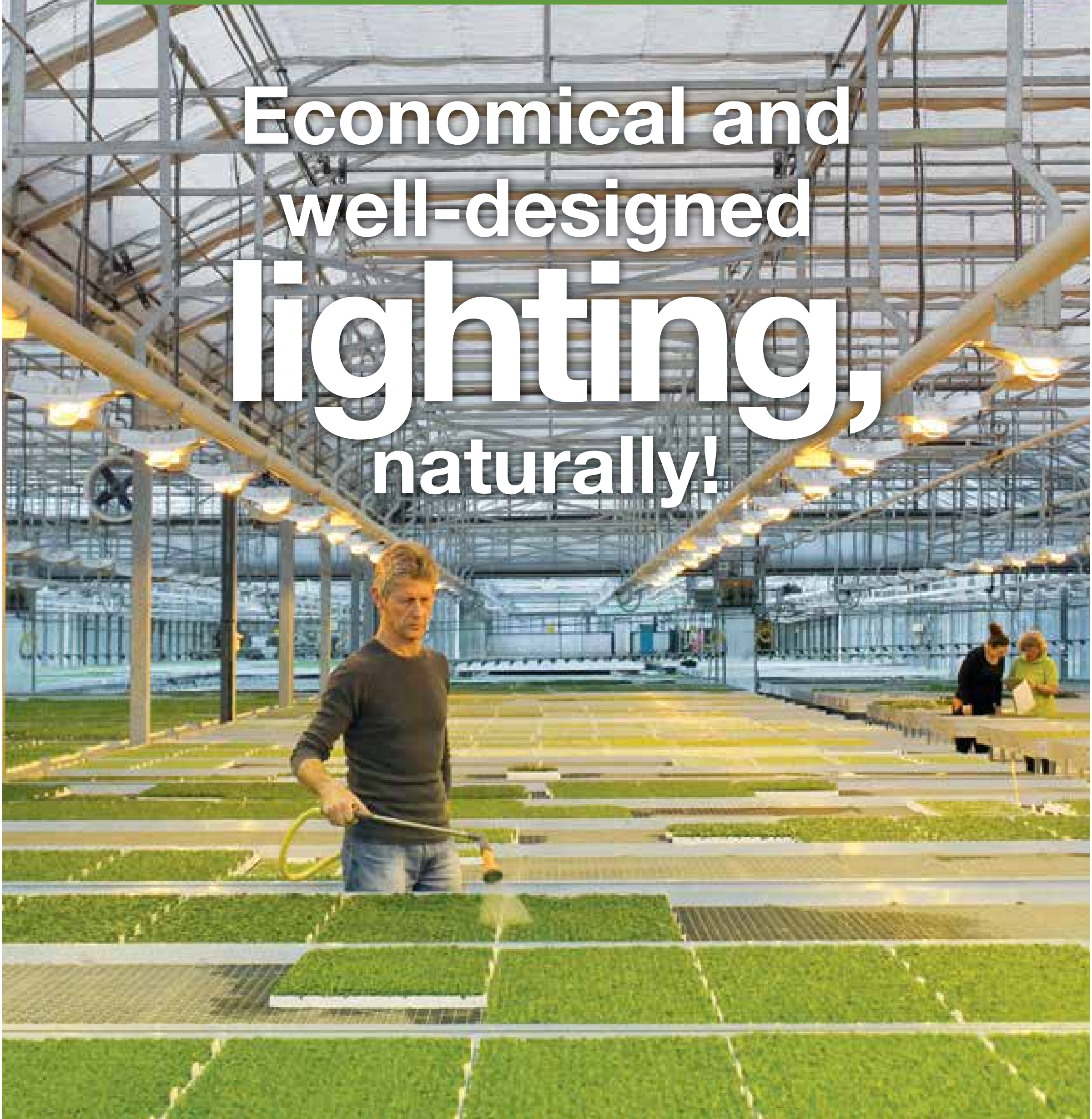
- Innovation guide for ornamental growers and landscapers -

Economical and well-designed lighting, naturally!



How to optimise your lighting, improve plant quality and increase profitability

PCS

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colophon

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Foreword

You can optimise lighting, improve plant quality and increase profitability

Light is an important growth factor, therefore supplementary lighting is essential in order to keep producing top quality plants all year round. Choosing the right lighting and setting the right lighting period increases plant quality and also has an effect on your energy consumption. This saves money and the environment.

This innovation guide from the PCS provides you with an overview of factors to be taken into account for energy-efficient and well-designed lighting. So your business will definitely benefit from using this knowledge. The guide helps you to identify the lighting needs of your crop and nursery, and make informed decisions. Your innovation pays off. Make maximum use of the practical knowledge that the PCS Ornamental Plant Research has built up in recent years, because we are of course happy to help you and the sector. Good luck!

Bruno Gobin
PCS Director

Sander Vercamer
PCS Chairman

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1

Know which light is essential for plants

Light is essential for the growth, development and flowering of plants. Plants react to the intensity, quality, duration and direction of light. In order for plants to make optimal use of light, we need to understand how plants interact with light.

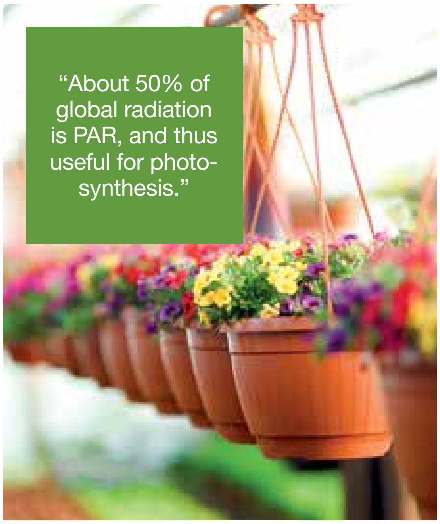
1.1. The sun, a source of light for plants

Our plants grow thanks to sunlight, which is available to us every day. This is the cheapest source of light and energy.

Due to its high surface temperature of 5,760°C, the sun emits radiation in the form of electromagnetic waves. This radiation is filtered through the atmosphere, and reaches our earth as global radiation.

GLOBAL RADIATION FROM THE SUN

Global radiation is situated in the wavelength range from 280 to 3,000 nm. Here we distinguish different types of light that are characterised by their wavelength. The wavelength is related to the radiant energy: the shorter the wavelength, the greater the energy content.



1. ULTRAVIOLET RADIATION (UV)

The part of the global radiation with the shortest wavelength is UV light (< 400 nm). About 3% of the radiation reaching the Earth, is UV light. This high-energy light can cause damage to plants, animals and people. Just think of the burning of our skin when we spend too much time in the sun without protection, but also of the degradation of plastics such as plastic films.

UV light is divided into:
- UV-C (< 280 nm)
- UV-B (280-315 nm)
- UV-A (315-400 nm)

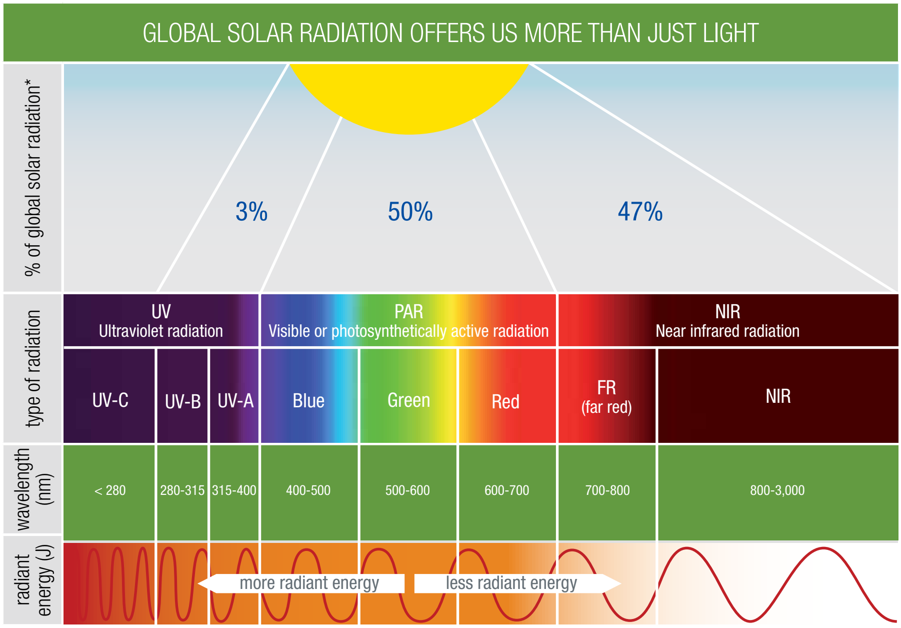
UV-C is almost completely absorbed by the ozone layer, minimising the harmful effects. UV-C light is known to be useful in horticulture for, among other things, disinfection of water, but irradiation of the crop is also possible for fungal disease control.

2. PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

About 50% of global radiation is in the wavelength range between 400 and 700 nm. This is the part of light that is visible to humans, but it is also used by plants for photosynthesis. Red and blue light are the most efficient for plant photosynthesis, but also help to control various plant processes such as germination, flowering, etc.

3. NEAR INFRARED LIGHT (NIR)

The part of global radiation that causes warming is about 47%, this is the near infrared radiation (700-3,000 nm). This part of the sunlight is hardly used by the plant, but causes the glasshouse temperature to rise.



* The proportions of different types of light are climate and region specific.

The part between 700 and 800 nm is the red light, and does contribute to morphogenesis, such as elongation of the plant.

LONG-WAVE RADIATION (FIR)

Far infrared (FIR) is radiation with a long wavelength, between 3,000 and 100,000 nm, which is not emitted by the sun but given off by objects with terrestrial temperatures.

LIGHT QUALITY AND LIGHT INTENSITY

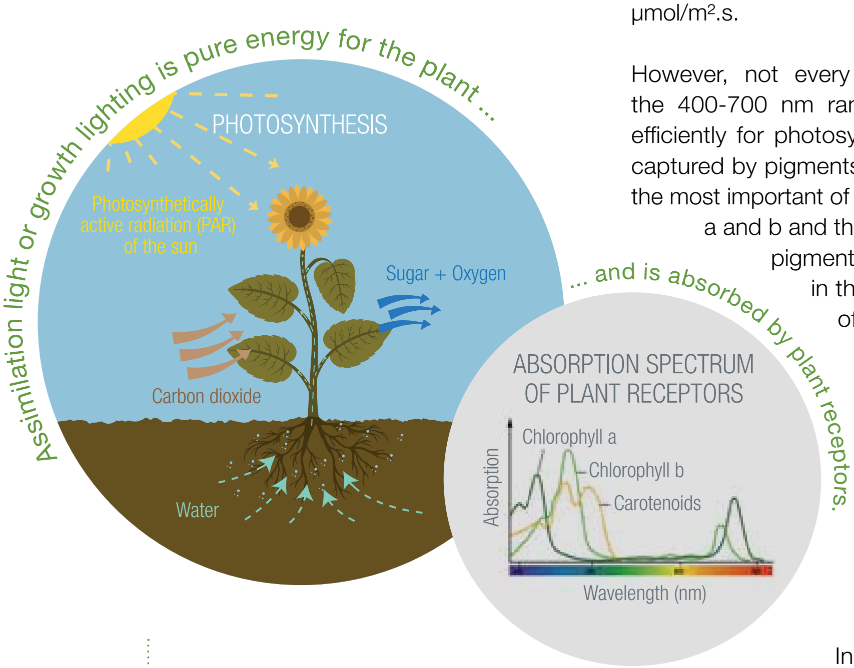
Both the light intensity and the light quality of global radiation reaching the Earth vary, and are influenced by various factors: the position of the sun, the latitude, the season, the time of day and the degree of cloud cover. For example, the proportion of UV radiation in summer months, when the sun is high, will be greater than in winter months, when the sun is low.

Proportions of certain light colours can also vary during the course of a day. For instance, the R/FR ratio remains fairly constant over the seasons, but at the end of the day, the proportion of far-red light increases, causing the R/FR ratio to fall in the evening.

Advice
By applying surface coatings, it is possible to increase the light transmission of glass, plastic sheets and films. Various shading products are also available on the market that can influence the intensity and quality of light in the glasshouse.

1.2. How much light does a plant need to grow?

The light requirement for sufficient photosynthesis and optimum plant growth always depends on the plant species and environmental factors.



Light is therefore essential for photosynthesis, and more specifically, light in the bandwidth of 400 to 700 nm. This radiation usable by the plant is called Photosynthetic Active Radiation (PAR) and is expressed in µmol/m².s.

However, not every light colour within the 400-700 nm range is used equally efficiently for photosynthesis. The light is captured by pigments in the chloroplasts, the most important of which are chlorophyll a and b and the carotenoids. These pigments mainly absorb light in the red and blue parts of the light spectrum. Red and blue light are therefore the most efficient colours for photosynthesis. Red light is used even more efficiently by the plant than blue light.

