IntelliGrow 2.0 – A Greenhouse Component-Based Climate Control System

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Abstract
Since 1996 a dynamic model based climate control concept (IntelliGrow) has been developed in Denmark. The aim of the system is to adjust the greenhouse climate dynamic, so that the natural resources are used as optimal as possible. The concept has been proved to work in both growth chamber and greenhouse experiments, with many different species of pot plants, resulting in energy savings up to 40%, depending on the outside climate. Based on the former work a new system (IntelliGrow 2.0) is being developed which offers an improved user interface and an extensible component model. The goal is to test the system in full scale in five Danish commercial nurseries. The four steps to reach the goal are: 1) development of a demonstrator giving the grower advice on optimal climate control based on the IntelliGrow concept 2) testing the demonstrator at research facilities followed by tests at growers 3) development of an active climate control system that will take full control of the greenhouse climate based on the overall goals set by the grower 4) tests of the active climate control system at research facilities and at the growers. It will be possible to adjust the control by adding new components. A special emphasis will be on components that utilize local weather predictions for energy saving purposes and timing of production as well as components with photosynthesis based strategies for use of artificial light. We expect that the extension of intelligent climate control will result in better production management and resource utilization. A fast flow of knowledge from research to practice in the future will be established. Design of the concept and the first results are presented in this paper.

INTRODUCTION
The greenhouse industry is a high energy demanding industry. Aaslyng et al. (2003) previously described the IntelliGrow system. IntelliGrow incorporate models for absorption of irradiance, leaf photosynthesis and respiration. It optimizes the climate by determining heating and CO₂ set points to ensure maximum net dry matter production, taking the use of non-natural energy into consideration. While the IntelliGrow was designed for research, this article outlines some requirements needed to build a new system suitable for use in commercial greenhouse production. Results from previous work can be found in Lund et al. (2006) and Ottosen et al. (2005).

The overall idea is to design a system that can control the greenhouse climate so that heat, light and CO₂ are optimized according to photosynthesis, with the aim of
minimizing use of resources and keeping to production schedule.

Strategy

Based on the existing IntelliGrow concept a new software is being developed (IntelliGrow 2.0) to be used by growers. First a demonstrator is developed that will show the grower how IntelliGrow operates. It will suggest new climate settings to the grower and provide reasons why the new settings are suggested. The grower can then choose to accept or reject the new settings.

The demonstrator will be tested initially at research facilities and then at grower’s sites. The test will naturally result in improvements of the system. The upgraded system will allow controlling the greenhouse climate actively based on individual models and limits set by the grower. The active climate control system will be subjected to similar testing at research facilities before tests are performed by the growers.

System Construction

The new system is composed of four main elements: communication, decision-making, data storage and presentation components (Fig. 1.).

The communication component is responsible for continuous exchange of data with climate computers, controlling the climate individually for all compartments. We hope to develop a generic system to be able to support different climate computers. In this project we aim to support two climate computers produced by Senmatic A/S: LCC1200 and LCC-Completa. In order to unify the communication process, we have decided to utilize SuperLink4 application made by Senmatic A/S as the intermediary layer between IntelliGrow 2.0 and the climate computers.

The data storage component receives important data from other parts of the system and saves it to a database for further analysis. The following information will be stored:

- Current climate conditions in all compartments,
- Current outside weather conditions,
- Weather forecast for next 5 days, updated every 12 hours,
- Set points for all climate computers,
- Planned control decisions and their reasons.

The new system will be designed in components, as described by Aaslyng et al., 2003, with a hierarchically arranged decision making component. The decision-making component will calculate the climate values such as set points for temperature and CO₂ concentrations depending on other climate control components like the boundary component. The boundary component handles climate control restrictions that for example ensure that the correct night length and minimum and maximum temperature are obtained.

The focus of the presentation component is mainly on informative and explanatory descriptions of all actions made by the system in order to reach the grower’s goals. This will help the user to understand the control process and to adjust it if necessary. This will also significantly increase user’s level of trust to the system, which is a key issue, if one wants to implement a more automated climate control system. The presentation component provides features for visualization, in form of graphs over a time, of parameters like: climate conditions, weather forecast, estimated energy consumption and estimated photosynthesis.

