THE LED LIGHTED MINI-GREENHOUSE FOR SCIENTIFIC AND EXHIBITION PURPOSES

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Abstract: In this paper we report the latest news and future plans of our mini-LED-greenhouse project. LEDall II, a mini greenhouse that uses LED lighting was designed for the exhibition and research purposes. Greenhouse has been featured in several exhibitions and has proved to be popular stop among people. Project's scientific side has shown that plants such as tomato and cucumber seedlings are growing under led lightning, but unfortunately the mini-greenhouse designed for easy transfer and exhibition purposes is too low for full-grown greenhouse plants. In this paper, we also present our new design LedALL III that can be presented in the University of Vaasa exhibition pavilions, but which may also be considered for the production and sale for Finnish households as exotic plants growing and decoration device.

Keywords: LED, light-emitting diode, greenhouse, plant growing

1. Introduction

The use LED lighting in a variety of lighting applications has become more common with increasing pace in recent years. There has been a growing interest in using LEDs lighting in the greenhouses since the LEDs are small, durable, long-lasting and possess high energy efficiency, and their wavelength can be selected to meet those that the plants uses for photosynthesis. LEDs are also less hot than the metal discharge lamps currently used, this is good for fire safety and also for that the lights do not burn the leafs of the plants. The discharge lamps have also the problem that pollinator bees are practically blind in those wavelengths that they emit. This means that they do not find their home and must be replaced often. LED lights can also be used to help bees to see inside the greenhouse.

In the University of Vaasa we have examined adaptive LED illumination for the photographic purposes in the project called LEDall [1]. In that project we build small device that finds optimum lighting conditions for an object to be photographed with the help of genetic algorithm (GA) optimization [2]. GA was used so that it first randomly draws a series of lightning pattern to LEDs and takes a series of photographs, user then selects those photographs that were best and GA creates new lighting patterns by using crossover and mutation.

The device was presented in exhibitions to show what kind of research we are doing at the University of Vaasa. Later, we started a research project studying the use of with

LED lighting in greenhouses [3]. As a pilot for our new project we designed and build new small LED lighting device, LEDall II – a mini greenhouse. This LED lighted mini-greenhouse was planned to be used for two purposes; to present our research in exhibitions and public events, but also for scientific purposes as a small plant growing device, a platform to study how plants grow under the LED lights.

There have

2. Related Work

We gathered a list of related work for our pre-study [3], we decide to cite only some of the related work published since then. First of all, there are 320 publications about using LEDs in the greenhouses at the ScienceDirect research database (http://www.sciencedirect.com/), more than half of them, 176, are published after our pre-study, which demonstrates the growing activity in this field in recent years. IEEE Explore (http://ieeexplore.ieee.org) lists only 25 articles with LED+greenhouse.

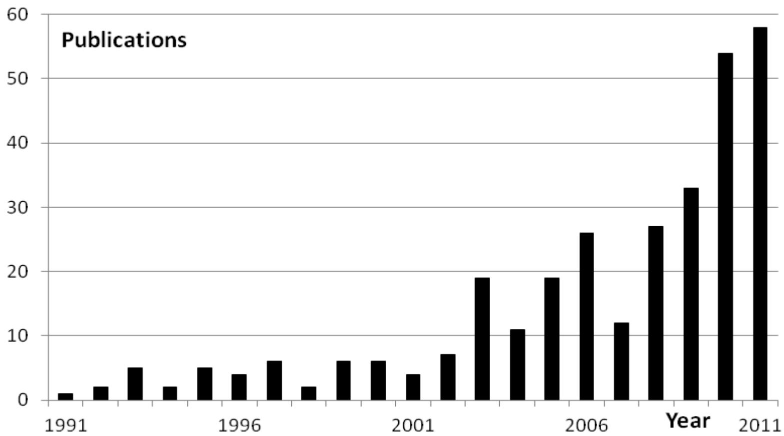


Fig. 1. The number of publications about LED lighting in greenhouses per year.