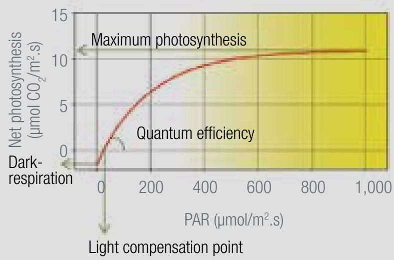
PHOTOSYNTHESIS AND LIGHT

Photosynthesis literally means synthesis by means of photons (= light). Light energy is used to convert CO_2 and water into sugars and oxygen. The sugars formed are the energy source for growth.

$$\underset{\text{Carbon dioxide}}{6\ CO_2} + \underset{\text{Water}}{6\ H_2O} \xrightarrow[\text{energy}]{\text{Light}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6\ O_2}$$

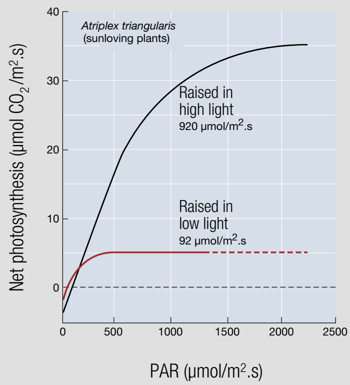
In addition to light, photosynthesis is highly dependent on the plant species and the environment in which the plant grows. Important environmental factors are CO_2 and temperature. Increased CO_2 concentration leads to increased photosynthesis. The CO_2 concentration in the air is normally 400 ppm, when it is increased to e.g. 1,000 ppm, this can result in 50% more photosynthesis. Temperature is especially important in processes where sugars are further converted into energy. At

LIGHT RESPONSE CURVE



Photosynthesis, measured at different light intensities, results in a light response curve. In the dark, there is respiration, net photosynthesis is zero at the light compensation point and the efficiency of photosynthesis is indicated by the initial slope of the curve.

PHOTOSYNTHESIS: GROWTH AT HIGH AND LOW LIGHT INTENSITIES



Taiz & Zeiger (2010)

Plants raised under low light intensities will have higher photosynthesis, the opposite is true at higher light intensities.

high temperatures, these processes are fast and, consequently, the rate of photosynthesis increases.

HOW MUCH LIGHT IS NEEDED FOR GROWTH?

Light is necessary for the growth (= assimilation of biomass) of plants. How much light a plant needs can best be determined by measuring photosynthesis at different light intensities. The result is a light response curve. A minimum of light must be present for growth (= light compensation point); when there is too little light, sugars are not formed but broken down (= respiration). Too much light is not a good thing either; from the point of view of photosynthesis, too much light is not more efficient (the curve flattens out to maximum photosynthesis), and then screening in the glasshouse may be needed to prevent damage to the plants due to too much radiation. Since the light response curve is not a straight line, not every extra µmol of light will produce the same amount of extra photosynthesis, and thus growth. Moreover, the light response curve depends on the light conditions in which a plant grows.

The light compensation point indicates the minimum amount of light needed at any one

LIGHT NEEDS FOR A NUMBER OF ORNAMENTAL CROPS

PLANT	MEAN DLI (MOL/M².DAY) IN THE GLASSHOUSE														
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Maranta, Saintpaulia, Spathiphyllum, Phalaenopsis	Minimum	Good	High	High	High										
Aglaonema, Bromelia, Dieffenbachia, Dracaena, Nephrolepis		Minimum	Good	High	High	High	High								
Caladium, Hedera		Minimum	Good	High	High	High	High	High	High	High	High	High			
Begonia (hiemalis), Sinningia, Schlumbergera		Minimum	Good	Good	High	High	High	High							
Cyclamen		Minimum	Good	Good	High	High	High	High	High						
Impatiens, Kalanchoe, Primula		Minimum	Good	Good	High	High	High	High	High	High	High				
Pelargonium peltatum		Minimum	Good	Good	High	High	High	High	High	High	High	High	High		
Fuchsia			Minimum	Good	Good	High	High	High	High	High	High				
Euphorbia			Minimum	Good	Good	High	High	High	High	High	High	High			
Hydrangea			Minimum	Good	Good	High	High	High	High	High	High	High	High	High	High
Chrysanthemum (pot), *Dianthus, Gazania, Gerbera, Lobularia, Pelargonium hortorum, Rosa* (pot), *Schefflera, Viola*			Minimum	Minimum	Good	Good	High	High	High	High	High	High	High	High	High
Aster, Catharanthus, Vinca, *Cosmos, Croton, Dahlia, Ficus benjamina, Lantana, Lavendula, Tagetes, Petunia, Phlox, Sedum, Verbena*				Minimum	Minimum	Good	Good	Good	High	High	High	High	High	High	High
Cut flowers (*Alstroemeria, Chrysanthemum, Gladiolus, Rosa*)					Minimum	Minimum	Good	Good	Good	Good	High	High	High	High	High

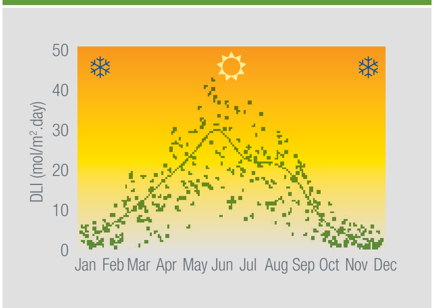
Minimum acceptable quality · Good quality · High quality

Torres & Lopez (2010)

Tip
Additional lighting can be controlled by DLI by measuring the light sum during the day and supplementing the deficit with assimilation lighting at night. If there was sufficient light during the day, there will be no need for supplementary lighting, resulting in savings.

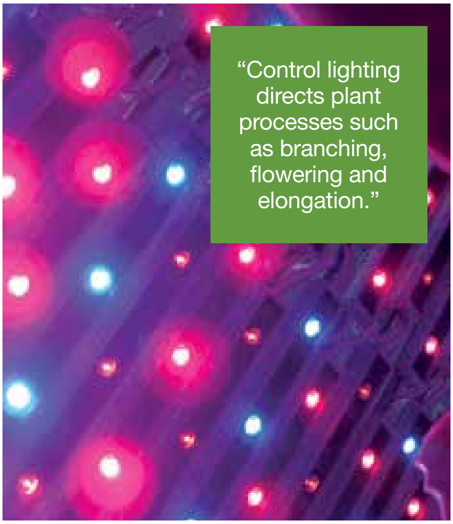
moment to ensure growth. Since we always have a day and a night, the light sum is especially important. Respiration (negative photosynthesis) takes place in the dark, and this must be compensated for by sufficient light during the day.
The total amount of light obtained in one day is called DLI (daily light integral), and is expressed in mol/m².day. The DLI determines the growth of the plant. A minimum DLI is required for growth. A higher DLI ensures more growth, but here too, the plant reaches a maximum at which extra light no longer adds growth or quality.

AVERAGE DLI IN BELGIUM



This graph shows the average DLI during the year in a glasshouse with 70% transmission in Belgium. Therefore, lighting will only be useful in the darkest months of the year.

1.3. How does a plant respond to light quality?



Supplying top-quality plants is a concern of every grower. In order to germinate, grow to a certain size or shape, or to flower, the grower can influence the plant quality with 'control' lighting. The light spectrum plays a crucial role in this.

PHOTORECEPTORS TELL THE PLANT WHAT THE LIGHT SPECTRUM IS

The role and effect of light on plant development is called photomorphogenesis. The spectral composition of the light will control the morphogenesis. To facilitate this, plants contain photoreceptors that are sensitive to certain light colours:

- The photoreceptor that absorbs the strongest red and far-red light, is phytochrome.
- Cryptochrome and phototropin are receptors sensitive to UV-A and blue light.
- UV-B light also has a specific receptor, called UVR8.

These receptors control various processes in the plant, such as cell elongation, leaf morphology, evaporation, day/night rhythms, flowering, rooting, branching, germination and such.

RED-FAR-RED RECEPTOR: PHYTOCHROME

Phytochrome exists in two forms, an inactive form (Pr) and an active form (Pfr). Under the influence of red light, the inactive form is converted to the active form; the reverse occurs under the influence of far-red light.

EFFECT OF LIGHT COLOURS ON THE PLANT*					
Type of light	UV-B (280-315 nm)	UV-A (315-400 nm)	BLUE (400-500 nm)	RED (600-700 nm)	FAR RED (700-800 nm)
Receptor	UVR8	cryptochrome, phototropin	cryptochrome, phototropin	phytochrome	phytochrome
MORPHOGENESIS					
Crop elongation	↓	↓	↓	↓	↑
Branching	↑		↑	↑	↓
Leaf surface	↓		↓	↓	↑
Leaf thickness	↑		↑	↑	↓
Stomata opening			↑		
PIGMENTATION					
Anthocyanins	↑	↑	↑	↑	
Flavonoids	↑	↑			
Chlorophyll	↓		↑	↑	
Carotenoids			↑		
GROWTH					
Photosynthesis	↓	↑	↑	↑	
Biomass	↓				
PHOTOTROPISM	↑		↑		
DEVELOPMENT					
Germination			↑↓	↑	↓
Flowering			↑↓	↑↓	↑↓

* In the presence of multiple colours of light.

Hemming (2004)

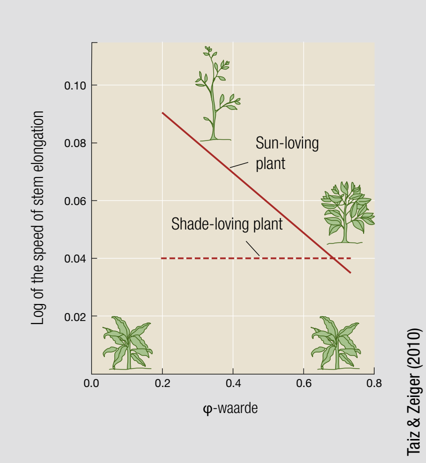
The relative amount of the active phytochrome will trigger different reactions in the plant. This means that the ratio of R/FR light is particularly important; a lot of red light will result in a lot of active phytochrome. We can therefore best characterise the light by determining the R/FR ratio. For this purpose, we use the narrow bandwidth of wavelengths for red and far-red light because the absorption maxima of phytochrome fall within them.

R/FR ratio

$$= \frac{\text{number of photons between 655 - 665 nm}}{\text{number of photons between 725 - 735 nm}}$$

This R/FR ratio is a simple approximation of the light being received. From the plant's point of view, it is better to determine the φ value. This is the phytochrome photo-equilibrium, or the amount of active phytochrome relative to the total.

STRETCHING IN THE SHADE



Sun-loving plants will stretch more and branch less at a lower φ value (more red light in the shade). Plants that are used to growing in the shade do not show this effect.

This φ value takes into account that the absorption spectrum of both forms of phytochrome overlap, so the two are always present together. For example, at 100% red light, not all will be converted to active phytochrome, but a fraction of inactive phytochrome will still be present. In addition, there is also a small absorption by phytochrome possible in the blue spectrum of light, which means the R/FR ratio remains the same, but the proportion of active phytochrome can be different, and so can the plant's reaction.

$$\varphi = \frac{Pfr}{Pr + Pfr}$$

The sunlight has an R/FR ratio of 1.2 and a φ value of 0.7. If additional red light is added to the sunlight, these values will increase (maximum φ value = 0.88). When plants grow in the shade or are under other plants, the fraction of far-red light will be higher, reducing the R/FR ratio and the φ value. This low ratio causes a well-known phenomenon: the plant will try to avoid the shade. It does this by elongating more, and therefore branching less. Some reactions caused by phytochrome, such as seed germination, can be triggered by very small amounts of light or short pulses of light. Phytochrome also plays a role in the day/night rhythm of the plant to induce flowering.

UV-A AND BLUE RECEPTORS: CRYPTOCHROME AND PHOTOTROPIN

The photoreceptors of the cryptochrome family sense the direction and amount of light. These photoreceptors play a role in the position of the crop during the day, but also in stomatal opening, inhibition of stretching and pigment synthesis. The other blue light receptor, phototropin, is responsible for phototropism or movement of the plant, which stimulates the plant to grow towards the light. It also regulates the opening of stomata and the movement of chloroplasts in the cell to protect them under high light intensities.

UV-B RECEPTOR: UVR8

UV-B is a very high-energy radiation that causes damage to cells. The UVR8 receptor plays a major role in minimising the damaging effect of UV-B. Thus, extra pigments are produced to capture the excess energy from the light, and the plant's recovery mechanism is increased.

Info
At sunset, the proportion of far-red light increases, therefore the R/FR ratio of sunlight can drop to 0.7.

1.4. Does a plant know the length of a day?

The response of plants to the length and time of day and night is called photoperiodism, and allows for seasonal events.

FLOWERING RESPONSE WITH LONG OR SHORT DAYS

The reactions of plants to day length are diverse: germination of seeds, formation of storage organs, initiation of dormancy (bud rest). However, photoperiodism is the most studied and best known in relation to flowering.

Flowering plants can be divided into three categories:

- Short-day plants: flowering only (or flowering is accelerated) when the day is short.
- Long-day plants: flower only (or flowering is accelerated) when the days are long.
- Day-neutral plants: flowering is stimulated by factors other than day length.

Advice
Not all plants react in the same way to photoperiodic lighting, even if they belong to a certain group (short-day plants or long-day plants). Determining the necessary light intensity and light quality for photoperiodic lighting is therefore best done with a small trial.

Short-day plants flower in short days when night length is greater than the critical night length, while long-day plants flower in long days when night length is less than the critical night length. This critical day/night length is highly dependent on the plant, and also depends on the latitude where the plants grow.

The number of short or long days needed to induce flowering is also highly plant dependent. In addition, some plants need short days at first and then long days or vice versa to flower.

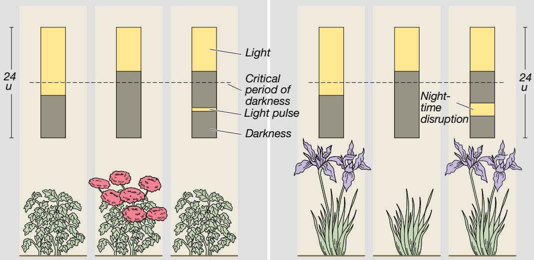
DETERMINING DAY LENGTH

Plants determine day length based on the night. Short-day plants keep track of time by measuring the dark period. When there is a long period of darkness, flowering occurs. If light is provided during the dark period, i.e. a night break, the plant remains vegetative. The same applies to long-day plants, which also measure the dark period. A short dark period ensures flowering, regardless of the length of the light period.

