optimal for light incidence in the Netherlands. At 30°, there is more runoff water.

A 10 ha greenhouse then has 115,600 m<sup>2</sup> of roof surface. If 50% drains away per day, there is between 57,800 and 115,600 liters less moisture to evaporate. Evaporation of 1 liter of water requires 2258 kJ of energy. 57,800 x 2258 kJ = 131 GJ or 36 to 72 MWh/day less heat loss by evaporation.



Luchttemperatuur °C	Verzadigde lucht g/kg	Lucht met 50 % r.v. g/kg	Bijbehorende dauwpunt temperaturen °C
10	7.7	3.9	
15	10.8	5.4	4.9
20	14.9	7.5	9.5
25	20.4	10.2	14.2
30	27.5	13.8	18.8
35	37.0	18.5	23.5

# Energy saving due to hydrophylic coating

A greenhouse complex of 40,000 m<sup>2</sup> has a CHP with 3,535 kW of boiler energy.

<https://kce.thomasmore.be/tool-verwarmingsvermogen.html>

A 10 ha greenhouse needs 2.5 times as much boiler energy. That is 8,837 kWh. In practice, a 10 ha greenhouse consumes up to 500,000 m<sup>3</sup> of gas (= 4,884.72 MWh) throughout January. With 50% condensation discharge through the coating, a 10 ha greenhouse can save 54 MWh of energy per day in January.

## What are the savings in money?

To go from MWh to m<sup>3</sup> of gas, divide by 0.0097694444 54 MW = 5,527 m<sup>3</sup> of gas at €0.XX = €XXXX/day in January

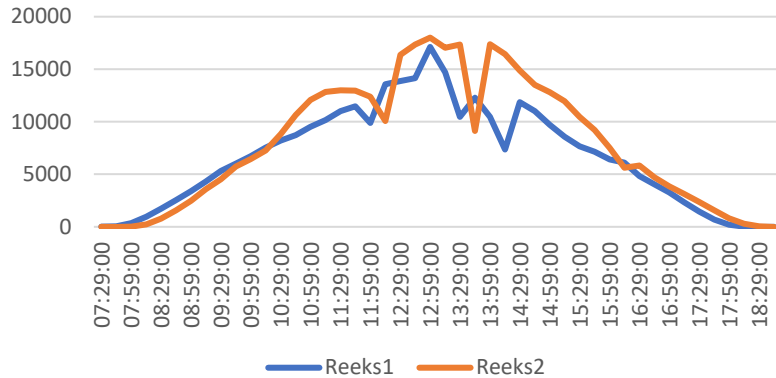


# Light gain v.s. temperature gain due to the coating Feb. March 2023

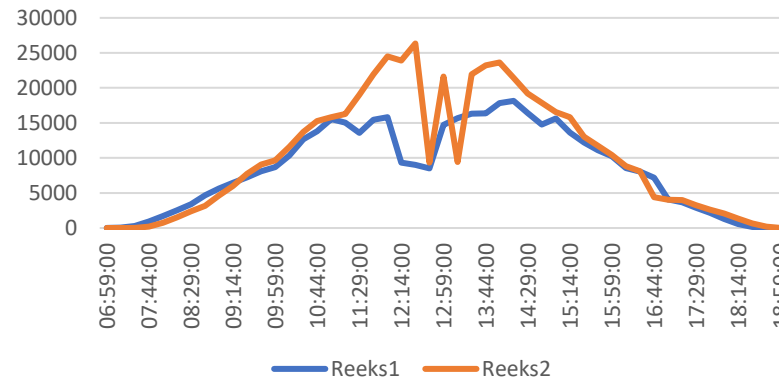
On cold and dark winter days, the screens remain closed. Light gain is n.a.

On sunny days, the light gain with coating is the greatest without ventilation. With ventilation, the coated window dries with a haze with 1 to 3% light loss (and CO2 loss and cold) WUR saw light gain in the morning on sunny days as long as the window is moist.