Fig. 1 shows the growth of publications in this field, the most popular topics in these publications are energy efficiency (11), solar cell (7), blue light LED (7), plant and root growth (6), life-cycle assessment (6), renewable energy (6), greenhouse gas emissions (5), life support (5), light quality (4), climate change (3), biological control (3).

These numbers shows that the publications discuss wide variety of topics and most of them do not fit to the most popular categories. However, these numbers may be inaccurate since many of the papers discuss greenhouse gases instead of the greenhouses. Also, we cannot directly search papers with the keyword “led”, since it has other use as well, and unfortunately many articles have not open the abbreviation.

Buck-Sorlin et al [4] have developed a simulated virtual model of 3-D position of assimilation lamps in virtual greenhouse. The study seems interesting but one would wish to see an actual greenhouse with the designed model installed.

Kitamura et al [5] have used LED lights in order for picking robot to identify sweet pepper fruits in a greenhouse. A robot uses stereovision and LED light reflection to recognize fruits. This is very interesting experiment, and they seem to have relatively good results, however, method seems to need more development before commercialization.

Ilieva et al [6] and Zyablova et al [7] have studied plant growing possibilities with LED lights in space facilities. The humans in space and the plant growing plans in space is also very popular topic among those who study LED lighted greenhouses. As we mention in [3] most of the studies we found back then were about that topic. Naturally the energy efficiency, light weight, small size, vibration resistance and wide operation temperature range makes LEDs suitable for space applications.

More earthbound experiments were done by Trouwborst et al [8] when they experiment with intracanopy lightning with T-SON lights and LEDs. Intracanopy lights means that not all lights are above plants, but some are in the middle of plants, this means the same what we planned with placing LED curtains between plants. They find some problems with intracanopy lighting, but overall they conclude it may be more efficient. They also find some problems with the LED lighting and cucumber leafs were darker than with normal lighting.

Iwai et al [9] have studied the amount of caffeic acid, rosmarinic acid and luteolin-glucoside in red perillas cultivated under red and blue LED lights or in normal greenhouse. They conclude that the content of acids were about 7 times higher in the plants grown under LED lights, whereas the content of luteolin-7-O-glucoside was 20 times higher. These are interesting results and we plan to do some similar tests that are explained in chapter 5.

3. Our LED Greenhouse Project

In 2007 we started a project to investigate the use of LED lighting in greenhouses (fig 2a). We started to discuss cooperation with the MARTENS Garden Foundation, and in those discussions it became clear that LED lighting would be most useful as the interim lighting when growing greenhouse tomatoes. Currently hot discharge lamps are used between tomato lines (fig 2b), there would be clear benefits if those could be exchanged to the hang curtains of relatively cold LED lights. The second thing we agreed was it would nice if we have prototype of the LED greenhouse for experiment with the cultivation of plants, the prototype should be so small that we could carry it and present it at the exhibitions. We decided we would build a mini-size prototype and present it at the agricultural exhibitions.

Our mini-size LED lighted greenhouse is 126 cm wide and the diameter is 36 cm, the efficient size is only 110 cm, since the ends take 16 cm of, and the distance between floor and LED plates are 28 cm, and the actual plant is even closer to LED plates. So, this prototype can only be used to grow plants until some 20 cm tall, after that they must be removed and plant to another location.

Figure 3. shows our greenhouse at the exhibition, note the fan at the end of the greenhouse (closer in fig. 4a). We installed an old computer case fan on both ends of the mini-greenhouse, the one blows in and the other one out. This way our plants get fresh air and the ventilation also prevents moisture accumulation on the tube walls, and it also reduces the chance of mold growth. One problem we did not pay enough attention when building the greenhouse was the irrigation system. Now we have to remove one end and pour water from there. This gets more difficult when plants grow taller, leading uneven watering between the plants in the sides and in the middle. This kind of watering is a bit messy also.

