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# IntelliGrow - a new climate control concept

In order to reduce energy consumption and the overall impact on the environment, new approaches may be required in the future production of pot plants. One novel approach is described here a climate control system based on plant reactions. Experiments at the Royal Veterinary and Agricultural University and the Danish Institute of Agricultural Sciences show that it is possible to save between 25% and 48% of energy consumption without affecting plant quality.

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## The climate from a plant perspective

All plant species are adapted to the environmental conditions in their natural habitat, and so species originating in a wide-ranging natural habitat will have greater adaptability than those from a narrow-range habitat. This knowledge is useful when collecting plant material for the production of pot plants. Most of our pot plants are of tropical or subtropical origin, because our indoor climate is closest to their natural climatic conditions. In traditional climate control, irradiance, air temperature, $CO_2$ concentration and air humidity are kept at constant levels estimated to meet the requirements of the cultivated plant species.

The choice of climatic conditions is based on the natural origin of the plant species and on long-term experience of greenhouse cultivation. We aim to keep the climate as constant as possible, but there are often major differences between desired climate and actual climate. When natural irradiance is low, it can be difficult to compensate with artificial light - especially when electricity costs are so high. When the outdoor temperature is high, it is not possible to cool the glasshouse except by shading and ventilation, and when the vents are open, extra $CO_2$ is not usually supplied. In general, too little attention is paid to outdoor conditions in the production of potted plants.

## Plants are dynamic in their response

Plants have ways of coping with unfavourable conditions. The leaves and roots adapt to derive the best possible benefit from the resources. In nature, some changes take place over a period of days or even weeks (for example, the mean daytime temperature and water and nutrient supply (while others, such as leaf temperature and irradiance, take place more quickly (minutes/hours). In the most extreme cases

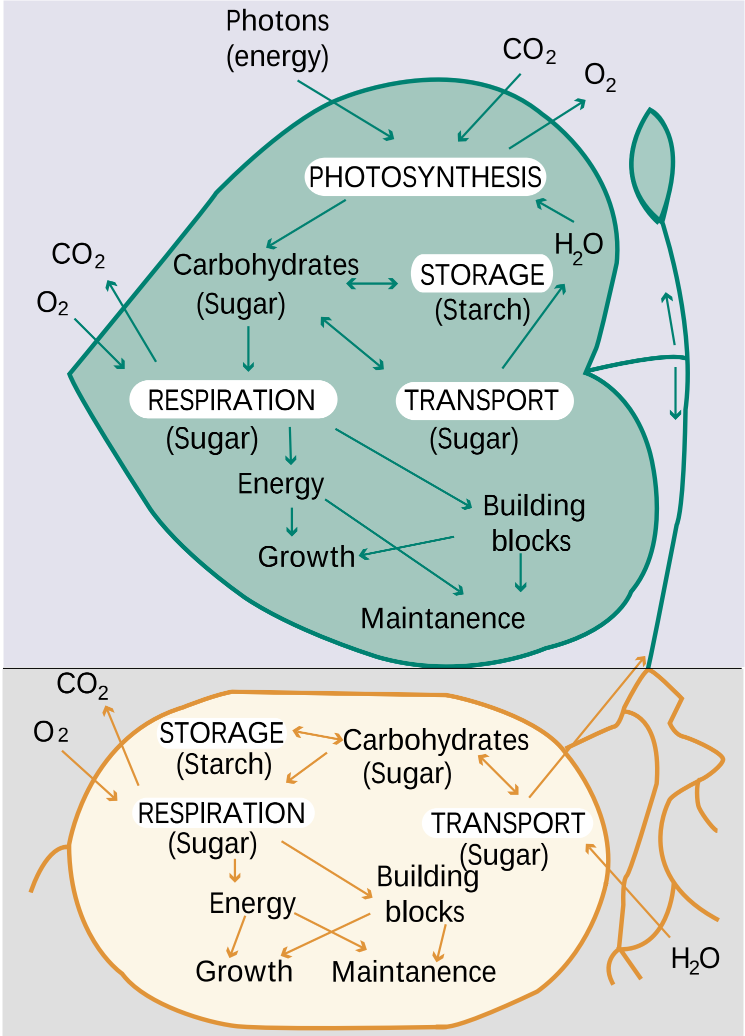


*Figure 1. Carbon balance of the plant. The interaction of the different processes determines plant growth.*

irradiance level can increase more than 10-fold in just a few seconds when the sun reappears from behind a cloud.