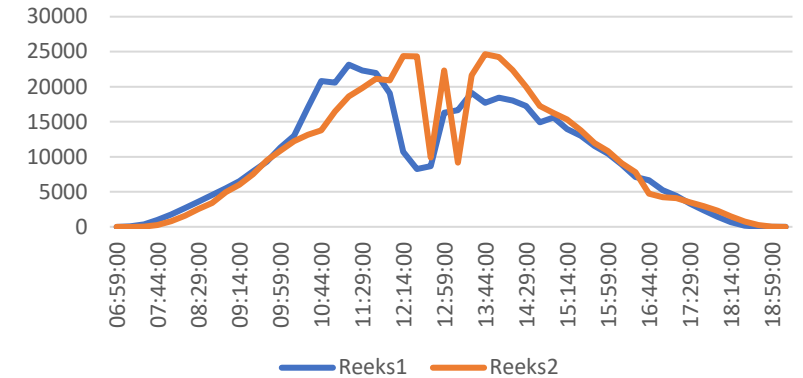
14-02 Lux



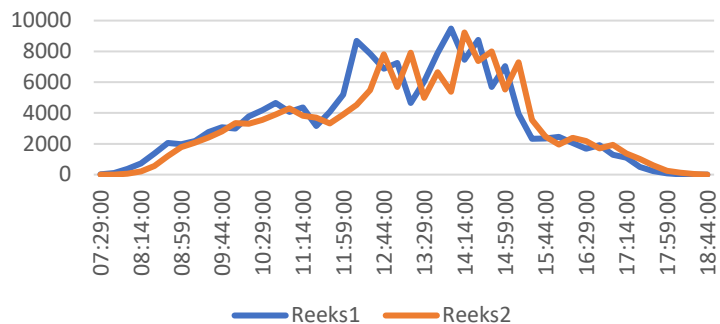
01-03 Lux



02-03 Lux

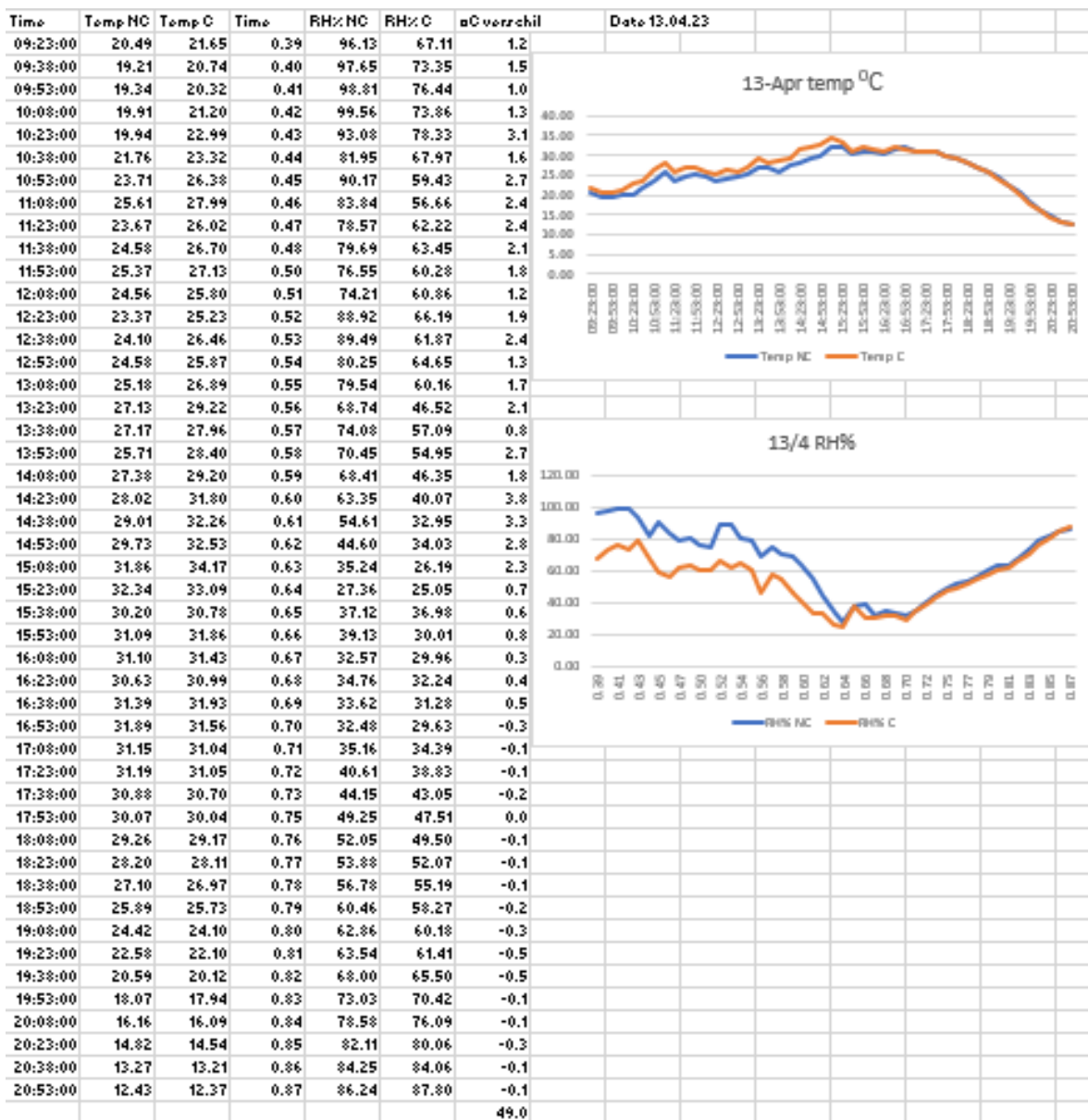


21-02 Lux



During the sunny period 26-2 to 2-3 there is 12.6% more light. On dark days there is often no light gain. Percentages. For plant growth, the number of micromoles or PPFD per day applies. On dark days there is an average of 8000 lux. 3% light loss is then 240 lux less. Sunny days are 20,000 lux. With coating there is then 12.6% or 2520 lux more light.

# Temperature gain by the coating in April 2023



Ammerlaan condensafvoer over 400 m2 kamerplanten					
2023	coated	ongecoat	gecoat	ongecoat	
	ml	ml	% vol	% vol	