The lighting conditions in our mini greenhouse can be changed with the help of computer. There is a PIC processor inside our greenhouse (Fig 4c) which acts as a slave, PC can send commands to the PIC, and on that basis it switched on some or all of the LEDs. There are two colors of LED, PIC can also turn on only some or all 505nm cyan-colored LEDs or some/all 660nm red LEDs. The total electric consumption of five LED plates is 30W (fig. 4b).

a) b)

Fig. 2. a) The typical Finnish greenhouse used to grow plants during the winter b) The hot hanging interim lights between tomato lines.

Fig. 3. The LEDall II mini-greenhouse at the exhibition.

The possible optimization of lighting conditions must be done by PC. We could attach light sensors to the PC and run e.g. genetic algorithm in PC to optimize the lighting conditions and the send the corresponding commands to the PIC slave.

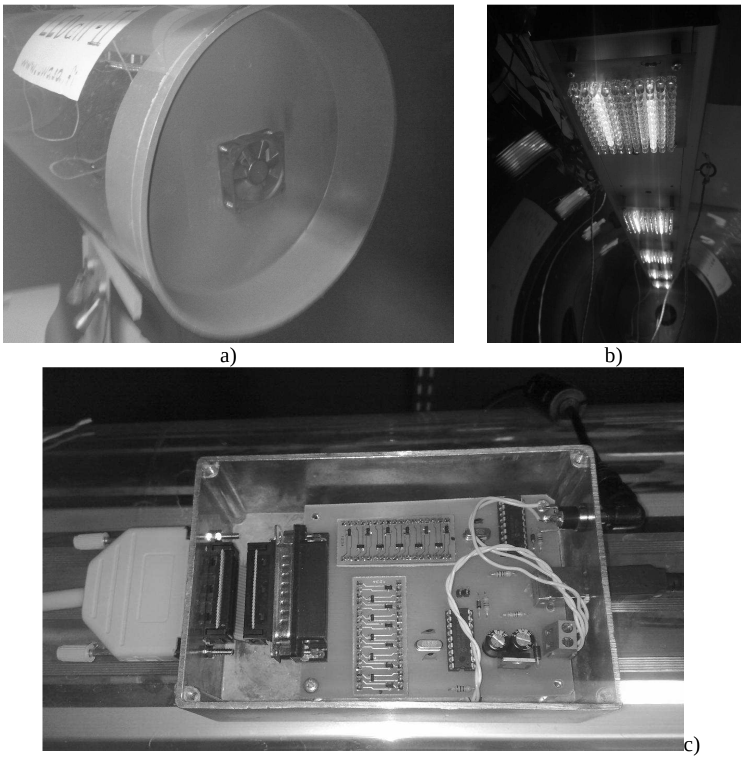


Fig. 4. The LEDall II mini-greenhouse views a) The fan at the side b) LED plates inside c) the PIC based controller unit.

We measured the illuminance curve of our (fig. 5) of our LED lighted mini greenhouse. As one can see from the figure the lighting conditions in our mini-greenhouse varies greatly by location, under the five LED panels there are lot of light, but in the middle of panels there is not much light. This problem might be fixed later, if we continue to use this model of LEDall in scientific experiments. At the moment the plants grow only directly under the five LED panels. Those seeds that are located between LED panels are stunted and often died. The figure also shows the measurement of the photon flow across the chlorophyll range, this curve is practically identical with the illumination curve. The information about chlorophyll range efficiency is important because the light in that range is what gets the plants grow.

The maximum illumination in the plants root level of our mini-greenhouse 1951 lx, while directly under the middle LED panel it is 18518 lx, when the probe touches the LEDS. Corresponding numbers for chlorophyll range photon flow are 79.0 and 368.1 μmol/m^{2}s. These numbers explains why the plants growing inside our greenhouse wants to grow directly under the LED-panels and when they get taller their leaf touches the panels.

Fig. 6 shows some examples of our plant growing experiments inside the mini greenhouse. In fig 6a there is dill, note that the dill only grows directly under the LED plate, those seeds between LED plates do not get enough light and does not grow. In fig. 6b there is potatoes, one can see that potato leafs have grown attached to the LED plates.