Moreover, photoperiodism is a reaction controlled by the phytochrome. High concentrations of active phytochrome (Pfr) and low concentrations of inactive phytochrome (Pr) cause long-day plants to flower while short-day plants do not. In many short-day plants, a night break is therefore only effective if the given amount of light was enough to convert sufficient inactive phytochrome to active phytochrome (sufficiently high φ value; high R/FR ratio). Phytochrome also plays this role in some long-day plants, but the control is more complex because a blue light receptor

FLOWERING IN SHORT-DAY, LONG-DAY AND DAY NEUTRAL PLANTS

SHORT-DAY PLANTS	LONG-DAY PLANTS	DAY-NEUTRAL PLANTS
flowering at short day length (night length > critical night length)	flowering with long day length (night length < critical night length)	



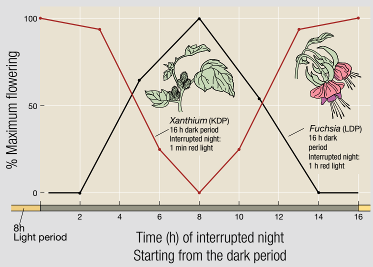
day length has NO IMPACT on flowering

e.g. *Chrysanthemum*, *Kalanchoe*, *Poinsettia*, violet	*e.g. summer flowers, Petunia, carnation, Cyclamen*	*e.g. sunflower, rose, Pelargonium*

Taiz & Zeiger (2010)

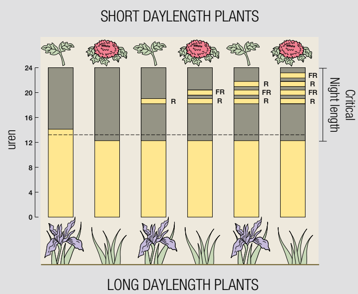
Short-day plants (long night) flower when the night length exceeds a critical dark period. An interruption in the dark period by a light pulse (night break) prevents flowering. Long-day plants (short night) flower when the night length is shorter than a critical dark period. With some long-day plants, reducing the dark period with a night break can bring about flowering.

NIGHT BREAK MOST EFFECTIVE IN THE MIDDLE OF THE DARK PERIOD



The time of the night break determines the flowering response. During a long dark period of 16 hours, a night break will cause long-day plants to flower, while short-day plants remain vegetative. In both cases, the effect is greatest when the night break falls in the middle of the dark period.

FLOWERING RESPONSE WITH RED (R) AND FAR RED (FR) LIGHT



Taiz & Zeiger (2010)

Effect of phytochrome on flowering: in short-day plants, a night break with red light will prevent flowering; if far-red is given, flowering will still occur. With long-day plants, the effect on flowering is reversed.

(cryptochrome) can also play an additional role.

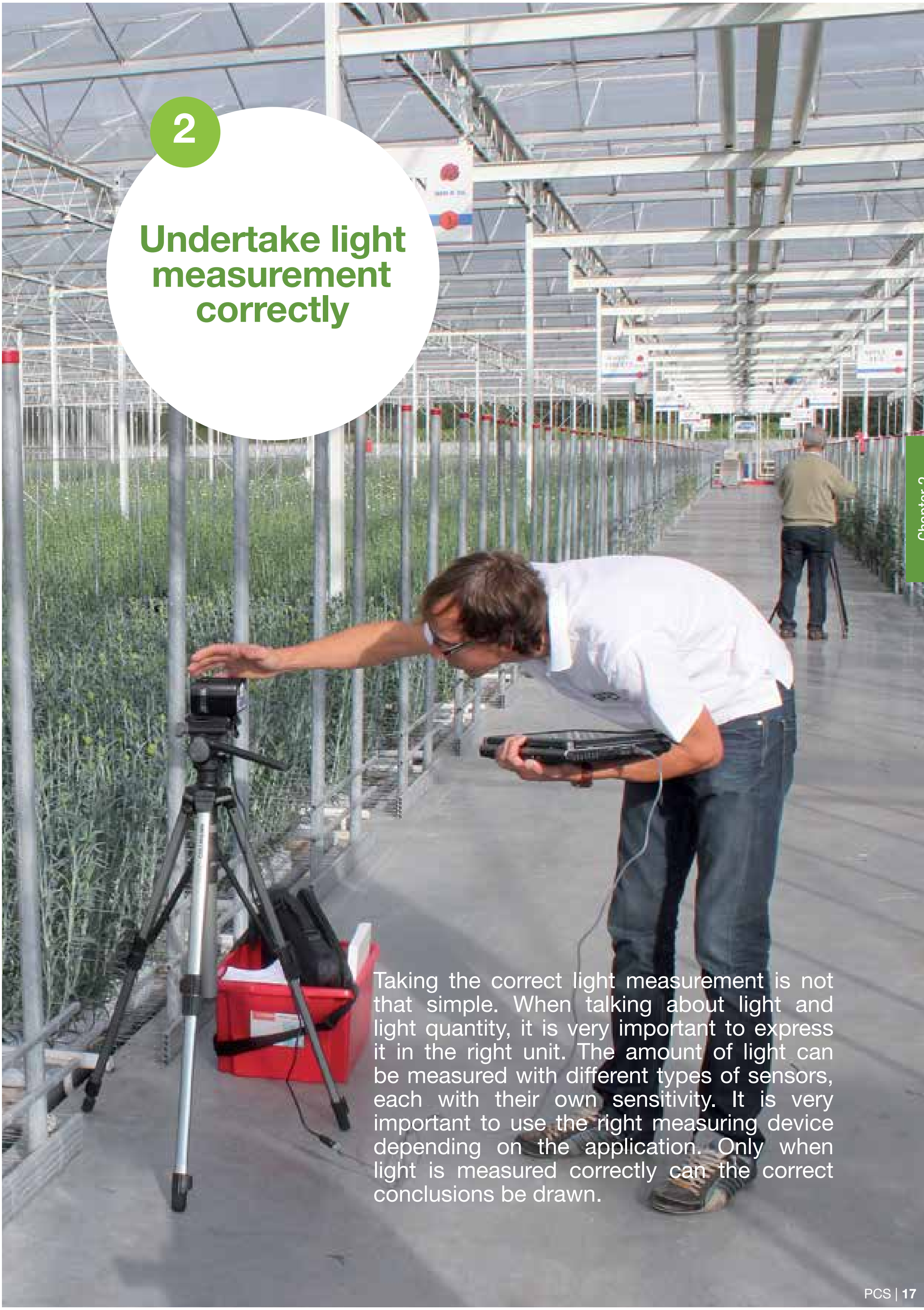
CONTROLLING FLOWERING WITH PHOTOPERIODIC EXPOSURE

The option of controlling flowering with a night break is used in horticulture. An example of how to prevent flowering in short-day plants by photoperiodic lighting at night is given on page 35.

The timing of the night break is critical to its success. For both long- and short-day plants, the night break is most effective in the middle of a 16-hour dark period. Only low light intensities (from 2 μmol/m².s) for 2 to 4 hours are required for this night-time break. Cyclical exposure is also possible as an alternative to a continuous night-time interruption. For example, lamps can be switched on for 6 minutes, and off for 24 minutes for a period of 4 to 6 hours during the night.

Focus: know which light is essential for plants

1. The light useful for photosynthesis is located between 400 and 700 nm (photosynthetically active radiation or PAR).
2. Plant growth is light-dependent: when there is too little light, growth is reduced; supplementary lighting can be useful in periods when there is little light.
3. A plant determines day length by measuring the length of the night. In the case of short-day and long-day plants, adjusting the night length can influence flowering.



2

Undertake light measurement correctly

Taking the correct light measurement is not that simple. When talking about light and light quantity, it is very important to express it in the right unit. The amount of light can be measured with different types of sensors, each with their own sensitivity. It is very important to use the right measuring device depending on the application. Only when light is measured correctly can the correct conclusions be drawn.

2.1. Which sensors do you use to measure light correctly?

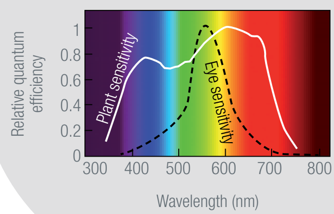
Various measuring sensors are available for light measurement. Always use the right device for the right purpose, only then can you draw the right conclusions from your measurement results.

LUX METER

The lux meter is the best known and most widely used instrument for light measurement. Most lamps are developed for applications aimed at the human eye. For these purposes, the intensity of the light is measured with a lux meter and expressed in lux (luminous flux/ surface area = lumens/m²). Lux is a photometric unit based on the average sensitivity of the human eye. This sensitivity is highest for yellow/ green light (555 nm) and decreases towards the longer (red) and shorter (blue) wavelengths.

plants have a totally different sensitivity to light colours than the human eye.

PLANT SENSITIVITY VERSUS EYE SENSITIVITY



However, plants have a totally different sensitivity to light colours than the human eye, they in fact benefit from the red and blue light. It is therefore a bad idea to take light measurements with a lux meter for horticultural applications.

Tip
The purchase of a PAR sensor is a worthwhile investment. A PAR sensor is available from €250.

PAR SENSOR

It is much better to use a PAR sensor. A PAR sensor measures light in the range of 400-700 nm, which is the photosynthetically active radiation, but, unlike the lux meter, it does not take the sensitivity of the human eye into account. This sensor measures the total number of 'photons' or light particles per unit of area and time (µmol photons/m².s) that are in the PAR range. So this device measures the amount of light that the plant can use to perform photosynthesis.

A PAR meter is the only reliable way to measure whether a light source is suitable for photosynthesis.

SOLARIMETER

A sensor that is present in most horticultural nursery weather stations, is the solarimeter. This sensor, which is used in meteorology, measures the radiant energy between 300 and 3,000 nm. That is why it is sometimes called a global radiation pyranometer. The measurement principle is based on a black surface that heats up when sunlight hits it. The temperature differences achieved in relation to a reference surface are a measure of the radiation intensity. Since no specific filter is present, it gives the energy of the radiation per unit area. This is expressed in W/m².

OVERVIEW OF LIGHT AND RADIATION METERS					
MEASURING DEVICE	LUX METER	PAR METER	SOLARIMETER	PYRGEOMETER	SPECTRORADIOMETER
Measurement	Brightness	Photon density for photosynthesis	Global radiation	Long-wave radiation	Light spectrum
Image					
Unit	lux	µmol/m².s	W/m²	W/m²	µmol/m².s.nm
Measurement range	400-700 nm	400-700 nm	300-3,000 nm	4,500-42,000 nm	200-1,000 nm
Appraisal	Human eye	Photons Photosynthesis	Radiant energy	Radiant energy	Photons per wavelength
Note	Not suitable for light measurements at plant level	Most suitable for checking how much growth light is being received	Ideal for use in weather stations	In combination with a solarimeter, this can be an aid in screen control	This meter is used for research only

This sensor is used to control climate computer processes: opening and closing screens, controlling assimilation lighting, irrigation, etc. But it is quite possible to have this control done by the PAR sensor based on measurements. Especially now that more and more shading is done with shading products and diffuse coatings, controlling the screens with a PAR meter in the glasshouse is a step forward. These meters are very sensitive to shadows, so it is better to install two PAR meters to average out the sun's elevation.

PYRGEOMETER

Energy losses (W/m²) due to radiation can be measured by a pyrgeometer or radiation meter. This sensor measures the long-wave heat radiation between 4,500 and 42,000 nm, and is used to measure the heat radiation from the glasshouse. It differs when the sky is clear or cloudy. In combination with the conventional measurement of the solarimeter at the weather station, the pyrgeometer can be a tool for more energy-efficient screen control. If the heat losses are greater than the incoming radiation, the energy screen can close sooner to save energy.

Maintenance
Have measurement sensors checked annually, and calibrated if necessary. Check them yourself too, and clean dirty sensors with a dry, clean cloth.

Advice
The PCS has a spectroradiometer and a portable PAR sensor. Do you have questions about the light spectrum and the light intensity of your lamps? Are you curious about which light spectra and intensities are retained by the covering materials on your glasshouse? Contact the PCS.

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SPECTRORADIOMETER

When we want to know the exact spectrum (wavelengths) of light emitted by a particular light source, we need to use a spectroradiometer. With this measuring instrument, the spectral distribution of light can be measured, and ratios between light colours can be determined. These measuring devices also have a wider measuring range. Depending on the type of device, it measures between 200 and 1,000 nm, and it gives us the number of photons or light particles per wavelength (µmol/m².s.nm).

These measuring devices are very expensive, but can be useful for research applications, for measuring light spectra from all kinds of light sources, including LEDs, or for understanding which light spectra are filtered out by the glasshouse's covering materials, films, screens or shading materials.

"A PAR meter is the only reliable way to measure whether a light source is suitable for photosynthesis."

KNOW HOW MANY MICROMOLES OF (GROWING) LIGHT IS DELIVERED

To have an idea of the amount of micromoles produced by your lighting installation, and to know its distribution over the crop, you can take measurements yourself. It is best to keep a few things in mind:

- Use a portable PAR meter to take the measurements.
- Plot a grid to check the uniformity of light distribution in the glasshouse.
- Take warm-up times for certain lamp types into account, such as high-pressure sodium lamps or energy-saving lamps. Therefore, switch the lamps on 30 minutes beforehand.
- Take measurements of your installation under low-light conditions: switch off other light sources, and measure in the evening or in the morning before the sun rises, or close blackout screens when taking measurements.
- The measuring device must not be colder than the ambient temperature, otherwise condensation will form on the sensor.
- Take the measurements at crop level and not just below the lamps, and at the same distance from the lamps for comparative measurements.
- Make sure the device is level for each measurement.
- Make sure that you are not too close to the sensor during the measurement to avoid shadows.