Another aim of the project is to develop an interdisciplinary network for fast flow of knowledge from research to practice. As partners include growers, one climate control computer company, one weather prediction service agency, consultants and researchers they might have different aims. Growers’ interests are to produce plants of high quality that can be sold, while researchers might want to reach the limits of possible reduction of resources and maybe to reach the limits concerning climate extremes possible for producing quality plants. The commercial companies might want to keep the knowledge gained during the process to their own, while researchers are obliged to publish. This
might cause controversies but collaboration and understanding among partners and their situation are the base for a good network, making the fast flow of knowledge from research to practice possible.

MATERIALS AND METHODS

Participating growers contributes to the design of the system. Information is collected through interviews and on-site visits. In order to estimate energy consumption, information about: type of greenhouse construction, the greenhouse size, lamps (W m⁻²) and curtains has been collected.

For the calculation of photosynthesis, outdoor light sensors at the growers (with possible calibration error) will be correlated to a standard photosynthetic active radiation (PAR) light sensor (400-700 nm, Spectrum Technologies, Inc., USA).

Light emission factors and the reduction of light received by the plants caused by the glass ($T_{Glass}$), greenhouse construction ($T_{Construction}$) and curtains ($T_{Curtains}$) will be found by using two WatchDog™ Data Loggers (Model #450, Spectrum Technologies, Inc., USA) and 3 PAR (Photosynthetically Active Radiation) Light Sensors (400-700 nm, Spectrum Technologies, Inc., USA). This has been found for one site and following procedure was used and will be used for all test locations: Light was measured outside ($PAR_{OUT}$) and inside both with and without curtains on a sunny day at noon when the sun is highest in the sky. Two PAR sensors were used inside the greenhouse to measure PAR at the plant level, simultaneously with the outdoor PAR measurement using one PAR sensor. At one spot inside the greenhouse, the light sensor received direct light through the glass ($PAR_{IN(Glass)}$), while the other sensor was located in an area only receiving indirect light due to shading of the greenhouse construction ($PAR_{IN(Construction)}$). Sizes of the areas ($A_{Glass}$ and $A_{Construction}$) during time of measurement were estimated using visual judgement and a tape measure. The light transmission factors found were weighted and depending on the area estimations. With curtains drawn 0%, at least 20 measurements over a period of 20 minutes were logged at all three places simultaneously followed by measurements performed with curtains drawn 100%.

Calculation of light reduction factors ($T_{Glass}$, $T_{Construction}$, $T_{Curtains}$) and $PAR_{IN}$ were performed in order to calculate light received by the plants ($PAR_{IN}$) using the following equations.

When no curtains were used $T_{Glass}$ and $T_{Construction}$ were found using the following equations:

$$T_{Glass} = 1 - \left( \frac{PAR_{IN(Glass)}}{PAR_{OUT}} \right)$$

$$T_{Construction} = 1 - \left[ \frac{PAR_{IN(Glass)}}{PAR_{OUT} \times A_{Glass}} + \frac{PAR_{IN(Construction)}}{PAR_{OUT} \times A_{Construction}} \right]/A_{Total} - T_{Glass}$$

When light were received by $PAR_{IN}$ sensor directly through the glass the curtains were drawn 100% and the $T_{Curtains}$ value were calculated as follows:

$$T_{Curtains} = 1 - \left[ \frac{PAR_{OUT} \times (1 - T_{Glass})}{PAR_{IN(Curtains)}} \right]$$

Light received by the plants ($PAR_{IN}$) is calculated as:

$$PAR_{IN} = PAR_{OUT} \times (1 - T_{Glass} - x \times T_{Curtains} - T_{Construction})$$

Where x is the percentage of how much the curtains are drawn.
The calibration of CO\textsubscript{2}, temperature and relative humidity (RH) sensors at all the locations will be done by Senmatic A/S. Information about present climate control strategies and energy sources have been collected in order to meet the grower requirements of the system being developed.