12-4 tot 13-4	500	420	50	100	
14-4 tot 17-4	2800	1620	55	100	
17-4 tot 18-4	275	25	75	100	
	3575	2065			

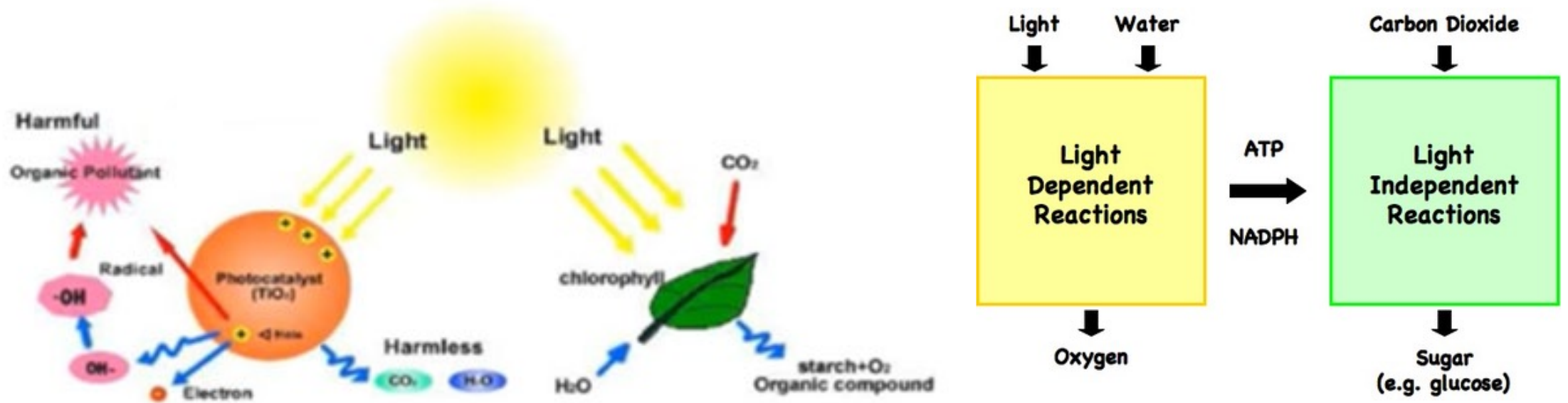
The evaporation of 30 to 50 cm houseplants is considerably less than that of seasonal vegetables. The plant occupancy varied daily. More water drainage was measured with coated windows. The amount of water in vegetable cultivation increases progressively with the size of the plant up to 8 litres/m<sup>2</sup> per day. The plants are cooled in the summer by evaporation. The tests carried out did not deviate from the normal course of events with regard to screening, ventilation, etc. Adapted methods can improve the results!