2.2. How to calculate with light?

In horticulture, we want to know how much PAR light our plants receive, which is why it is best to measure the light with a PAR sensor. If this is not available, you can use other measuring devices, but converting light values is not that easy. Especially since every light source also produces a different light spectrum, and conversion between the units is spectrum - and therefore light source - dependent.

FROM GLOBAL RADIATION (W/M²) TO PAR LIGHT(µMOL/M².S)

The amount of daylight in the glasshouse varies constantly, but as a grower, you rarely measure the light directly in the glasshouse. It is likely that a sensor located in the glasshouse will be influenced by shadow effects, pollution, or become overgrown by the crop. Therefore, the intensity of the natural growth light in the glasshouse is usually derived from measurements with the global radiation meter (solarimeter). This radiation is expressed in W/m². Converting from W/m² (global radiation) to µmol/m².s (PAR light) is not that simple. Throughout the year, about 50% of the global radiation falls in the PAR range (400-700 nm). On a cloudy day, this percentage of growth light will be higher than on a clear day.

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CONVERSION FACTORS FOR THE PAR ELEMENT

FROM	TO	SUNLIGHT	HIGH-PRESSURE SODIUM*
µmol/m².s	W/m²	0.219	0.201
W/m²	µmol/m².s	4.57	4.98
µmol/m².s	lux	54	82
lux	µmol/m².s	0.019	0.012
W/m²	lux	249	408
lux	W/m²	0.00402	0.00245

* These values apply to a 600 W high-pressure sodium lamp.
De Groote *et al.* (1992)

CONVERSION FACTORS FOR THE PAR ELEMENT

RADIATION SOURCE	µMOL/M².S PER W/M²
Solar radiation - diffuse	4.57
Solar radiation - clear weather	4.24
High-pressure sodium (600 W)	4.98
Light bulb	5.03
TL warm white	4.57
TL cool white	4.66

Hamlyn (2014)

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CALCULATION EXAMPLE: HOW MANY µMOL PAR LIGHT ENTERS THE GLASSHOUSE?

If we observe a global radiation of 200 W/m² with the solarimeter at the glasshouse weather station, how many µmol PAR light enters the glasshouse if it has an average light transmission of 70%?

- In a glasshouse with 70% light transmission, about 30% of the light is blocked. Of the 200 W/m², 70% will penetrate into the glasshouse:

  Radiation energy of sunlight in the glasshouse at plant level
  = 200 W/m² x 0.7 (70% transmission) = 140 W/m²

- About 50% of global radiation is in the wavelength range between 400 and 700 nm (PAR light).

  Radiation energy of PAR light in the glasshouse at plant level
  = 140 W/m² x 0.5 (50% PAR)
  = 70 W/m² PAR light

- With the conversion factor from the table, we can convert W/m² into µmol/m².s for sunlight. In the table you can see that this factor for diffuse sunlight is 4.57:

  Photons of PAR light in the glasshouse at plant level
  = 70 W/m² PAR x 4.57 (diffuse sunlight conversion factor)
  = 320 µmol/m².s

Decision: So at that moment, the plants therefore receive 320 µmol/m².s of light which is useful for photosynthesis.

Tip
In practice, light units are still all too often expressed in lux. Please note that to convert light values from lux to µmol/m².s, different conversion factors must be used, depending on the light source. So avoid measuring with a lux meter. It is better to use a PAR sensor.

HOW DO YOU CALCULATE THE RADIATION/ LIGHT SUM?

Intensity of radiation/light is the amount of radiation/light at one moment or in one second, i.e. the amount of radiation/light per unit of time. A meter that measures radiant energy, such as a solarimeter, expresses the intensity in W/m² or J/s.m². A PAR sensor measures the intensity in µmol/m².s. If we want to calculate light sums, the intensity is multiplied by the time factor:

Radiation sum (J/m² or MJ/m²)
= radiation intensity (W/m²) x time unit (s)

Light sum (µmol/m² or mol/m²)
= light intensity (µmol/m².s) x time unit (s)

Sometimes it is appropriate to know how much radiation or light there has been during the course of the day. In horticulture, daily light integral (DLI) PAR sums are increasingly used.

DLI (mol/m².day)

$$= \frac{\text{light intensity (µmol/m}^2\text{.s) x 86,400 s}}{\text{1,000,000}}$$

This is the total amount of growth light that the plant receives during one day. Depending on the daily light sum already achieved, assimilation lamps can be switched on or off. After a sunny day, for example, there may have been sufficient growth light, so that less lighting is needed.

HOW MUCH EXTRA LIGHT DOES ASSIMILATION LIGHTING PROVIDE?

CALCULATION EXAMPLE 1: WHAT IS THE PROPORTION OF ASSIMILATION LIGHTING?

High-pressure sodium lamps (600 W), which produce 7,000 lux when measured with a lux meter, are used to provide supplementary lighting for 4 hours. 30% of the sunlight is blocked by the glass and structures of the glasshouse.

SITUATION 1: on a clear summer's day in June, a daily radiation sum of 20 MJ/m² is realised outside

1. Calculate the amount of PAR light at plant level:

A. Daily solar radiation sum in the glasshouse:

- 30% of the sunlight is blocked by the glasshouse:

Radiation energy of $_{\text{sunlight in the glasshouse at plant level}}$
= 20 MJ/m² x 0.7 (70% transmission)
= 14 MJ/m²

- About 50% of global radiation is in the wavelength range of PAR light:

Radiation energy$_{\text{PAR light in the glasshouse at plant level}}$
= 14 MJ/m² x 0.5 (50% PAR) = 7 MJ/m² PAR

- For the conversion to daily light integral (DLI) we use the conversion factor for bright solar radiation because we are dealing with a sunny day:

DLI $_{\text{sunlight in the glasshouse at plant level}}$
= 7 MJ/m² x 4.24 (bright sunlight conversion factor)
= 29.7 mol/m².day

B. Radiation sum through assimilation lighting in glasshouse:

Radiation intensity $_{\text{lux > µmol/m².s}}$
= 7,000 lux x 0.012 (high pressure sodium conversion factor)
= 84 µmol/m².s

Duration $_{\text{assimilation lighting}}$ (in seconds)
= 4 hours x 3,600 seconds = 14,400 s

Radiation sum $_{\text{assimilation lighting at plant level}}$
= 84 µmol/m².s x 14,400 s
= 1,209,600 µmol/m².day = 1.2 mol/m².day

SITUATION 2: on a dark day in March, the light sum outside is only 2.5 MJ/m².

1. Calculate the amount of PAR light at plant level:

A. Daily solar radiation sum in the glasshouse:

- 30% of the sunlight is blocked by the glasshouse:

Radiation energy of $_{\text{sunlight in the glasshouse at plant level}}$
= 2.5 MJ/m² x 0.7 (70% transmission)
= 1.75 MJ/m²

- About 50% of global radiation is in the wavelength range of PAR light:

Radiation energy$_{\text{PAR light in the glasshouse at plant level}}$
= 1.75 MJ/m² x 0.5 (50% PAR) = 0.88 MJ/m² PAR

- For the conversion to daily light integral (DLI) we use the conversion factor for diffuse solar radiation because we are dealing with a dark day:

DLI $_{\text{sunlight in the glasshouse at plant level}}$
= 0.88 W/m² PAR x 4.57 (diffuse sunlight conversion factor)
= 4.0 mol/m².day

B. Radiation sum through assimilation lighting in glasshouse:

Radiation intensity $_{\text{lux > µmol/m².s}}$
= 7,000 lux x 0.012 (high pressure sodium conversion factor)
= 84 µmol/m².s

Duration $_{\text{assimilation lighting}}$ (in seconds)
= 4 hours x 3,600 seconds = 14,400 s

Radiation sum $_{\text{assimilation lighting at plant level}}$
= 84 µmol/m².s x 14,400 s
= 1,209,600 µmol/m².day = 1.2 mol/m².day

Situation 1 continued:

C. Total light sum at plant level:

DLI $_{total}$
= 29.7 mol/m².day + 1.2 mol/m².day
= 30.9 mol/m².day

2. Calculate how much additional light (%) was provided by the lamps:

% PAR light $_{\text{assimilation lighting at plant level}}$
= (1.2 mol/m².day: 29.7 mol/m².day) x 100 = 4%

In this case, 4 hours of supplementary lighting with high-pressure sodium lamps only provide **4% extra PAR light** for the plant.

Situation 2 continued:

C. Total light sum at plant level:

DLI $_{total}$
= 4.0 mol/m².day + 1.2 mol/m².day
= 5.2 mol/m².day

2. Calculate how much additional light (%) was provided by the lamps:

% PAR light $_{\text{assimilation lighting at plant level}}$
= (1.2 mol/m².day: 4 mol/m².day) x 100 = 30%

In this case, 4 hours of supplementary lighting with high-pressure sodium lamps provide **30% extra PAR light** for the plant.

Conclusion: On sunny days, the proportion contributed by assimilation lighting is very small, so additional lighting is of no real use here. Controlling lighting based on radiation sums or DLIs allows for more efficient and energy-saving lighting.

CALCULATION EXAMPLE 2

How many µmol/m².s of PAR light are delivered by high-pressure sodium lamps (600 W) when 7,000 lux are measured with a lux meter?

High-pressure sodium $_{\text{lux > µmol/m}^2\text{.s}}$
= 7,000 lux x 0.012 (high pressure sodium conversion factor)
= 84 µmol/m².s

Please note: This conversion factor applies only to 600 W high-pressure sodium lamps. Other lamps require other conversion factors.

CALCULATION EXAMPLE 3

How many µmol/m².s of PAR light do the plants get if we measure 7,000 lux with a lux meter in the glasshouse during the day?

Sunlight $_{\text{lux > µmol/m}^2\text{.s}}$
= 7,000 lux x 0.019 (sunlight conversion factor)
= 133 µmol/m².s

CALCULATION EXAMPLE 4

If we speak of 80 µmol/m².s supplementary light with high-pressure sodium lamps (600 W), how many lux does this involve?

High-pressure sodium $_{\text{µmol/m}^2\text{.s > lux}}$
= 80 µmol/m².s x 82 (high pressure sodium conversion factor)
= 6,560 lux

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PAR MEASUREMENTS REMAIN THE MOST RELIABLE MEASUREMENTS FOR GROW LIGHTS

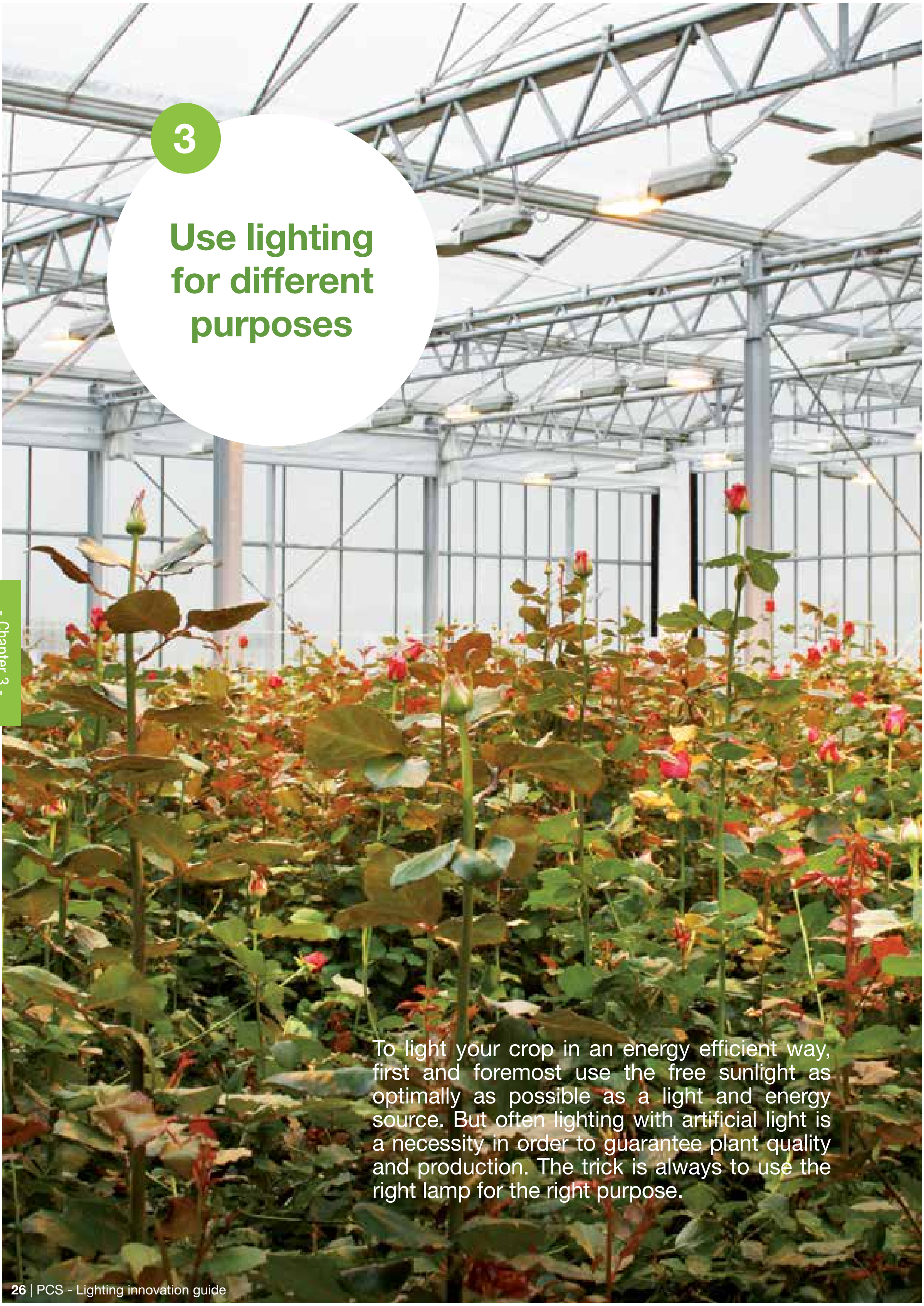
All too often, people speak in terms of 'lux' when talking about assimilation lighting. Yet PAR measurements give us the only reliable value if we want to know how much growth light is available to the plant. Conversion factors are available for a number of lamps that allow us to convert the light intensities to μmol PAR, useful for the crop.