RESULTS AND DISCUSSION

While IntelliGrow is designed for research purposes further requirements need to be implemented in the new system in order to use it in a commercial scale of greenhouse production. For this purpose the participating growers contributed to the design of the system. As expected, the growers involved in the project were and still are generally positive about the ideas behind the system. One major concern about the system is a possible breakdown of the climate control computer controlling other compartments at the locations. Growers wish the system to be user friendly and to enable them to understand how the program operates. The demonstrator and the presentation component is therefore an important part of the system, providing features for visualization, in form of graphs over a time, of parameters such as climate conditions, weather forecast, estimated energy consumption and estimated plant photosynthesis.

The present climate strategies depend on the species grown, which include \textit{Hibiscus}, \textit{Campanula}, miniature roses and \textit{Euphorbia}. The system will eventually change the way of controlling the climate at the different locations, therefore a component including a plant model might be necessary in the future. In order to develop a plant model component, close connection to a grower being specialized in cultivating the particular plant species is needed.

It is important that the system is constructed so that it can accommodate greenhouses of tomorrow. One climate control action, e.g. opening of the windows, influences several climate parameters such as temperature, humidity, and CO\textsubscript{2} concentration to different degrees, depending on the specific construction of the greenhouse. Thus differences between greenhouses concerning constructions and installations will result in different strategies to obtain a specific indoor climate change. The aim of changing one specific greenhouse climate parameter will therefore be separated from the climate control action. In this way it will be possible to account for differences between greenhouse constructions using greenhouse model components.

Light Estimation

To calculate the photosynthesis it is necessary to have estimates of PAR reaching the plants at all times. As outdoor light sensors were used, a starting aim was to use existing sensors and subsequently to estimate indoor PAR.

Only a few growers use a PAR sensor to measure outdoor light at the present moment. Instead sensors measuring lux (380-780 nm, lumen m\textsuperscript{-2}) are used. Because of different optical properties of the outdoor sensors, the use of different sensor types was found to be a challenge and a source of error for the indoor PAR estimation. The optimal consequent action is to replace all outdoor sensors by a standard PAR light sensor. The change in spectral distribution of PAR does not change dramatically through the glass of standard greenhouses but it will be possible to add a component to adjust this in special cases in the future.

Light emission factors and the reduction of light caused by the glass, greenhouse construction and curtains, differ between the locations. Light reduction factors (\(T_{\text{Glass}}\), \(T_{\text{Curtains}}\), \(T_{\text{Construction}}\)) will be used to calculate PAR received by the plants (\(\text{PAR}_{\text{IN}}\)) as described in previously. One example of the allocation of PAR in % of the outdoor PAR at one location is illustrated in Figure 2 A.

The most common curtain system allows the curtains to be drawn in percentages. This can be used in the calculation of the PAR reaching the plants. However, the differences between the correlations of \(\text{PAR}_{\text{OUT}}\) and measurements of \(\text{PAR}_{\text{IN}}\) done in the areas \(A_{\text{Glass}}\) and \(A_{\text{Construction}}\) were noticeably big (Fig. 2. B and C). The influence of light differences needs to be considered when doing an average calculation of the
photosynthetic photon flux density, since high light may lead to photoinhibition while low decreases the photosynthesis. Further studies might be needed in order to estimate the error of averaging the \( \text{PAR}_{\text{IN}} \) over areas of low and high light inside a greenhouse.

One grower has a system with eight rolling curtains that can be controlled separately. It is possible to allow no direct sun to reach the plants while only one or some of the curtains are drawn at the time. This makes estimation of PAR inside the greenhouse a challenge because the light reaching the plants can not be expressed in percentages of how much the curtains are drawn. Figure 2 D shows one example of a correlation between \( \text{PAR}_{\text{OUT}} \) and \( \text{PAR}_{\text{IN}} \) when curtains were drawn to 100%.