Obviously mini greenhouse was not ideal for growing potatoes since they grow too fast and too tall.

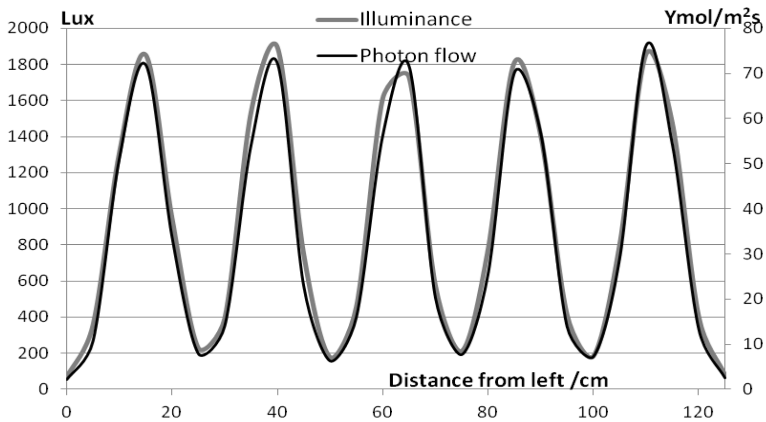
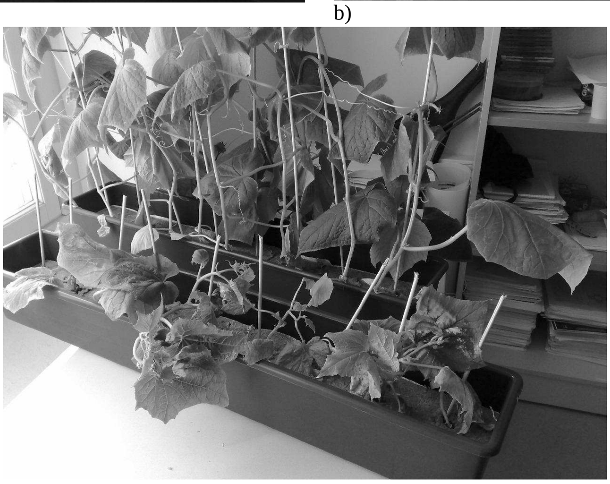


Fig. 5. The illuminance and photon flow across the chlorophyll range curves of our mini-greenhouse.

a)

b)



c)

Fig. 6. The plant growing experiments a) dill, b) potato, c) cucumber.

In fig. 6c there are two sets of cucumbers, the ones in the back have grown in the sunlight by the window and the ones in front have grown in our mini greenhouse, they have never seen any other light than the LED lights inside our greenhouse before this comparison. These two sets of cucumbers are exactly as old, about five weeks. The ones that have grown in our greenhouse are stunted compared to the ones that have grown in the sunlight, the sunlight ones are about five times taller. This shows us that our LEDs are not powerful enough for growing healthy plants. This is partly why we are now planning a new version of the greenhouse.

We also find out that practically all plants (cucumber, tomato, dill, potato, eggplant, capsicum annuum) we have tested grows too tall to our greenhouse, the only exaction being the Finnish forest strawberry.

We have had more success at the exhibition part of the project than in the scientific part. The mini LED greenhouse have been proved to be very popular stop among participants, an creates a lot of discussions. We have also been presented in a number of newspaper articles, the most notable being in the largest Finnish agricultural newspaper [10].

4. Future Plans

We are currently planning a new LEDall III version, which would stand in upright position. It would only host one plant, but the plant would have space to grow as tall as it likes, since the new model would be roofless. We are considering the use of RGB LEDs this time because they could allow us showing interesting light effects on the exhibition use. However, the wavelength of LEDs must be close to the chlorophyll absorbance numbers.