WITH LED LIGHTING, IT IS ONLY POSSIBLE TO MEASURE WITH A PAR SENSOR

However, with the advent of LED lighting, the conversion of light values has become virtually impossible. After all, different types of light give us a completely different light spectrum. It is therefore impossible to give standard conversion values here. However, it is recommended to carry out the measurements immediately with a PAR sensor.

Focus: perform the light measurement correctly

1. Do NOT use a lux meter to measure light for horticultural applications. The best suited is a PAR-sensor, which measures the photosynthetically active radiation in μmol/m^2.s.
2. Measure the global radiation (W/m^2) with a solarimeter.
3. Calculation with light units is spectrum, and thus light source dependent! Different conversion factors apply depending on the light source.



3

Use lighting for different purposes

To light your crop in an energy efficient way, first and foremost use the free sunlight as optimally as possible as a light and energy source. But often lighting with artificial light is a necessity in order to guarantee plant quality and production. The trick is always to use the right lamp for the right purpose.

3.1. Which lamp types are available to light your crop?

When using artificial light, always carefully select the lamps that provide the required light intensity and light spectrum for the required purpose. The most common lamp types are listed below.

HIGH-PRESSURE SODIUM OR HPS LAMPS

Since the 1980s, high-pressure sodium lamps have become commonplace in horticulture in order to be able to market high-quality plants even in low light periods. These HPS (High Pressure Sodium) lamps, also known as SON-T lamps, are gas discharge lamps that emit a yellow/orange-like light when the sodium gas is energised. This gives a fairly wide light spectrum between 400 and 700 nm, which is useful for crop growth, but also provides a lot of extra heat.

The commercially available types of these sodium lamps differ in terms of wattage (400, 600 and 1000 W). There are lamps with an integrated reflector, but usually the reflector, which ensures the proper direction and distribution of the light, is attached to the luminaire.

An installation requires a substantial investment, and consumes a considerable amount of electricity. Through increased production, quality improvement and/or better scheduling of the product linked to higher prices, the required investment should pay for itself.

Before purchasing, please contact the supplier. They can draw up a lighting plan according to the requirements of your crop.

Because the optimum lighting is different for every crop. For example, the uniformity of the lighting for a single harvest crop such as cut chrysanthemum is very important. When growing cut roses, the grower is more likely to opt for the use of reflectors so that more light can penetrate to the young shoots at the bottom of the crop.

FLUORESCENT OR TL LAMPS

Generally speaking, fluorescent lamps, also known as TL lamps, are used in growth rooms or multi-layer systems, such as in *in vitro* production. The now established energy saving lamps are also fluorescent lamps.

"Remember that the cost of purchasing lamps is only one aspect, energy consumption is just as important"

Maintenance
Make sure that the light output is maintained, and check all lamps annually at the beginning of the season. The reflectors should also be cleaned regularly, more than 60% of all light reaching the crop is reflected light. The contamination and deterioration of reflectors therefore have a major influence on the performance of your installation.

Tip
Have a lighting plan drawn up by your installer beforehand, and get adequate advice about the options available. It is important that the fittings, reflectors, distribution and distance between the lamps and the crop are properly coordinated.

Info
With many lamp types, such as high-pressure sodium lamps, only a small part of the electrical consumption is converted into PAR light. A large part of it results in heat radiation.

THE COLOUR TEMPERATURE AFFECTS THE LIGHT SPECTRUM

KELVIN (K)	DESCRIPTION
2,000	sunrise and sunset high-pressure sodium lamp
2,800	light bulb
3,500	one hour after sunrise
4,000	TL-lamp cool white (840)
5,000	daylight
5,600	standard daylight
6,000	afternoon sun
6,500	clear blue sky
7,000 - 10,000	heavy clouds, shade north side

Energy-saving lamps, halogen lamps and LED lamps have a colour temperature between 2,700 K (warm glow) and 4,000 K (cold white glow)

Legislation
Production and sale of energy-intensive household bulbs, including the incandescent bulb, has been scaled back since 1 September 2009. From 1 September 2016, only bulbs with energy labels A and B will be allowed.

A fluorescent lamp is a lamp that emits light by energising a mercury vapour, the ultraviolet rays emitted react with the lamp coating to create visible light.
The light spectrum or the light colour emitted by the lamp is determined by the composition of the fluorescent powder contained in the interior of the tube. Thus, white light with different colour shades can be achieved. The lamps are therefore classified according to colour temperature. For applications in multi-layer systems, a colour temperature of 4,000 K (cool white type) is usually used. Compared to an incandescent lamp, these lamps contain less red light, which leads to a more compact crop growth.

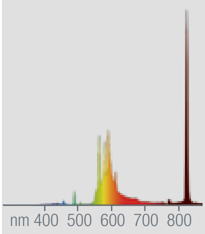
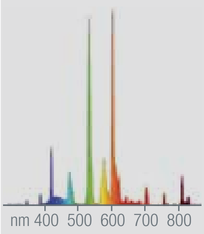
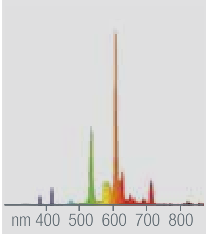
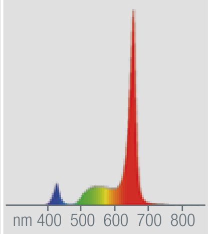
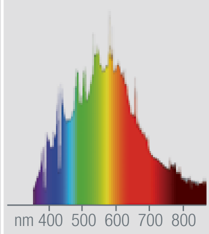
ENERGY-SAVING AND HALOGEN LAMPS

If no growth is intended, but control of plant development is required, e.g. the flowering period, this can be done with relatively low light intensities. Incandescent lamps were the ideal tool for this. Due to the low R/FR ratio, these lamps were highly suitable for influencing flowering and height among other things, in a number of crops. However, these lamps were more of a heat source than a light source: only 10% of the energy was converted into light. Since 2009, legal restrictions have been imposed on the production and marketing of these energy-intensive lamps.

Alternatives to incandescent lamps are compact fluorescent and halogen lamps. Energy-saving lamps have limitations for control light applications. Because of the warm-up time, they are less suitable for cyclic lighting. The absence of far-red light also makes them less suitable for cut flower production, where additional stem elongation can have a positive influence on crop length.

LED-LAMPS (LIGHT EMITTING DIODES)

In recent years, LEDs have also been introduced onto the market for horticultural applications, both for assimilation lighting and for growth control lighting. LEDs are available in various designs. For instance, there are LEDs on the market with an E27 fitting as a replacement for the incandescent or energy-saving lamps, long narrow luminaires as a replacement for fluorescent lamps in applications in multi-layer systems, but also LEDs that achieve higher light intensities and are hung as top lighting in the glasshouse as an alternative to high-pressure sodium lamps. LEDs produce light according to a different principle than conventional light sources. This involves a semiconductor chip containing two areas: a ‘p-area’ with a surplus of positive

OVERVIEW OF AVAILABLE LAMP TYPES FOR HORTICULTURE					
LAMP	HIGH-PRESSURE SODIUM LAMP	FLUORESCENT LAMP	ENERGY-SAVING LAMP	LED-LAMP	PLASMA LAMP
Example of light spectrum					
Image					
Application in ornamental horticulture	Supplementary assimilation lighting	Assimilation light in multi-layer systems	Growth control light for night interruptions	Various possibilities in terms of intensity and spectrum, both assimilation and growth control light	Simulation of sunlight in daylight-less conditions

charge carriers, and an ‘n-area’ with a surplus of negative charge carriers. When a current flows through the ‘p-n junction’, light is emitted.

LED light consists of basically one colour and is monochromatic. The wavelength, and thus the colour of the light, depends on the conductor material used. Nowadays, LEDs are available in colours covering the entire spectrum. Since the production of 1 μmol with red LEDs requires less energy than the production of 1 μmol with blue LEDs, it is best from an energy point of view to generate red light. In order to prevent excessive elongation, it may be necessary to add additional blue light. However, this depends on the crop, the duration of lighting, and the amount of blue light already received via sunlight.

“With the advent of LEDs, it is even more important to measure the light with a PAR sensor.”

White LEDs have also been developed. These consist mainly of an LED chip that generates blue or UV light and is covered by a fluorescent phosphor powder that absorbs the blue or ultraviolet light. The absorbed energy is released by the powder, emitting

Advice
Controlling morphogenesis is possible with LED light. However, the effect of LEDs on plants is very dependent on the plant species; research on other plants cannot be used as standard. Trials per plant species, sometimes even per cultivar, are therefore necessary.

Safety
The use of pure short-wave blue light is under discussion and is associated with an increased risk of eye damage and a negative effect on alertness and mood. This issue is also known in medical literature as 'blue light hazard'. Normally, the pupils contract when you look into bright light. This does not happen when using only blue light because the eye does not immediately recognise this type of light.

FULL-SPECTRUM LAMPS

More and more attention is also being paid to full-spectrum lamps. These are lamps that approach the light spectrum of the sun, such as plasma lamps, but they can also be fluorescent lamps or LEDs.

more or less white light, just like fluorescent lamps. White light or arbitrary mixing of colours can also be created by mixing light from red, green and blue LEDs in the proper proportion. If production operations or other work has to be carried out under the LEDs, it is advisable to choose a type that also contains white light. This type will be slightly less efficient, but with only blue and/or red light, the plant colour cannot be estimated. White light is also much more pleasant to the eyes.

PLASMA LAMPS

The production and development of the plasma or sulphur lamp has been halted for a long time, but a few companies are currently working on the further development of this lamp. Plasma lamps produce a spectrum identical to sunlight, including UV-A and UV-B light, and are therefore also called artificial sunlight. Plasma light is created by heating mainly sulphur with a kind of microwave. This creates a liquid plasma, similar to the surface of the sun. Because there is no burning process, the lamp is said to have an extremely long life of up to 50,000 hours, and its luminosity does not deteriorate. However, these lamps are quite expensive and are mainly used to generate sunlight in rooms lacking daylight, and are currently largely used for research purposes.

3.2. Applications using assimilation lighting

In the winter months, the days are much shorter and light intensities lower, so both the growth rate and the quality of our plants can drop significantly. By using artificial light, it is possible to produce high-quality ornamental plants in this low-light period.

STIMULATING PHOTOSYNTHESIS

High-pressure sodium lamps are often used to promote photosynthesis, thus ensuring plant quality during the winter. This type of light has a broad spectrum and high heat production. An alternative could be the high light intensity LED lamp. LEDs mainly provide red and blue light, making them more efficient for plant photosynthesis. Due to the LEDs' limited heat production, additional heating is sometimes required to maintain the glasshouse temperature, which can be detrimental in terms of energy consumption.

LED as intermediate lighting in combination with high-pressure sodium lamps as top lighting.

Tip
Due to the lack of radiant heat, LEDs can be hung very close to the crop, or even within crops. But with heat-loving crops, it may be necessary to compensate for this loss of heat by heating.

TESTED: HYBRID LIGHTING IN CUT ROSE PRODUCTION

Rose production is strongly influenced by temperature, light level and day length. Cut roses are known as a very light-intensive crop that only reaches its photosynthesis saturation point at very high light levels - around 500 µmol/m².s according to Dutch research (De Hoog, 1998). The use of assimilation lighting is therefore necessary to produce high-quality flowers all year round. When rose production evolved in the 1980s from growing in open soil to growing in substrate under lighting, originally lighting levels of 30 µmol/m².s were used. But these light levels were soon raised to over 100 µmol/m².s. The necessary electricity is also increasingly generated in CHP installations, and the heat produced in this way is stored in buffer tanks. With rising energy costs and increasing competition from imported flowers, lighting efficiency is being questioned.

"Use of assimilation light in rose production can greatly increase production in the winter period."

The arrival on the market of LEDs for horticultural applications prompted a series of lighting trials. The first trials with LEDs were started at the PCS in 2008 in the production of *Rosa hybrida* 'Avalanche', then still with water-cooled LED systems with red and blue LEDs. The absence of radiant heat did not improve the energy

Tip
In addition to increased production and better quality, the use of assimilation lighting can also lead to a flattening of labour peaks, which is an advantage, especially on larger nurseries.

PRODUCTION FIGURES *ROSA HYBRIDA* 'AVALANCHE'	HPS	HPS + LED
Number of stems / m	*191*	*194*
Average length (cm)	*68*	*67*
Average weight (g)	*30*	*32*
Average biomass (kg)	*5.7*	*6.2*

Production figures from 01/09/10 to 31/03/11.

efficiency of this application. This led to a switch to hybrid lighting: a combination of high-pressure sodium lamps (400 W / lamp) as overhead lighting and LEDs (45 W / lamps) as intermediate lighting. This was compared to traditional high-pressure sodium lamps (600 W / lamp). The lack of radiant heat makes it possible to hang the LED modules with lower light intensity, close to the crop.