# 3. Catalyser

Our glass coating is a catalyst. The effect of light is enhanced by the photo catalysis process without consuming the catalyst (coating).



# Photokatalysis is as natural as Photosynthesis



## Photocatalysis

Photocatalysis is a photochemical process. Sunlight produces hydroxyl molecules also called free radicals in a natural inert material (TiO<sub>2</sub>). The natural cleaners of our atmosphere.

Permanent cleaning of surfaces and air.

## What are the residual materials?

Bacteria, fungi, algae and viruses decay into CO<sub>2</sub> and H<sub>2</sub>O.

## Photosynthesis

Photosynthesis is a photochemical process in which sunlight and water. In chloroplast ATP is produced after which CO<sub>2</sub> is absorbed under the influence of light which converts the ATP into glucose.

Growth of plants, food and biomass.

Absorbs CO<sub>2</sub> into biomass and produces O<sub>2</sub>.

# What does the coating do in the photocatalysis process?

The catalyst accelerates and enhances a chemical reaction but is not itself consumed

The TiO<sub>2</sub> coating provides photocatalysis under the influence of UVA (daylight) which produces free radicals (hydroxyl - OH molecules) Hydroxyl is an extremely volatile radical and eliminates (oxidizes) almost all harmful substances. The collective name for these harmful substances is VOCs (Volatile Organic Compounds). Examples of VOC: fungi, bacteria, algae, NO<sub>x</sub>, CO, fine dust  
The end product of the reaction is H<sub>2</sub>O, Co<sub>2</sub> and harmless Non Organic compounds

Insects are not affected by this biological control



# The effect against algae



Before 3 april



After 27 april



Ammerlaan, Thursday 4 may



monday 8 may



Before. 3 months after coating.



Ammerlaan Thursday 4 may



monday 8 may

# Photocatalysis stops algae growth and breaks down harmful micro plastics

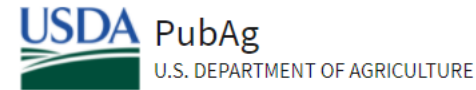
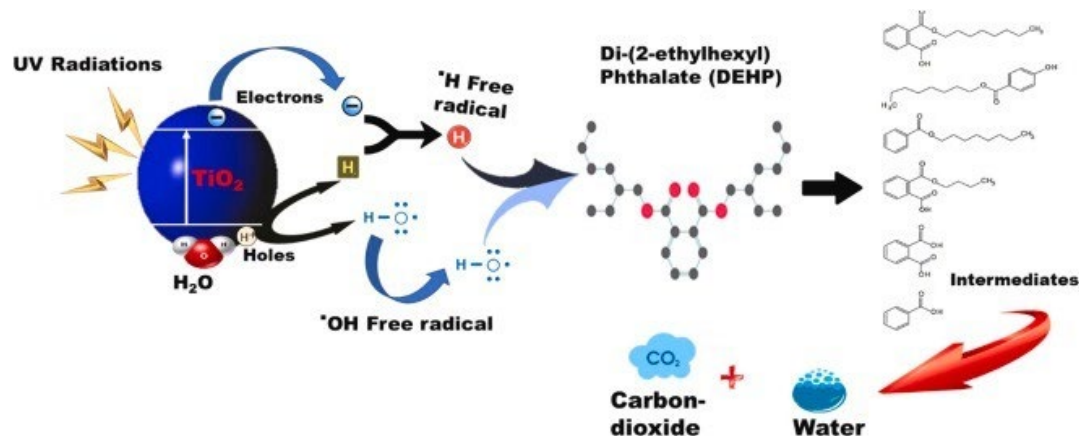
Microplastics <5 mm are a cause of concern. They are present in water, soil, air and other environmental media. They are emerging pollution because they persist for a long time due to their chemical stability after entering the environment. There are many harmful microplastics in the environment, including polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyamide (PA), polyoxymethylene (POM), etc. Microplastics are unknowingly ingested by organisms through the food chain transferred to animals with toxicological effects on animals and humans. Disruption of nutrition leads to reproductive disruption, energy metabolism, liver changes, etc. Pollutant additives in the production of plastics are present and absorbed from consumed water leads to great damage. Elimination of microplastic pollution is a high priority. Photocatalysis is a promising solution. Insects are not affected by this biological control.