In nature, many environmental factors and plant reactions are closely linked:

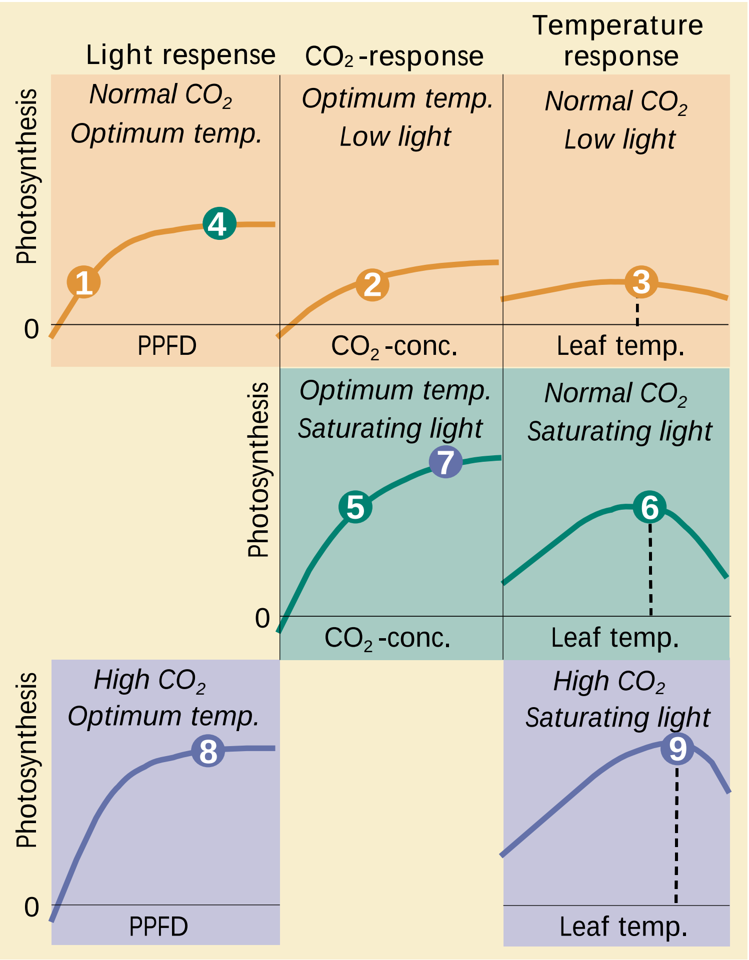
- When the sun shines, it is usually warmer than it is in cloudy weather.
- When a good water supply is available to a plant, transpiration of the leaves will ensure that leaf temperature does not rise, despite high irradiance.
- When the plant has insufficient water, the stomata will close and the leaf temperature will rise several degrees above air temperature.

If the conditions in a glasshouse are kept fairly constant, the result will be strong growth, but at the risk of producing plants without the ability to adapt. A constant climate affects production in two ways. First, the plants built-in ability to respond dynamically to the climate is not utilized to enhance production. Secondly, we run the risk of producing plants that are not accustomed to change, and therefore reduce their ability to cope with post-harvest stresses, or what is also called „keeping quality“.

## Plant physiology

If we are to promote and utilize the natural adaptability of plants in the controlled system of a greenhouse climate, we have to know more about the physiology behind the growth mechanisms. Photosynthesis occurs in the plant

*Figure 2. In IntelliGrow carbon uptake is optimized based on how the photosynthesis responds to changes in irradiance, $CO_2$ and temperature. The three red, green and blue points, respectively, represent the same photosynthesis. At low irradiance (1), the $CO_2$- and the temperature response curves will be flat, and the photosynthesis therefore low, irrespective of $CO_2$ and temperature (2 + 3). If the irradiance is saturating for the photosynthesis (4), the $CO_2$- and temperature response curves will be steeper. The photosynthesis at 5 and 6 is therefore higher than it is at 2 and 3. At high $CO_2$ concentrations (7), the light response curve rises steeply from low to saturating irradiance (8). Saturating irradiance, combined with high $CO_2$ concentration (7+8), results in a steeper temperature response curve, where temperature optimum is higher (9) than at normal $CO_2$ contents (350 ppm) of the air (3 + 6).*



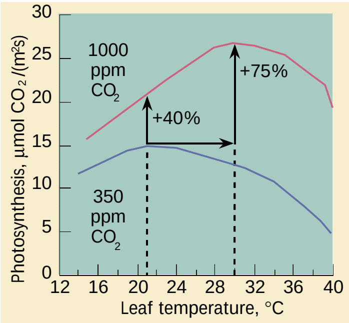


*Figure 3. Temperature response of photosynthesis measured on Chrysanthemum at saturating irradiance (PPFD) and two $CO_2$ concentrations.*

when $CO_2$ and water produce sugars through solar energy. The sugars, along with nutrients and water, promote growth.