The production was almost identical for the high-pressure sodium lamps + LED combination as for the high-pressure sodium lamps alone, and the quality of the flowers was also comparable. However, the total energy consumption for lighting was 2% more for the hybrid lighting compared with the high-pressure sodium lamps. So it did not result in any energy saving. In the meantime, the development of LEDs is continuing, these lamps are becoming more efficient and the cost price is likely to drop even further.

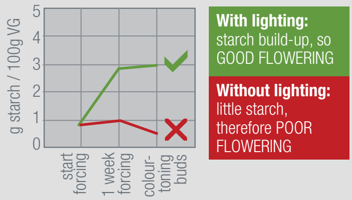
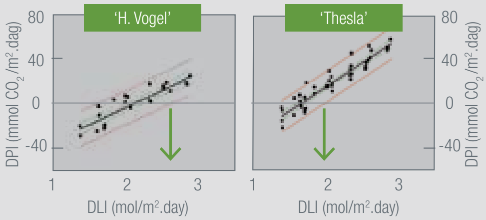
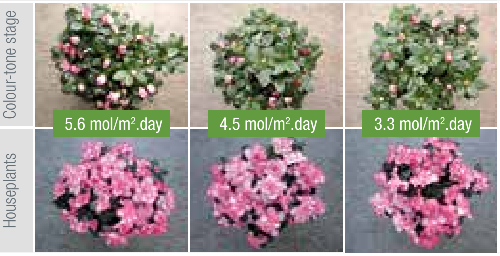
TESTED: LESS LIGHTING IN THE FORCING OF AZALEAS

During forcing, vegetative azaleas are brought into flower. This is necessary in order to sell beautiful flowering azaleas. In the winter months, lighting is a necessity when forcing these plants. Plants that are not exposed to light cannot photosynthesise sufficiently, so no starch reserves are produced during forcing. Unlit plants will therefore not flower sufficiently for the consumer.

Traditionally, azaleas are lit using high-pressure sodium lamps for 16 to even 24 hours. Since the energy costs for lighting have risen sharply in recent years, the possibility of shortening the lighting duration was investigated. The amount of light needed by azaleas to photosynthesise and build up starch was therefore examined. Photosynthesis measurements showed that this is cultivar dependent. The early cultivar 'H. Vogel' (from 7°C cooling) needs more light than the late cultivar 'Thesla'. Moreover, experience has shown that mature plants, plants that were given enough cold to break flower bud dormancy, need much less light than immature plants that really need to be 'forced' and therefore require more light to ensure the same quality of flowering.

Additional lighting can provide better quality, but there is also a limit to this. Various DLIs, have shown that the flowering quality no longer increases, despite the extra lighting. The flowering time can only be varied by a few days between the minimum light requirement and 16 hours of lighting. With a difference between 3.3 mol/m^2.day and 5.6 mol/m^2.day, this can be 2 to 3 days on average. However, this is not the overall case. The less mature the plant, the greater the chance of noticing a difference in early flowering.

TESTED: LESS LIGHTING IN THE FORCING OF AZALEAS

Is lighting necessary for flowering?		Yes, in the winter months, lighting is a necessity when forcing these plants.
What happens when azaleas get less light?		With the right cultivar and sufficient maturity, less lighting can be used, which results in energy savings.
Does extra lighting always result in more flowering?		Not always, additional lighting can provide better quality, but there is a limit to this as well. So don't apply light for more than necessary and save energy.

Top: Forcing azaleas 'H. Vogel Nordlicht' (from 7°C cold store): lighting during the first week ensures the build-up of starch in the leaves, which is necessary to guarantee further flowering. **Centre:** Measurement of the daily photosynthesis sum (DPI) at different daily light sums (DLI) shows a clear difference in light requirement between 'H. Vogel' and 'Thesla'. 'H. Vogel' (from 7°C cold store, early production) appeared to need a minimum of 2.7 mol/m².day to carry out enough photosynthesis during the day (green arrow), while this was only 2 mol/m².day for 'Thesla'. But plants also differ from each other; the red lines indicate how 95% of the plants react. The minima have therefore been calculated here so that they apply to 95% of the plants studied (Christiaens *et al.*, 2014). **Below:** Forcing azaleas 'H. Vogel Huelsten' from 7°C cold store) under different DLIs, i.e. different number of lit hours. The highest light sum is in the colour-toning stage some two days earlier, but the final flowering quality in the living room does not differ for the three light sums.

So there is no need to always monitor for 16 hours during forcing. The lighting can be controlled to a certain DLI. The light sum can be measured during the day, and any shortfall can be compensated for at night with assimilation lighting.

In January 2015, in such a trial at the PCS, high-pressure sodium lamps were lit for an average of 6.6 hours per day at an intensity of 75 µmol/m².s to achieve a DLI of 3.3 mol/m².day.

3.3 Applications using growth control lighting

"Incandescent bulbs are being replaced by energy-saving bulbs or LEDs."

Photoperiodic lighting is used in horticulture to artificially extend the length of the day. As a result, either flowering is stimulated, or the plant is deliberately kept vegetative. Only low light intensities are required for this application. Until recently, incandescent lamps were the standard for photoperiodic lighting. But by necessity, ornamental growers are now replacing them with more sustainable lamps, such as energy-saving lamps or LED lamps with low light intensities.

STIMULATING FLOWERING

In the case of long-day plants, lighting with photoperiodic control light can lead to a reduction in production time and make scheduling easier to programme. The previously used incandescent lamp, with its relatively high production of red and far-red light, was an ideal and cheap instrument to influence flowering and also stem elongation in these crops.

In the meantime, the use of more energy-efficient lamps, such as energy-saving bulbs and LEDs, is becoming a necessity. The spectrum of the energy-saving lamps lacks this red and far-red light, which turns out to be a disadvantage for a number of crops. The warm-up time is also a disadvantage; most energy-saving lamps only reach the desired light intensity a few minutes after they have been switched on. This makes the lamps less suitable for short cyclic lighting. This can be remedied by lighting over a longer, sometimes continuous, period. The advantage of LED lamps is that you have the opportunity to 'play' with colour spectra and colour ratios, and thus the R/FR ratio of the intended application.

TESTED: BLOOMING OF *RANUNCULUS* WITH ENERGY-SAVING LAMPS AND LEDS

In order to bring *Ranunculus* into flower on time, ornamental growers sometimes use photoperiodic control light. If required, this can be done with LEDs. A comparative trial by the PCS, in which the use of energy-saving lamps and LEDs with only red and blue light was compared to unlit plants, proves this. The difference in light spectra between the lamps used did not produce any notable differences in flowering time or plant structure. However, early flowering was clearly achieved when the day was extended with continuous lighting from midnight to sunrise. Both LEDs and energy-saving lamps therefore offer a good alternative to the incandescent lamp in this situation.

Ranunculus unlit versus lit with energy saving lamps.

Advice

There may still be many crops and applications in which the lighting strategies can be further optimised. Effects are often crop-dependent, and cannot simply be copied for another crop. Trials per plant species, sometimes even per cultivar, are therefore necessary.

KEEPING THE CROP VEGETATIVE

For short-day plants such as *Chrysanthemum, Kalanchoe*, etc., day lengthening is used during the winter period to keep them vegetative. Under natural daylight conditions, these plants would immediately begin to flower in the winter period. This is not always desirable.

“For photoperiodic lighting, lamps with low light intensities and thus low wattages are sufficient.”

TESTED: *CHRYSANTHEMUM* CUTTING PRODUCTION WITH ENERGY-SAVING LAMPS AND LEDs

In *Chrysanthemum* production, incandescent lamps were used to prevent the mother plants from forming flowers in autumn. In practice, when switching to energy-saving lamps, it turned out that there were some problems with bud formation. As a possible alternative, LEDs were therefore trialled alongside incandescent and energy-saving lamps. Incandescent lamps (150 W / light) were included in the trial as a control and switched on in a cyclic regime (10 min on / 20 min off), the energy saving lamps (30 W / light) and LED's (18 W / light) were also used in a cyclic regime, 15 min on /15 min off. This research showed that more budding still occurred with the energy-saving lamps. The absence of red light also resulted in less stem elongation, which is not really desirable in cutting production. When LEDs were used with only red and blue light, i.e. without far-red, there was noticeably more budding. However, when far-red light was present, the result was comparable to that of incandescent lamps. Thus, the effect of far-red here was not what was theoretically expected (see page 14). So this trial provided us with surprising results. This indicates that small trials are certainly necessary to test the theory before making any investment.

- Chapter 3 -

3.4. Applications without daylight

Top left: Production layer under mobile benching lit with LEDs. **Top right:** Growth room with fluorescent lamps. **Bottom left:** Tissue culture room with fluorescent lamps. **Bottom right:** Forcing of tulips under LED light.

USE WITH *IN VITRO* AND *IN VIVO*

In *vitro* plants in growth rooms and *in vivo* plants in multi-layers, are grown without daylight. The grower can choose between fluorescent and LED lamps. With LED, the optimum light recipe can be composed, which is useful for controlling plant quality.

In vitro plants have been grown without daylight in a room with fluorescent lamps for years. For *in vivo* plants, the concept of a room without daylight is still in development. But with the advent of LED lighting, research is being done to make this possible. In the absence of daylight, however, the effects of LEDs can differ significantly from those in the presence of daylight, because the proportions of the light colours are not affected by natural light. For example, extra blue light during daylight will result in more compact plants, while a daylight-less system with only blue light will result in more elongated plants. For applications in a daylight-free room, LEDs offer more possibilities than fluorescent lamps for controlling plant development.

TYPES OF SYSTEMS

In a densely built-up yet highly fragmented Flanders, expansion in glasshouse horticulture is not always achievable. A more efficient use of space, such as multi-layer production, can therefore provide a solution. By growing more plants in the same glasshouse area, production capacity can be increased, but multi-layer production also reduces one of the biggest fixed costs per unit produced, namely heating.

When we think of applications without daylight, we immediately think of the closed multi-layer systems. But a second production layer can also be built in the glasshouse under the existing tables, where there is also no, or minimal daylight. Besides *in vitro* applications, in practice, several companies have already switched to a multi-layer production system. Tulip growing and lettuce are the best known examples. Large-scale examples in the ornamental plant sector are limited. The installations range from basic, to highly automated. It is therefore very typical for multi-layer production that the application is very nursery-specific. A general calculation of the feasibility can therefore only be calculated per nursery.

A closed multi-layer system is a growth room where light, temperature, humidity and CO_2 concentrations are controlled to meet the optimal needs of the plant. These needs are always plant dependent. The great advantage of a growth room is that there are no external influences. There are no fluctuations in temperature, humidity or other uncontrollable factors. Thus, continuous year-round production is possible, with consistent plant quality.

However, multi-layer production also increases the consumption of water and fertilisers per m^2 of glasshouse area. A water recirculation and purification system is therefore unavoidable. The opportunities for multi-layer production lie mainly in the cultivation of crops with few production operations. We are thinking in particular of certain phases in the production process, such as flowering, rooting, hardening off, germination ... that can be controlled in a closed system.

TESTED: RED COLOURATION OF *CRYPTHANTHUS* WITH LEDs

Due to the absence of UV in sunlight during the winter period, it is not so easy to give *Crypthanthus* its typical reddish colour, but around Christmas and Valentine's Day, this colour is crucial. To solve this problem, PCS trialled various LED combinations on the

Advice
If you want more information about the possibilities of multi-layer production, please contact PCS.

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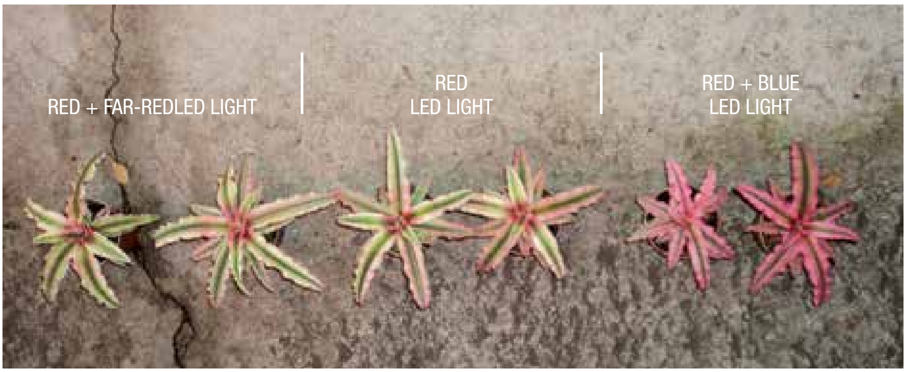


In order to deliver red-coloured *Crypthanthus* to customers on Christmas and Valentine's Day, growers can light these plants with red and blue LEDs.

crop. After a few weeks, the plants turned out red under a combination of red and blue LEDs, while this was not the case with the other light recipes (without blue). With LEDs in growth rooms, we can therefore colour *Crypthanthus* red and guarantee a good delivery to the customer around Christmas and Valentine's Day.

TESTED: ROOTING OF *CHRYSANTHEMUM* AND *LAVANDULA* CUTTINGS IN A GROWTH ROOM WITH LEDS

The first experiences with rooting *Chrysanthemum* cuttings were gained in growth rooms with different light recipes. The short rooting period is a phase in the production process that lends itself ideally to a multi-layer system. These trials showed that rooting of cuttings under LEDs is certainly possible in the absence of daylight and, through better climate control, is even faster than in the glasshouse. A higher light intensity (86 versus 43 µmol/m².s) and presence of blue light (here 12%) gave the best rooting. The plant habit was also good with these light recipes. When only red light was used, rooting was slightly less good and the crop showed noticeably more elongation.