# Glass coating also eliminates harmful microplastics like PFAS

Removal of PFAS, Phthalates, alternative plasticizers and organophosphate esters.

For a long time it was thought that photocatalysis only eliminated micro-organisms. Phthalates and VOCs are eliminated by photocatalysis. It turns out that many harmful inorganic substances such as NO<sub>x</sub>, H<sub>2</sub>S, CO, ammonia and other harmful chemical substances and gases are also broken down into harmless residues such as water and CO<sub>2</sub>. The photocatalysis process takes place daily in our atmosphere. In order to prevent algae formation in the greenhouse, a coating was applied to plastic. By chance it was discovered that harmful plastic was broken down within a few weeks.



[PFAS and their substitutes in groundwater: Occurrence, transformation and remediation](#)

Author: Bentuo Xu, Shuai Liu, John L. Zhou, Chunmiao Zheng, Jin Weifeng, Bei Chen, Ting Zhang, Wenhui Qiu

Source: Journal of hazardous materials 2021 v.412 pp. 125159

ISSN: 0304-3894

Subject: electrochemistry, groundwater, groundwater treatment, human health, light, microfiltration, oxidation, perfluorohexane sulfonic acid, photocatalysis, remediation, risk, soil, sorption, sulfites, surface water

Abstract: Poly- and perfluoroalkyl substances (PFAS) are increasingly investigated due to their global occurrence and potential human health risk. The ban on PFOA and PFOS has led to the use of novel substitutes such as GenX, F-53B and OBS. This paper reviews the studies on the occurrence, transformation and remediation of major PFAS i.e. PFOA, PFNA, PFBA, PFOS, PFHxS, PFBS and the three substitutes in groundwater. The data indicated that PFOA, PFBA, PFOS and PFBS were present at high concentrations up to 21,200 ng L<sup>-1</sup> while GenX and F-53B were found up to 30,000 ng L<sup>-1</sup> and 0.18–0.59 ng L<sup>-1</sup>, respectively. PFAS in groundwater are from direct sources e.g. surface water and soil. PFAS remediation methods based on membrane, redox, sorption, electrochemical and photocatalysis are analyzed. Overall, photocatalysis is considered to be an ideal technology with low cost and high degradation efficacy for PFAS removal. Photocatalysis could be combined with electrochemical or membrane filtration to become more advantageous. GenX, F-53B and OBS in groundwater treatment by UV/sulfite system and electrochemical oxidation proved effective. The review identified gaps such as the immobilization and recycling of materials in groundwater treatment, and recommended visible light photocatalysis for future studies.

**Fotokatalyse wordt beschouwd als een ideale technologie voor goedkope afbraak van gezondheidschadelijke microplastics**

# Applying the coating is quick

Percentage of light gain due to absence of algae. Measured in the morning between 9 and 10 o'clock

datum	buiten	TiO2 ruit	standaard	verschil	
2021	Kjoule	lux	ruit. lux	lux	
18-May	190	17100	16800	-300	1.80% onbewolkt
26-May	170	11000	10850	-150	1.40% licht bewolkt
02-Jul	90	1630	1600	-30	1.84% bewolkt
09-Jul	20	1210	1170	-40	3.30% zwaar bewolkt
21-Aug	104	4820	4600	-220	4.70% bewolkt
25-Sep	300	8100	7950	-150	1.90% onbewolkt
05-Oct	200	6050	5750	-300	5.00% licht bewolkt
23-Oct	192	10100	9600	-500	5.00% zon l. bewolkt
09-Nov	210	14000	13200	-800	5.70% zon