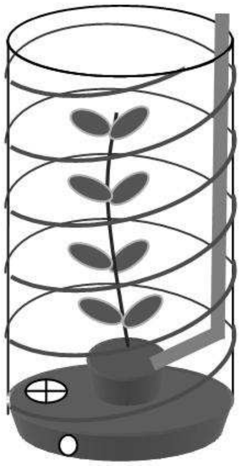
Fig. 7a shows the design of the new LEDall III mini-greenhouse. The outside wall is transparent polycarbonate, and the LED stripe spirals the outside wall. New prototype also has pipe for adding water to the plant in order to prevent watering issues we had with the current model. There is fan in the bottom and a hole for air intake, air will flow upwards, the model is roofless, so the plant can grow out of the greenhouse. The new greenhouse is used more realistically with the help of outside sunlight. The normal large greenhouses also use sunlight as much as possible and their walls are transparent.

The new greenhouse is controlled by Arduino based program, some experiments with the light sensors and LEDs are already been made (fig. 7b). New features would include steady lighting, i.e. photosensor feedback is used to ensure exact lighting conditions, LEDs will give more light when the outside light reduces.

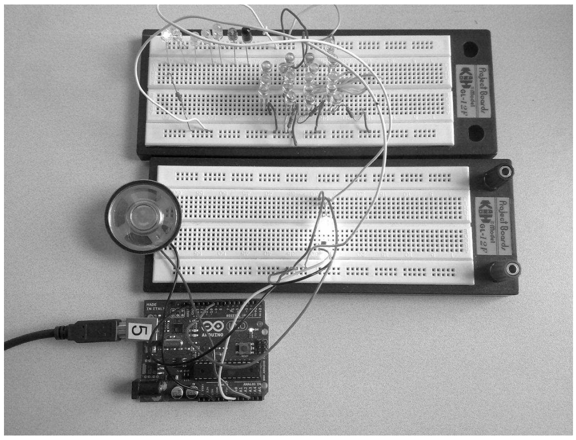
We are also planning to program genetic algorithm directly to the Arduino in this version in order to optimize lighting conditions, and in order to see if the Arduino based GA is useful.

We have also planning to play sounds for the plants, since some studies have suggested that the plants grow better with classical music. We think that the music would also interest participants in exhibition. Unfortunately we do not afford to pay copyright payments, so we have to stick with our own melodies, but we are currently also experimenting with playing sounds with Arduino.

We have also had ongoing project FIELD-NIRce (http://www.fieldnirce.org/) where we built a carry bag, field bag, that can be used for near-infrared (NIR) measurements. With carry bag we have made measurements such as trying to identify plant diseases from the spectra. The aim is soon to make comparative plant breeding experiments with some plants grown in the LED lighting and same plants under the normal room light in a sunny window. After the plants have grown we measure their NIR spectra and explore whether a pants under the different light conditions also has different NIR spectra, i.e. whether they have some chemical differences.



a)



b)

Fig. 7. a) The design of new LEDall III mini greenhouse for one tall plant. b) The Arduino experiment board used to create control software for our new mini-greenhouse.

5. Conclusions

The scientific part of this project have not been highly successful, we have found several drawbacks in our mini greenhouse. However, we have been able to grow several different plants under the LED lights which show that they can be used, but more ambitious plans must be implemented after we have built the next version of the mini greenhouse. All the knowledge collected with the experiments during this project is valuable when designing better apparatus LEDall III.

The exhibition part of the project has been successful, this kind of interesting device have been proven to be good way to exhibit our research in the University of Vaasa. Several people have also asked to buy one LED pipe like this one and asked the price. It seems that there would be some amount of commercial demand if we would start to sell these mini greenhouses. The new upright standing version of the greenhouse LEDall III would be nice decoration device for homes. Many exotic plants do not grow that well in Finland, but they might succeed inside this device in the Finnish living rooms.

Acknowledgements

The European Union Interreg Botnia-Atlantica project Field-NIRCe is acknowledged for cooperation within this project. The authors also like to acknowledge the late Martens Trädgårdsstiftelse for cooperation within this project.

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