The amount of irradiance the plant will be exposed to is determined by the irradiance level, leaf area, the size of the plant in question, and how much it is shaded by neighbouring plants. The sugar produced by photosynthesis (Figure 1) is distributed to the roots, new leaves and buds, where metabolism for growth and respiration is needed. At respiration, $CO_2$ is released. This process is inevitable, as respiration is necessary for both maintenance and new growth.

All these processes depend partly on the amount and availability of irradiance, $CO_2$, water, nutrients and leaf temperature. The association between these factors and photosynthesis is illustrated in Figure 2.

As water and nutrition are usually maintained at stable levels during production, our interest is concentrated on temperature, $CO_2$ concentration and partly on irradiance. Figure 3 illustrates how the environmental factors affect one another and how they affect photosynthesis in Chrysanthemum. At ambient $CO_2$ concentration and high irradiance, photosynthesis has a temperature optimum of 21ºC. But when we supply the plants with 1000 ppm $CO_2$, photosynthesis at 21ºC rises by 40%. Therefore an increase in both temperature and $CO_2$ will result in 75% higher photosynthesis. What is regarded as the optimum temperature at one $CO_2$ concentration may not be optimum at another.

## Lose on the swings what you make on the roundabouts

During winter-time, the light level is far from adequate, and as light is the energy source promoting photosynthesis and growth in the plant, it follows that under low light conditions the other environmental factors cannot be utilized efficiently. Irradiance level is therefore the most growth-limiting factor during winter. If the temperature is reduced owing to low irradiance, energy addition can be reduced since it cannot be used toward growth. When irradiance is adequate, the plants are able to utilize both a higher temperature and $CO_2$ concentration.

This balancing act is accomplished in a completely new form of greenhouse climate control aimed at supplying heat and $CO_2$ in the periods when plants can make optimal use of them. It is therefore possible to save energy, with only minimal change in plant growth rates caused by fluctuating irradiance. This climate control concept is known as IntelliGrow.

## Climate control based on components

Different plant species have different temperature and irradiance requirements, so future control systems will need to be adaptable from one nursery to the next. Growers will have to have the opportunity to program the components of the control system in accordance with the needs of the individual nursery. In other words: Each individual grower must be able to choose freely which

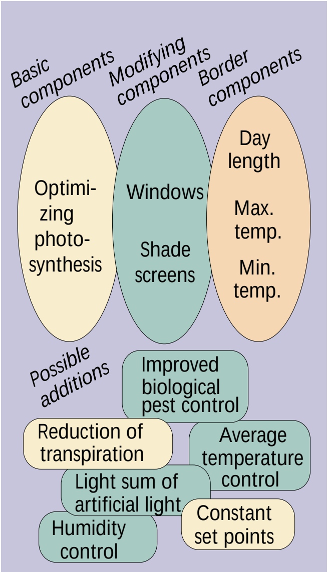


*Figure 4. The components of the climate control in Intelligrow.*

| CO$_2$-conc. (ppm) | Temperature (°C) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 15 | 16 | ... | ... | 20 | ... | 30 | |
| 300 | 1.4 | 1.4 | | | 2.4 | | 1.6 | |
| 350 | 1.4 | 1.4 | | | 2.6 | | | 80% photosynthesis |
| 400 | 1.6 | 1.6 | | | 2.7 | 2.7 | 1.9 | |
| ... | | | | | | | | |
| ... | | | | | | 3.0 | | |
| 1200 | 1.7 | 1.8 | | | 2.8 | | 2.8 | |
| ... | | | | | | | | |
| 2000 | 1.7 | 1.9 | | | 2.9 | 3.2 | 3.0 | 100% photosynthesis |

*Table 1. The photosynthesis index at different temperatures and CO$_2$ concentrations at a random irradiance level.*

‚bricks‘ he will use when constructing the climate control system for his greenhouses. IntelliGrow is a system comprising a series of different components.

One component deals with one specific function, e.g. control of the rate of photosynthesis (see Figure 4 for examples of some of the components). The components incorporate the knowledge base of scientists with many years of research. At the same time the components represent one way to distribute this knowledge and make it useful. Components can meet the specific requirements of the individual nursery.

Very advanced processes can be controlled, including not just temperature but also plant reactions such as control of cell elongation or transpiration. In this way the focus of the climate control system is shifted from technology to plants, the environment and crop protection.