# Is it safe ?

Biocide? A rigid EU rule states that anything that kills germs or vermin is a biocide. Pepper growers traditionally used milk to disinfect tools and hands. If milk is used for that purpose it is a biocide and approval is required. Peanut butter as a bait on a mousetrap is the same. The coating on the glass is nano-titanium dioxide (TiO<sub>2</sub>) but is not a biocide itself. However, UV light on TiO<sub>2</sub> produces the natural hydroxyl cleaning molecules that in turn kill pathogens. That is why it is considered a biocide just like milk. For that reason, it is not claimed that the coating disinfects. The coating remains active as long as the sun shines and is not used up. TiO<sub>2</sub> is an inert substance that does not react with anything. It has been in toothpaste, sunscreen, candy, sweets and hundreds of foods for over a century.

Dangerous? In the greenhouse, 1.4 grams of nano-TiO<sub>2</sub> coating is sprayed on 100 m<sup>2</sup> of glass. That is 14 mg/m<sup>2</sup> and those particles are firmly attached to the glass. A 35-year-old TiO<sub>2</sub> dust inhalation study showed that rats inhaled 250 mg/m<sup>3</sup> of TiO<sub>2</sub> dust daily for 2 years. At 50 mg/m<sup>3</sup> daily, no harmful effects were observed. The exposure ratio is lost when the glass coating was applied once with 14 mg of TiO<sub>2</sub> on 1 m<sup>2</sup>. All studies concerned TiO<sub>2</sub> dust. The coating solution is an invisible suspension and does not come off the glass.

There are beautiful solutions. Are we throwing the baby out with the bathwater?



# Belangrijke opmerkingen bij het gebruik van de coating

- The coating works best in closed greenhouse cultivation.
- Ventilation reduces the effect of the coating (disease pressure).
- Only apply to dry windows. Applying to dirty windows is also possible and removes algae, but the coating disappears with the algae and dirt. Then apply again later.
- Applying to clean windows immediately provides light and temperature gains
- The coating is safe, but applying it with a face mask is safer
- NOTE: THE COATING HAS A POSITIVE EFFECT ON THE CLIMATE IN THE GREENHOUSE. BY ADJUSTING THE CULTIVATION METHOD, EVEN MORE BENEFIT CAN BE ACHIEVED.

# When is the Photocatalysis most effective



- Drainage of water through the coating,
- higher temperatures in the greenhouse and lower humidity are effective from mid-November to mid-April.
- Less effect in the summer In the first year
- From the end of August up to 5% more light due to the absence of algae.
- The scientifically proven effects on fungi, bacteria, ethylene, fine dust and NO<sub>x</sub> were not included in this study

Lots of water drainage

# Conclusies

- Condens heeft in de winter resulteert in grote energiebehoefte in de kas
- Ventilatie in de winter kost warmte, energie en CO<sub>2</sub>. De coating spaart energie.
- Onder daglicht faciliteert de coating een blijvend fotokatalyse proces
- De coating heeft zelfreinigende werking op vuil, fijnstof, pathogenen, schimmels, en VOC's
- Algen verdwijnen, betere lichtdoorlatendheid en geen chemische middelen meer
- Schadelijke gassen waaronder NO<sub>x</sub> (belangrijk bij paprika's) worden eveneens geëlimineerd
- De reststoffen van het gehele proces zijn H<sub>2</sub>O en CO<sub>2</sub>
- De coating is goedkoop, eenvoudig aan te brengen en blijft tenminste 2 tot 3 jaar werken
- Terugverdientijd van enkele weken tot een paar maanden

## **Kweekmethoden aanpassen**

De positieve eigenschappen van de coating vraagt om nieuwe benadering van kweken. In de wintermaanden is dat volgens een gesloten kassysteem. Daarna afhankelijk van vegetatie, temperatuur en verdamping.