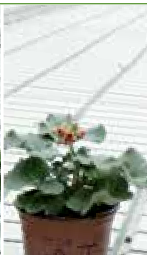
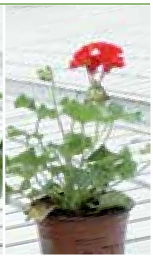
Further trials with *Chrysanthemum* and lavender, looking at the effect of far-red light, showed that with extra far-red better rooting can take place, but that the cuttings stretched severely. However, this stretch can be reduced by using a fraction of blue light. However, more research is needed, for instance into the influence of lighting on branching and bud formation, and the need for hardening off the crop.

ELONGATION AND ROOTING IN LAVENDER UNDERLEDs

RED	FAR-RED	ELONGATION	ROOTING
60 µmol/m².s	0 µmol/m².s	+	-
60 µmol/m².s	30 µmol/m².s	-	+
60 µmol/m².s	60 µmol/m².s	-	++

Rooting of lavender with extra far-red light improves rooting, but also makes the plants too stretched and generates fine leaves. Additional blue light can provide a solution for this.

ELONGATION AND LEAF COLOUR ON *PELARGONIUM* UNDER LEDs

	RECIPE 1	RECIPE 2	RECIPE 3	RECIPE 4	RECIPE 5
					
Red	85 µmol/m².s	33 µmol/m².s	50 µmol/m².s	33 µmol/m².s	33 µmol/m².s
Blue	15 µmol/m².s	67 µmol/m².s	50 µmol/m².s	67 µmol/m².s	0 µmol/m².s
Far red	0 µmol/m².s	0 µmol/m².s	0 µmol/m².s	67 µmol/m².s	67 µmol/m².s
Compactness	++	++	+	-	--
Leaf colour	++	++	+	-	-

TESTED: PRODUCTION OF BEDDING PLANTS IN LED-GROWTH ROOM WITHOUT DAYLIGHT

To investigate the influence of blue, red and far-red light on crop development, *Pelargoniums* were grown under 5 LED combinations of red, blue and far-red in the absence of daylight. Nicely compact, flowering plants with dark green leaves were achieved under recipe 1 (85% red and 15% blue) and recipe 2 (33% red and 67% blue). From a purely energy point of view, recipe 1 is a more interesting option than recipe 2. As soon as red light was added, much more elongation resulted. It is clear that, in the absence of daylight, by making limited changes to the light conditions, it is possible to produce a morphologically very different plant.

TESTED: NO DAYLIGHT FORCING OF AZALEA WITH LEDS

As mentioned earlier, during the forcing of azalea, sufficient light is needed for flowering. But can forcing also occur without daylight? Thus, crops could be forced in multiple layers. PCS trialled whether LED lamps in a closed production system offer an alternative to the classic high-pressure sodium lamps in the glasshouse. As part of the work programme, trials were conducted to see whether forcing under LED without daylight is as good as under high-pressure sodium lamps. As this was certainly the case, the search continued for the appropriate LED recipe. Numerous LED recipes with different ratios of red, blue and far-red light were trialled.

FORCING AZALEAS WITH NO DAYLIGHT

Forcing of azaleas: without additional lighting the plants flower later than under LED light in a closed production system and under high-pressure sodium lamps. There are no visible differences in time to flowering between LED light and high-pressure sodium lamps.

Each time, the differences turned out to be minimal. Moreover, responses to the same light recipe sometimes differed. Even with different batches of the same cultivar, the results of different LED recipes were different.

In general, we can conclude that a multi-layer system with LEDs can be used for the forcing of azaleas, and this can be done with red light only. Red LED light is the most energy-efficient, and is best used by the plant for photosynthesis.

–

Focus: Use lighting for different purposes

1. When using artificial light, always carefully select the lamps that provide the required light intensity and light spectrum for the purpose.
2. The purchase price of the lamps is one aspect, but how much energy the installation consumes is just as important.
3. Applications without daylight are best trialled for each crop.

4

The economic situation with lighting

The feasibility and success of lighting in ornamental horticulture depends on a number of factors: light distribution across the crop, light colours used, potential heat radiation, electrical efficiency, cost price, etc. This makes it difficult for the grower to make the right choice. Nevertheless, a sustainable solution can be found by observing a number of points of attention.

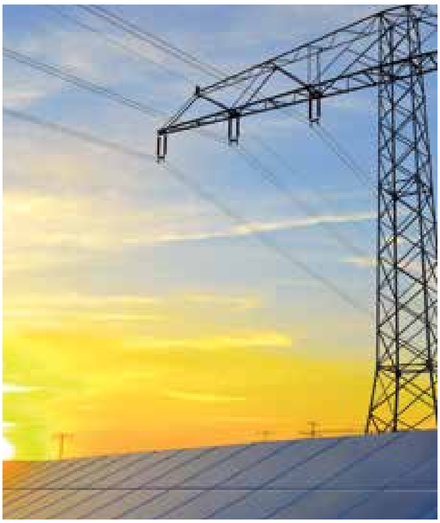
4.1. Managing energy consumption

Whether you generate your own energy or purchase it on the electricity market, it is still necessary to set up and maintain the lighting installation in the most sustainable way possible. You will reap the rewards of this in the years to come.

THE CROP VERSUS THE ENERGY CONTRACT

Assimilation lighting forms an important element of the energy balance of a protected ornamental nursery. Lighting provides heat and light for photosynthesis, but it also consumes energy. This may or may not come directly from primary energy sources such as gas or electricity from the grid. It is therefore important to make a well-considered decision to generate your own energy, to enter into a suitable contract on the energy market, or a combination of both. The type of energy contract that is required depends on the period and duration of lighting, and the electrical capacity of the installation. In many cases, however, the maximum amount of electricity that you can draw at any one time, also called the peak capacity, will be the determining factor. This information can usually be found on the energy bill. Smoothing out these peak power demands can result in a more advantageous energy contract through a well thought-out lighting plan and well-planned lighting regime.

Info
In the case of high-voltage installations, the energy supplier does not take the monthly peak capacity into account for invoicing purposes. The average consumption per quarter-hour or maximum quarter-hourly power is then decisive.



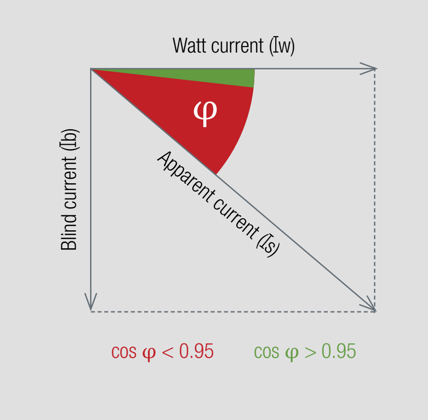
When negotiating an energy contract, the distribution network operator imposes a number of requirements on the consumer. For example, a public consumer must ensure that the total power consumed is constantly in phase with the mains voltage.

CONTROLLING THE POWER FACTOR

In some (traditional) lamp types, the current will not be stabilised by resistors, but with a reactive element, such as a coil or a capacitor. This is necessary to prevent losses caused by the joule effect, which causes heating of the power cables. However, since stabiliser coils or ballast resistors consist of coiled wires, heat losses will occur. These losses ensure that the power consumed from the electricity grid is always higher than the rated power indicated on the lamp. For example, a 600 W HPS light can consume 645 W.

When using alternating current, there are always two types of energy: active or active power and reactive or reactive power. When using electricity, only the active power is converted into mechanical energy, such as light. The reactive power is used for magnetism in electrical appliances, transformers, chokes etc.

POWER FACTOR



The reactive power is also transported by electricity grids and also causes heat losses in long cables

These active and reactive powers include a watt current (Iw), which is in phase with the mains voltage, and a reactive current (Ib), also called magnetising current. The latter lags 90° behind the wattage and the mains voltage. The wattage current and the reactive current can be added up vectorially to form the apparent current (Is) or the total current, which creates a phase angle Phi (φ) relative to the wattage current and the mains voltage. The apparent or total current is the current that actually flows through the conductors of the electricity circuit from the power generator to the consumer. This is also the same current that causes, among other things, heat development in conductors.

> “In many cases, the peak power will determine the energy cost.”

The figure shows that the smaller the reactive current, the smaller the angle φ will become. In practice, this is referred to as the cosine φ (power factor), which can lie between the values 0 and 1. The ideal situation is therefore when there is no reactive current. The angle φ is then 0° and the cosine of 0° is then 1.

When negotiating an energy contract, the distribution network operator imposes a number of requirements on the consumer. For example, a public consumer must ensure that the total power consumed is constantly in phase with the mains voltage. This then comes down to a cos φ that should not fall below 0.95. Users with too low cos φ can be fined by the distribution network operator. After all, these consumers oblige the energy suppliers to supply more power to the electricity grid than is strictly necessary, which entails additional infrastructure costs for the supplier. The reactive power must also be generated in the power plants. More power on the grid also results in additional heat generation during electricity transmission, and thus higher cable losses. A possible surcharge for bad cos φ and reactive current can be found on your energy bill under the term 'Surcharge for reactive consumption - kVARh'.

However, it does not have to come to that. You can limit your reactive energy, which largely determines the cos φ, by installing a capacitor battery in parallel to your lighting installation. This will save you even more on your electricity bill, as the surcharge for reactive consumption will disappear.

In addition, the current in your grid drops significantly, resulting in more power in your electrical installation. A capacitor battery obviously requires an investment, but one that pays for itself in full. Be sure to ask your lighting system supplier and have all the above parameters checked with new or renovated systems.

AVOID HARMONIC DISTORTION

Harmonic distortion of the mains voltage is a quality indication of the mains voltage, expressed in %. The higher the value, the worse it is. The voltage in Belgium has a frequency of 50 Hertz. Harmonic distortion occurs when frequencies other than this basic frequency are also present in the voltage. In most cases, these are multiples of 50 Hz, the so-called higher harmonics. Some inexpensive types of LED lamps and fluorescent tubes consume less energy than traditional lamps, but sometimes also generate more current harmonics, creating mains pollution and a low power factor. If such lamps are used, a surcharge for reactive consumption may also be applied. It is therefore possible that in the near future the limits on harmonics and mains pollution will become stricter. Always ask your installer for the necessary information.

Tip
Correcting harmonic distortion is not as simple as correcting the power factor with capacitors. Prevention at the source is therefore very important.

SWITCHING ON IN PHASES AT THE START

Plants need a certain period of adjustment after switching on the lighting before they can make the most of the extra light. This can sometimes take up to half an hour. It makes sense to install the lamps in different switching circuits, so that they can be switched on in phases. Just do not leave 500 or so lamps per hectare switched off for half an hour, it can save a lot of energy! This is of course easier to apply in new installations. The conversion of existing switching circuits does require some adaptation work.

WILL WE BE ABLE TO USE DC VOLTAGE IN LIGHTING IN BELGIUM IN THE FUTURE?

Since 2012, prototypes of DC voltage lamps and switchgear have been trialled on a practical scale in the Netherlands. This would result in significant energy savings, although it depends on the efficiency of the luminaire and lamps themselves. The power supply is via the central connection to a bus system with much thinner cabling. In addition, fewer components are required for installation. They have a longer life and are more durable and cheaper.

4.2. Making an informed investment in new lighting

Installing lighting in glasshouse horticulture requires considerable investment if done on a large scale. Ornamental growers should therefore not take any chances when purchasing lighting, as the installation of lighting has to be based on a good cost-benefit analysis.

IS LIGHTING ECONOMICALLY FEASIBLE?

It is necessary to thoroughly assess the payback period and economic added value beforehand. Lighting can pay for itself by ensuring better plant quality, more yield per square metre of production area, a shorter production period, or production in periods when prices are more favourable. The possibility of planning production and the associated spread of work throughout the year are also advantages of lighting. The glasshouse nursery can thus operate more efficiently.

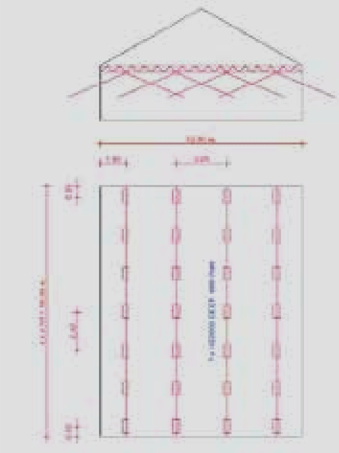
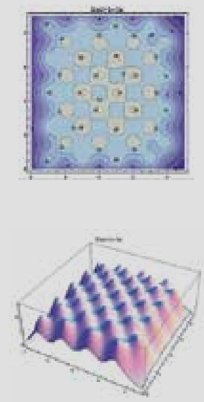
INVESTMENT AND OPERATING COSTS

On the other hand, of course, there are the investment costs for lamps, lamp fittings, cabling, controls, installation costs and any extra construction materials, high voltage supply, etc. and daily operating costs for electricity consumption, depreciation costs, cleaning and maintenance, lamp replacement and electronic components of the lighting installation. The installation, excluding the lamps, will normally be depreciated over 10 years. The depreciation period of the lamps, on the other hand, is highly dependent on the number of hours of use each year.

A cost, in addition to the purchase price, is associated with the lifespan of classic lamps. The manufacturer always specifies a certain number of hours of use during which the lamps retain a certain percentage of their radiation. After this number of hours, the efficiency of the lamp deteriorates significantly and it has to be replaced. Not only to maintain the lighting intensity, but also to avoid damage to electronic equipment. In addition to the lamp’s working life, a certain failure rate must always be taken into account.