Thus, a set point no longer concerns temperature and CO$_2$, but, for example, the rate of photosynthesis, flowering time and energy consumption. When the ‚bricks‘, i.e. the components, are chosen and subsequent set points are determined, it is up to the hardware of the traditional climate control system to regulate the climate.

## How does IntelliGrow work?

Ever since the early 1990s, researchers at the Royal Veterinary and Agricultural University (RVAU) and at the Danish Institute of Agricultural Sciences (DIAS) have developed of a climate control system which is currently adjusted to natural irradiance, and since the winter of 1997/98 they have been testing and adjusting this system in experimental glasshouses at the Section of Horticulture, RVAU, and at the Department of Horticulture, DIAS.

The system comprises a traditional but well-equipped glasshouse with PC-control of the climate computer, a data-logger with a large number of sensors, and software containing the necessary components. The climate is measured at three levels: outside and inside the glasshouse and in the plant canopy. The first two levels are measured using conventional methods, while measurement of the plant canopy is by a new technique. In the canopy, plant temperature and CO$_2$ concentration are measured in and just above the plants; the irradiance is measured underneath and just above the canopy. Biological and physical components need exact climate information if they are to work correctly and even small differences may be important. The calculated environmental set points are transferred to the climate computer which handles the actual climate control.

## What is IntelliGrow?

IntelliGrow comprises a basic photosynthesis model, and controllers of windows and shading screens. 2) windows, and 3) shading screens.
The photosynthesis component is based on work done by plant physiologists over the years, resulting in models describing the

response of photosynthesis to environmental factors. Its function is to optimize the climate of the glasshouse in relation to the current irradiance. In Table 1 we show how the system works. First, the irradiance is measured, and then a photosynthesis table of the rate of photosynthesis at different temperatures and $CO_2$ concentrations (at the measured irradiance) is calculated. The maximal photosynthesis is the largest figure and equal to 100%. The table is scanned to find a photosynthesis that fits the photosynthesis percentage chosen. Temperature level and $CO_2$ concentration are read and used as set points. A set point of 100% secures a high photosynthesis, but energy consumption is large and the plants might be long and thin. A more reasonable set point has proved to be between 80% and 90% of the optimal photosynthesis.

This component results in a very dynamic climate. Depending on the irradiance, the temperature can vary from 15ºC to 30ºC and the $CO_2$ concentrations from 350 to 2000 ppm. Examples of the temperature and $CO_2$ concentration at different irradiances and set points are presented in Table 2.

The components for shading screens and windows are relatively simple under the present climate control system, and are based on energy considerations. These are used in an attempt to utilize free solar heat to best possible advantage. The shading screens are drawn back in the morning at a relatively high irradiance level and drawn over in the evening before the irradiance gets too low. The limits for the screens are chosen to balance the energy expenses and savings. During the day, the screens are used only when the temperature in the plant canopy rises above a certain relatively high level. The window component ensures that the windows are open only when needed, so the average $CO_2$ concentration in the glasshouse increases. This is due to both a greater supply of $CO_2$, owing to a longer period with closed windows, and the remains of previously supplied $CO_2$.

The components are made up of three layers. First, a basic value for temperature and $CO_2$ concentration of the glasshouse is calculated. Other components are then used to determine whether the calculated values need to be adjusted. This ensures, among other things, that the production is ready in due time and that energy costs are viable. The adjusting components ensure proper plant development, i.e. flowering, proper height, flowering time, and so on. The last layer of components includes brief rules about keeping the temperature within defined limits. The development of these rules is the key focus of the research and development of the project.

| | ☁ | | ⛅ | | ☀ | |
|---|---|---|---|---|---|---|
| | PPFD=115 µmol/($m^2$s) | | PPFD=680 µmol/($m^2$s) | | PPFD=1380 µmol/($m^2$s) | |
| % photo-synthesis | °C | ppm $CO_2$ | °C | ppm $CO_2$ | °C | ppm $CO_2$ |
| 40 | 15 | 300 | 15 | 300 | 15 | 380 |
| 50 | 15 | 300 | 15 | 300 | 15 | 620 |
| 60 | 15 | 300 | 15 | 460 | 18 | 620 |
| 70 | 15 | 300 | 18 | 540 | 19 | 940 |
| 80 | 15 | 300 | 18 | 860 | 22 | 1100 |
| 90 | 15 | 300 | 22 | 1100 | 26 | 1180 |

*Table 2. Examples of set points for temperature and* $CO_2$ *concentration at three different irradiance levels and set points of photosynthesis. For irradiance levels, see measurement of ‚light'.*

## The climate?

As already mentioned, IntelliGrow is based on a set of minimum and maximum values for temperature and $CO_2$. Figure 5 exemplifies the temperature on a sunny spring day. In the completed experiments the temperature was between 15°C and 30ºC. These values need to be calibrated to the culture in question, but the limits will always be lower/higher than the standard today.

