Using the LED Lighting in the Greenhouses – a Pre-study

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Abstract
In this paper, we describe our ongoing project of studying the use of LED lighting in special circumstances, e.g. in greenhouses. So far we have build a small prototype of LED greenhouse that we have showed in the exhibitions. We have grown seeds and they grow with only LED lighting, but we do not yet have any real results of how well they grow compared to normal lighting, or what is the comparable energy need. We have measured our planthouse lighting spectra and compared it with the absorbance of leafs of those plants that we are growing.

Keywords
LED, greenhouse, plant growth, planthouse prototype, lighting spectra, absorbance

1 INTRODUCTION
This pre-study is a survey and review of what kind of research has already been done in the LED-greenhouse area, since we need to know what is already been done and what are the results, so that we can direct our research towards the open questions.

Originally LEDs were invented 1962. But the first LEDs were quite dim. Long time they were mainly used as signal lights. Although some people suggested already back in the 1960's that they will eventually replace the light pulps. However, it took till 1993 when the bright blue LED was invented before this development could really start [1]. Since then the LED-techniques have developed and grown quite rapidly.

Some countries are already making laws requiring more energy efficient light equipments, *e.g.* Australia has decided that after 2010 the lighting systems are only allowed to use energy saving lamps (Compact fluorescent lamp) or LEDs [2]. Also in Finland there is some discussion about banning the traditional light pulps [3].

The lighting uses approx. 30% of the all electric energy produced in the world. Since LEDs use only about 20% of the energy that the light pulp with the corresponding illumination, the use of LEDs could produce large energy savings.

Most of the LED greenhouse studies are published by NASA *etc.* scientists studying how the spacecraft could be self-sufficient in the long spaceflights and how the biological life support system for space crews and space agriculture could work [4], [5]. Obviously the advantages of LED greenhouse in space flight are the low energy demand and the low weight of the lighting system.

Later, the LED lighting have also started to interest the greenhouse farmers right here in earth as well, mainly due the lower energy demand, but also because with LED lighting, the used light frequencies can be concentrated only on those that the plants require for growing, and therefore produce no wasted light energy.

The main advantages of using LED lighting in general are thought to be [2]:

- Low energy consumption
- Long lifetime
- Small size
- Fire safety, do not produce excess heat
- Slow voltage, make them safe and enables the use with battery powered devices

1.1 Related work
The idea of using LED lighting in greenhouses was patented in USA first time back in 1991 [6]. In this patent they describe how to use optoelectrical device for illuminate plants with appropriate wavelengths. It seems that patent is more about representing the idea with chlorophyll absorbance wavelengths than actual technical detail what kind of optoelectrical device is actually used.

The same principle has been patented also later [7]. This patent present plant cultivator system for research purposes with LED illumination element. They represent squared box type prototype of small LED greenhouse.

Moreover, patent [8] describes LED lighting system with different wavelength LEDs and the angles of LEDs for commercial or home plant growth.

In Finland there is currently at least one patent application for a kind of "light curtains" for greenhouses [9].

The use of LED lights in greenhouse do not limit just to the illumination. There is also studies of how insects could be detected and expel from the greenhouse by using LEDs [10]. There is also studies proposing devices that observe plant health and diseases based on LED light [11].

Despite the already published studies, this research area is still quite fresh, *e.g.* IEEE Xplore do not find any research studies with the keywords greenhouse + "light emitting diode" or "LED". This means that the technical aspects of LED greenhouses are still mainly unstudied. Most of the research papers of this field are published in biological or agricultural journals. There are also many whitepapers in the internet, and a few master studies [9], [12] of this subject have been written.

2 OUR LED GREENHOUSE PROJECT

We have previously worked with LEDs when we built an illumination apparatus, LEDAll that uses LED lighting and optimizes the lighting condition with genetic algorithms for an object to be photographed [13].

We start to build our greenhouse prototype by searching from the internet what light frequencies the plants need for growing. Li [14] have measured the absorbance curves of chlorophyll A and B in the diethyl ether (fig. 1).

Chlorophyll is a green pigment found in most plants. The name is originated from the ancient Greek: chloros = green and phyllon = leaf. Chlorophyll absorbs light most strongly in the blue and red wavelengths, but poorly in the green portions of the electromagnetic spectrum. This causes the green color of those organisms that contain chlorophyll, like plant leaves. Chlorophyll is necessary for photosynthesis. The function of chlorophyll is to absorb light and allow plants to obtain energy from light [15].

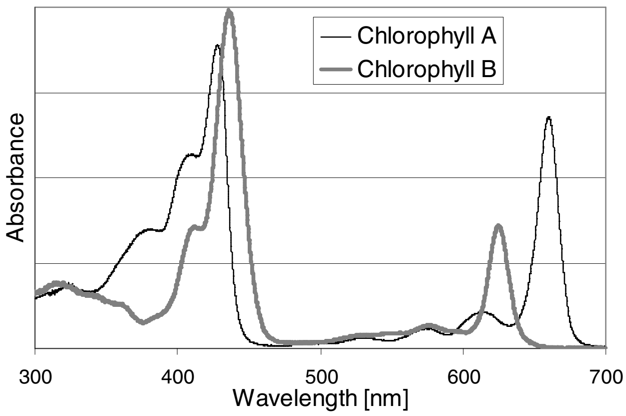

Figure 1. The absorbance curves of chlorophyll A and chlorophyll B [14].

From the fig. 1 it is easy to see that the plants mainly need light frequencies between 400-500nm and 600-700nm. However, there exists research study claiming that the seeds need some green light as well [16]. Subsequently, we decided to install mainly 660nm red LED lights to our greenhouse, and also some 505 nm cyan LEDs.