It could be argued that one of the larger daily cost items is the energy consumption of the installation. In many cases, when there is no CHP on the nursery, the lighting will have a significant impact on the energy contract

Info
The service life of high-pressure sodium lamps is estimated at 10,000 hours, with LED this can be up to 25,000 hours.

LIGHTING PLAN HIGH PRESSURE SODIUM LAMPS	UNIFORMITY OF LED LIGHTING
	

Only with a correct lighting plan and a proper installation will the lighting achieve its full potential.

agreed. However, we should not consider this electricity consumption separately. The use of high-pressure sodium lamps, for example, also generates considerable heat in the glasshouse. Even though this source of heat may not be the most efficient way of heating, it does mean that at the time of lighting, a little less heating is required.

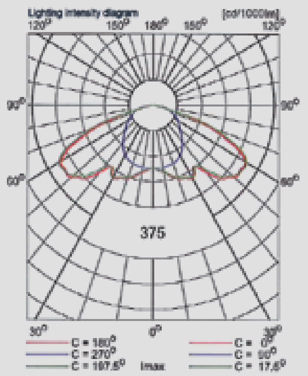
ADVICE AND LIGHTING PLAN

When installing assimilation lighting or photoperiodic lighting, it is best to seek advice from experts and suppliers. Only with a correct lighting plan and a good level of installation will the lighting achieve its full potential. Glasshouse horticulture will generally work with the same software applications as other industries when it comes to drawing up a lighting plan. That is why, even today, calculations are sometimes made in lux by the manufacturer. However, with the advent of LEDs, more targeted 3D software is being used specifically for production purposes.

POINTS TO CHECK

Uniform light distribution in the glasshouse is important to avoid quality differences in production. This must be taken into account in the lighting plan. In general, the ratio of minimum to maximum lighting intensity over the fully exposed area should be at least 0.7.

LIGHTING INTENSITY DIAGRAM
HIGH PRESSURE SODIUM LAMPS



In addition to the desired light intensity at plant level, the size of the installation will also depend on any spatial constraints, such as the glasshouse design, suspension height and other technical installations, such as screens and irrigation lines, distance to the crop, etc. Depending on these influencing factors, the most suitable fixtures and degree of coverage for each glasshouse and application will need to be considered separately.

The correct choice of luminaire type ensures that an optimal result is obtained with a minimum number of lamps. The fewer lamps that need to be installed, the lower the investment costs and the more natural light can still penetrate the glasshouse. The lamp therefore provides additional light, while the fixture ensures the spatial distribution of that light. Each luminaire type has its own characteristics and has its own application. This information is clarified in a lighting intensity diagram prepared by the manufacturer.

ANNUAL COST OF LIGHTING

The annual cost for the installation and lamps can be calculated as follows:

Annual installation cost
= I x [(a+i+n)/100]

I = investment cost of the lighting system (excl. lamps)
a = depreciation rate
i = interest on the investment amount
n = maintenance cost in % of new value

Annual cost of the lamps
= L x [(b/B) + (i+n)/100]

L = investment cost of the lamps
b = Number of hours of use per year
B = economic life of lamps
i = interest on the investment amount
n = maintenance cost in % of new value

Maintenance
Luminaires and reflectors become contaminated by dust and plant protection products. Therefore, have them cleaned regularly.

CALCULATION EXAMPLE

Suppose that an azalea nursery wants to illuminate 4,000 m² during the winter months (September to March) with a light intensity of 75 µmol/m².s or about 15 W/m² for 16 hours. What is the annual cost of the lamps?

1. Calculate the number of hours of use per season, and the lifespan

> Number of hours of use (b)
> = 212 days (Sept. to March) x 16 hours
> = 3,392 hours of use

If we know that the average economic life of a lamp is 10,000 hours:

> Lamp's lifespan
> = 10,000: 3,392
> = 2.95 year

The lamps must therefore be replaced after 3 years.

2. Calculate the number of lamps you need

Suppose the nursery was to use a 600 W lamp with an efficiency of 33% (a high pressure sodium lamp converts 25-40% of its used energy into light and the rest into heat).

> Number of lamps
> = (4.000 m² x 15 W/m²) / (600 W x 33%)
> = 300 lamps or 1 lamp per 13.5 m²

3. Calculate the installed power

> Installed power
> = 300 lamps x 645 W / lamp*
> = 194 kW

* A 600 W light easily consumes 645 W due to ballast losses etc.

Such connection will be provided as high voltage by the distribution network operator.

4. Calculate the installation costs

The installation cost for an installed capacity of 645 W (wiring, luminaire including 600 W lamp, €30 / lamp) will be approximately €245 / unit.

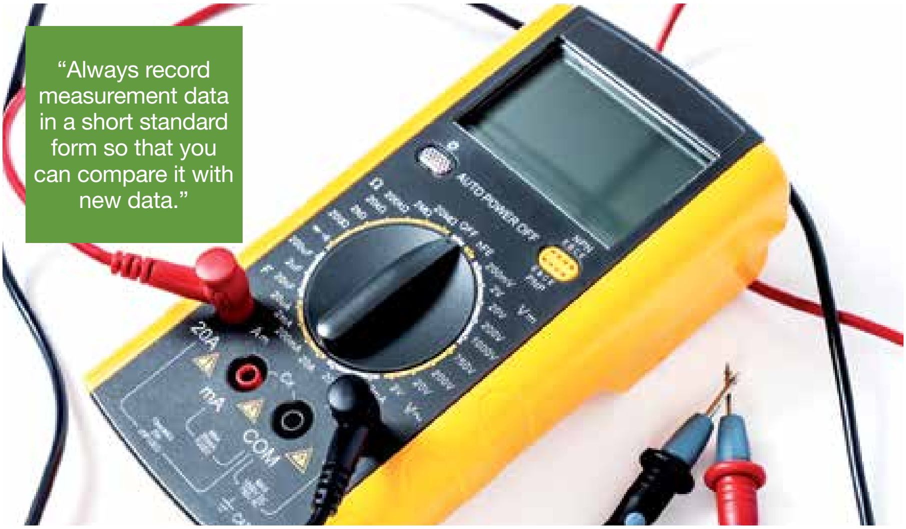
In this example, we assume a depreciation period of 10 years, an interest rate of 2% and maintenance cost of 1% of the new value.

> Annual installation cost = I x [(a+i+n)/100]
> = €215 x 300 lamps x [(10 + 2 + 1)/100]
> = €8,385
>
> Annual cost of the lamps = L x [(b/B) + (i+n)/100]
> = €30 x 300 lamps [(3,392/10,000 hours)
> + (2 + 1)/100]
> = €3,330

Decision: The annual cost of the lamps in this case is €3,330.

If the nursery worked with a controlled DLI and an average of 6.6 hours of lighting per day were sufficient, only 1,400 hours of use would be needed. The annual cost of the lamps is then only €1,530, or an annual saving of 54% on the lamps without taking the lower electricity consumption into account.

4.3. Saving by optimising the lighting efficiency



"Always record measurement data in a short standard form so that you can compare it with new data."

Regular maintenance and measurement of the lighting installation can significantly increase its service life and avoid the risk of failure.

LIGHT GUARANTEE

New high-pressure sodium lamps usually need to be used for around 100 hours before the light voltage and internal functioning of the light are completely stable. As the light approaches its full service life, it may go out after a while and then come back on after it has cooled down. This is also called 'cycling' or 'commuting' of a lamp. It is an indication that the lamp should have been replaced. Failure to replace a lamp on time affects the light output and the service life of various components in the fixture. It is therefore important to check the light output of the lamps every growing season and, if necessary, replace them in time. LEDs, energy-saving lamps and other types also have an economical number of hours of use. These are usually determined by the manufacturer under laboratory conditions. After their economic life, lamps may still work, but at a much lower efficiency. The energy consumption in relation to the light output will therefore increase considerably.

CAPACITORS IN LUMINAIRES

In horticulture, there are many types of high-pressure sodium fittings that are becoming more efficient every day. They

POINTS FOR ATTENTION DURING INSPECTION AND MAINTENANCE

POINT OF INTEREST	TO BE CHECKED
Schematic of the installation	Is this up to date?
Distribution units	Must not exceed 60°C.
Mains power analysis	Switch on the lighting for at least one hour and measure the power factor, current and voltage at various locations.
General measurement of capacitors	Measurement of the capacitance of a representative number of capacitors. If more than 2 capacitors have lost more than 15% of their original value, all capacitors must be replaced.
Light output	Have the light output measured at crop level; PCS can help you with this. Replace lamps in good time to prevent energy and output losses and have any reflector caps cleaned in good time.
Overview of measurements	Always keep a record of all measurements so that you can compare them at the next check-up!

Safety
Malfunctioning or worn capacitors can overload the lighting system and even cause a fire hazard!

can be divided into two groups: luminaires with electronic or electromagnetic ballasts. However, for both types it is not recommended to carry out repairs to fixtures yourself. While the luminaires with electronic ballasts in principle have no replaceable parts, the capacitors are an important point of attention in the conventional luminaires with electromagnetic ballasts. The capacitors, for example, provide a limitation of the current, the reactive current compensation. In normal circumstances, the service life of such capacitors is around 30,000 hours, so in practice about 8 years. After this period, they must be replaced.


Harmonic distortion of the mains voltage leads to a significantly reduced service life of capacitors.

Harmonic distortion of the mains voltage leads to a considerably shorter capacitor life, voltage peaks and excessive temperature. If the harmonic distortion is too high, it will also lead to additional heating of the cabling, connections and components in the luminaire and distribution devices. An increase in temperature due to harmonic deformation increases the risk of fire. This is also the case with ageing, such as corrosion of the installation due to the influence of plant protection products. If the temperature in distribution units gets too high, it leads to accelerated ageing of the components in the boxes.

BASELINE MEASUREMENT

In order to be able to detect deviations, the lighting installation should be tested regularly (annually from 3 years). For new installations, it is advisable to make a baseline measurement after 100 hours and with the lighting installation fully operational in order to determine, among other things, the harmonic distortion and measure the earth resistance. It is important to keep a record of the measurement data so that it can be compared at the next measurement.

Focus: The economic situation with lighting

1. Evaluate on a regular basis whether your energy contract still meets your business needs.
2. By checking the system, a surcharge due to a deviating cos φ or reactive power can be avoided.
3. Have a new lighting system completely evaluated for light output and energy consumption.

Keyword list

Absorption spectrum	p. 13
Power factor	p. 42
Assimilation lighting	p. 19, 23, 25, 28, 31, 33, 42, 46
Reactive power	p. 43
Chloroplasts	p. 8, 13
Capacitor	p. 42, 49
Cryptochrome	p. 11, 12, 13, 16
DLI (daily light integral)	p. 10, 22, 32, 33, 48
Fluorescent lamps	p. 27, 29
Photons	p. 8, 18, 19, 20
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Photoreceptors	p. 11, 13
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Light compensation point	p. 9
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UVR8	p. 11, 12, 13
φ (cos φ for power factor)	p. 43
φ (phytochrome photo equilibrium)	p. 12, 13, 14

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Research on light and energy

Scientific and practice-oriented research, conducted by the PCS and various national and international partners, forms the basis of this innovation guide.

Flowering regulation and quality in azalea: interaction between genetic, physiological and crop-related factors (2008-2012), implemented by PCS, ILVO and Ghent University and financed by IWT.

Climate Control Advisory Service: Energy saving in ornamental plant production under glass by introducing innovative techniques based on physiological backgrounds (2009-2013), implemented by PCS and financed by IWT.

Energy Conscious Farming (2010-2012), implemented by Inagro, PSKW, PCG, PCH, PCS, Hooibeekhoeve, Poultry Farming Experimental Farm, PIBO-Campus, ILVO, NPW and financed by EFRO.

GreenGrowing: Energy saving in glasshouse horticulture in the North Sea region (2011-2015), implemented by Aarhus University, Syddansk University (Denmark), High School Osnabrück, Chamber of Agriculture Lower Saxony (Germany), Bioforsk (Norway), SLU (Sweden), PCS, PCG (Belgium) and TNO (Netherlands) and funded by the Interreg IVB North Sea Region Programme.

Knowledge-driven control of plant physiological processes in ornamental horticulture to improve plant quality (2012-2016), implemented by ILVO, Ghent University and PCS, and financed by IWT.

Practical research PCS, carried out by the various departments of the PCS and financed by the Flemish government, the Province of East Flanders and the ornamental plant sector.

10 tips for economical and well-designed lighting

1. Use the sunlight as optimally as possible.
2. To check the light intensity and light distribution of your lighting installation, always use a PAR sensor.
3. Have the sensors checked annually, and calibrated if necessary. Clean them regularly with a clean cloth.
4. Choose lamps according to the application you intend to use, and evaluate new lighting for controlling plant processes in a small trial beforehand.
5. Avoid unnecessary hours of use: control assimilation lighting based on radiation intensity, or the desired DLI.
6. Investigate whether local energy production is an option for your nursery, and see how you can reduce peak power in your glasshouse by using phased lighting.
7. Choose an energy contract that matches your lighting strategy. Compare energy suppliers for businesses at www.vreg.be.
8. Replace lamps and other components in time to avoid energy losses, and consider purchasing additional capacitors to avoid reactive currents.
9. Choose energy-efficient lamps and remember that the purchase cost of the lamps is only one aspect, how much energy the system consumes is just as important.
10. As soon as the lighting system is three years old, it is best to have it checked by a recognised expert. Always carry out a baseline measurement with a new installation.

Do you have any questions?

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