During the night, the temperature is kept at a minimum level of 15ºC. When the sun begins to have an effect, the shading screens are removed earlier than they are today. If the weather is cloudy, the temperature does not rise above 15ºC, whereas on a sunny day the temperature might rise to 30ºC, and only then are the windows opened. As this rarely happens during winter-time, the glasshouse will require very little ventilation. The shading screens are drawn at sunset. The temperature will fall slowly to 15ºC, but the windows are not opened to force the temperature down.

The climate is very different from today's greenhouse climate. The temperature limit of 30ºC is particularly high, but in the completed experiments there was no damage to the plants. Furthermore, no problems have been observed with condensation of water vapour on the plants at low temperature, probably because the air cools relatively slowly and condenses mainly on the windows and not on the plants, making leaf pathogens less of a problem.

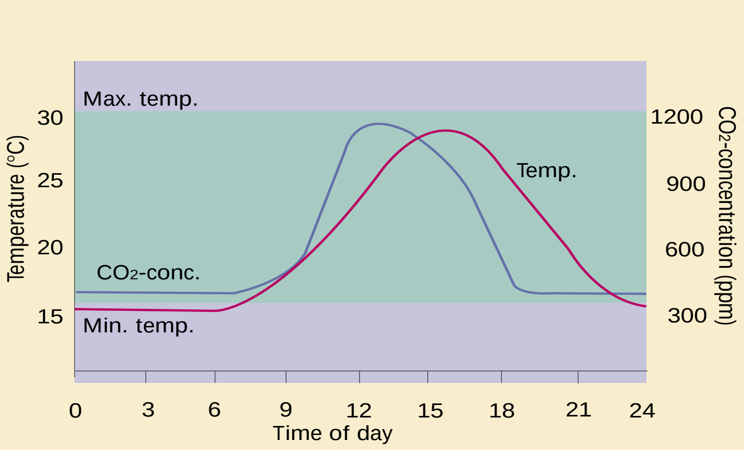


*Figure 5. Typical curves for temperature and $CO_2$ concentration in the glasshouse on a sunny spring day. If irradiance is low, the set point of the temperature will not rise above 15ºC, but under most conditions the temperature will passively rise to approximately 20ºC in the glasshouse.*

*A series of sensors is coupled to a small ventilated box where air and leaf temperature, irradiance, $CO_2$ concentration and air humidity are measured in the vegetation.*

### Measurement of ‚light'

‚Light' can be seen by the human eye within a wavelength range of approximately 450-650 nm, and is measured in lux. The plant utilizes irradiance within 400-700 nm for photosynthesis. It is measured as Photosynthetic Active Radiation, PAR, W/m$^2$ or Photosynthetic Photon Flux Density, PPFD, µmol/(m$^2$s), which is an international standard for measurements of irradiance in relation to the photosynthesis of plants.

1 W/ m$^2$ (PAR) = 4.6 µmol/(m$^2$s) (PPFD) and full sunlight in the summer at noon give PPFD = approximately 2000 µmol/(m$^2$s).

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## Much energy can be saved

Compared to a standard climate control system, energy saving for the period from January to May 1998 was 40% at the Section of Horticulture and 33% at the Department of Ornamentals, and these results have been replicated in all later experiments.

The energy savings are due to:

- Lower night temperatures
- Adjustment of the day temperature to the present irradiance
- A higher ventilation limit
- Better utilization of the free heat

The response of the plants to the new climate dependeds on the species and the time of the year. During the winter months, growth and flowering were slightly delayed, while during the spring months growth rate was increased. The keeping quality seemed to be influenced by the climate only to a minor degree. During the winter months the plants were more compact, while later on they became either taller or larger. The number of buds and flowers seems to increase with the dynamic climate control. The experiments comprised the following plant species: pot roses, Hibiscus, Campanula, Asters, Gerbera, Polyscias, Kalanchoë, Chrysanthemum, Petunia and different herbs. All were grown in the same climate, so the climate was not optimal for all species. In future experiments the climate will be adjusted to suit also tropical plant species.

*The glasshouse is only a thin shell, and since the Meteorological Office in Denmark forecasts heavy cloudy weather and low temperatures for most of the winter, irradiance is so low that the plants come to a standstill irrespective of temperature conditions. Energy can be saved here, too.*