Calculation of \( T_{\text{Construction}} \) is depending on the area of \( A_{\text{Construction}} \) and \( A_{\text{Glass}} \). Estimation and measurements of light reduction factors were performed at noon because \( A_{\text{Construction}} \) gets bigger during dusk and down and will eventually influence the calculation of the \( T_{\text{Construction}} \) factor. Light does change during the day and the way of calculating PAR inside a greenhouse can be done in many ways. Like the shade distribution from the greenhouse construction inside a greenhouse is dependent on the degree between sun and the horizon, so is the outdoor PAR light sensor signal. Therefore it is considered acceptable to base the indoor PAR levels upon the outdoor PAR sensor signal even though the shading of the construction changes during the day. The significance of not considering the change of light in terms of indirect light due to the greenhouse construction compared to the outdoor sensor signal will depend on the greenhouse construction in each individual case, and was therefore not analysed. It will be possible to include such adjustments in the system when a greenhouse model component is developed.

**Sensor Quality**

The economical outcome of a changed climate control strategy depends mainly on the crop requirements and the degree of implementation. Adjustments of e.g. a new light strategy are needed for each location in order to achieve optimal use while electricity prices, greenhouses and the installations differ between locations. Thus the economical outcome of introducing IntelliGrow 2.0 will differ between locations but can easily be estimated.

Both relative humidity and temperature sensors installed at the test locations were fairly stable and comparable with sensors used at the plant level during pretesting. Infrared gas analysis sensors for CO\(_2\) measurements used at the locations were of different types. One type of infrared gas analysis sensor, used for CO\(_2\) measurements at several growers, was not corrected for changes in temperature and pressure and thus not considered accurate enough for accurate control CO\(_2\) dosage in a dynamic climate.

A secondary benefit of the project is that growers become aware of the quality of their sensors and greenhouse installation systems, resulting in discussions whether CO\(_2\) sensors should be replaced by more accurate and stable sensors. The outdoor light sensors measuring lux might be replaced by PAR sensors. In general, more and improved sensors might be needed through out the commercial greenhouses for more precise monitoring and climate control in the future.

With a strong interdisciplinary network new components can easily be developed, tested and distributed. As weather forecasts are included in the system, weather dependent climate control components will be easy to develop.

A future aim and feature of the system is to meet production schedule by monitoring and adjusting photosynthetic light hours and temperature hours received by the plants. The system is expected to be a great help for the growers in the future for production planning and for reduction of resource use.

**CONCLUSIONS**

It is considered highly economically beneficial to introduce and use IntelliGrow 2.0 in commercial greenhouse productions. No major investments are needed to introduce and apply the new system. Estimation of PAR reaching the plants at all times is a
challenge and outdoor light sensors used at some locations that do not reflect measurements of a standard PAR sensor, should be replaced.

The economical outcome of a changed climate control strategy will depend on the plants being produced, the greenhouse and installations etc, but we aim to make the system flexible so that it can accommodate the differences.

The IntelliGrow 2.0 platform is continuously improved and new components can easily be developed, tested and distributed. The participating growers are in general positive about the system, which is expected to be a great help in commercial plant production in the future.

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Literature Cited


Figures

![Architecture of IntelliGrow 2.0](image.png)

Fig. 1. Architecture of IntelliGrow 2.0.
Fig. 2. Light measurements at one commercial greenhouse. A: The allocation of the outdoor PAR in the greenhouse. B: Correlations between the outdoor PAR and PAR measured inside the greenhouse with 0% shading and the sensor measuring in an area getting light directly through the glass ($A_{Glass}$). C: Correlations between the outdoor PAR and PAR measured inside the greenhouse with 0% shading and the sensor measuring in an area getting light indirectly through the glass due to the construction ($A_{Construction}$). D: Correlations between the outdoor PAR and PAR measured inside the greenhouse with 100% shading in an area of $A_{Glass}$. 

\[ y = 0.813x - 97.1 \]
\[ R^2 = 0.969 \]

\[ y = 0.261x + 203.0 \]
\[ R^2 = 0.911 \]

\[ y = 0.101x + 55.5 \]
\[ R^2 = 0.949 \]