In figure 2 there is a picture of our LED greenhouse prototype. It is a plastic tube about 1.3 meters long and 40cm by diameter. It has fans at the both ends, and five LED elements in the inside roof. The LED elements contain two different kind of LEDS; red (80%) and cyan (20%). The lighting conditions (intensities of red and cyan) are controlled by a computer that sends the instructions to the PIC based embedded control box in the top of the tube. The computer also handles the lighting periods, 18 hours of light per day, and 6 hours dark. The plants need night period for resting and growing roots.

The plants are put inside. They are seeded in mineral wool cubes that are watered beforehand with fertilizer liquid. The prototype does not have sprinkler system. Thankfully, in the early stages the seeds do not require watering. In the later stages, it is done manually.

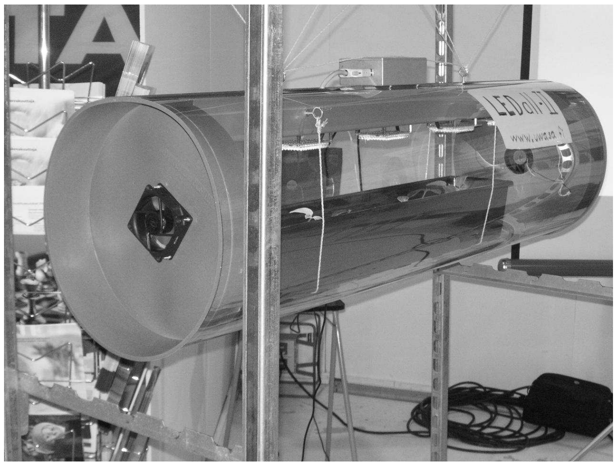

Figure 2. Our prototype of LED greenhouse.

Figure 3. The cucumber seedlings grown inside the LED greenhouse.

Figure 3 shows some cucumber seedlings that have been growing inside our LED greenhouse. The seedlings have never seen natural light or any other light except the LED light with the spectra shown in figure 4.

The seedlings grown in LED light seem to grow less tall and leafier than those grown with natural light. This might be due that they get enough light energy inside LED tube without growing the extra height.

However, with natural light all seeds start to grow, with LED light 20% of seeds start to grow, but died, another 20% grown stunted, only 60% of seedlings grown normally and looked healthy.

The reason that causes some seeds to die or stunted might be the lack of blue and green light [16] inside our LED greenhouse. The other reason might be the lack of light for those seeded between the LED elements, since all the seedlings exactly under the LED elements grown healthy, and those that died or stunted were under the gap between LED elements. The LEDs have quite narrow illumination angle, so it seems that this might cause some seeds to lack of sufficient light energy.

We have measured an absorbance curve of cucumber leaf through the thin leaf (fig. 4). This leaf was gown normally in the sunlight, not with the LED lighting, because we think the lighting condition may have an effect on absorbance. We are planning to measure leafs grown with LED lights and compare the absorbance curves later.

Figure 4 also represents the lighting spectra of our LED greenhouse (all LEDs with maximum power). The spectra have two peaks at 505 and 660 nm, but there are also some light also in neighboring wavelengths.

The higher LED spectra peak at 660 nm is quite well located to the same wavelengths as the higher absorbance peak of cucumber leaf (fig. 3). The other LED spectra peak at 505 nm is not so well co-located with leafs lower wavelength absorbance peak.

It seems that our 505 nm LEDs have a bit too high wavelength. This cyan was selected due that they had higher intensity than the other blue LEDs available with reasonable price. We still have four LED element positions free in the greenhouse prototype roof, so we plan to install more suitable blue LEDs there in the future.

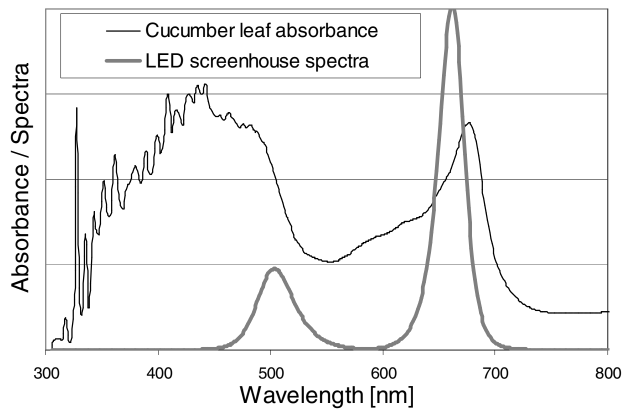

Figure 4. The absorbance curve of cucumber leaf and the spectral curve of our LED greenhouse lighting.

Figure 5 collects the theoretical absorbance curves of chlorophyll A and B from [14], and our measured absorbance curve of the cucumber leaf. From the fig. we can see that for some reason the measured absorbance curve is quite different from the theoretical. The lower absorbance peak spreads for wider frequencies (320-520 nm) than the theoretical frequencies (400-470 nm).

Also the measured higher frequency peak is in higher frequency (avg. 677 nm), than the theoretical peaks (chlorophyll A avg. 660 nm and chlorophyll B avg. 625 nm). These differences may be due measurement device error or inaccuracy. Due that error, we cannot determine from our measurements whether the cucumber leaf contains more chlorophyll A or B. However, the higher frequency peak measured at avg. 677 nm would hint more towards chlorophyll A.

Figure 5 also shows the spectral curve of our LED greenhouse. We can see that the higher frequency illumination peak is exactly concentrated on the same frequency as chlorophyll A. The lower frequency illumination peak is even worse located with the theoretical chlorophyll absorbance's than with the measured one. This means that we need to add some more accurately selected blue LEDs to our prototype later.

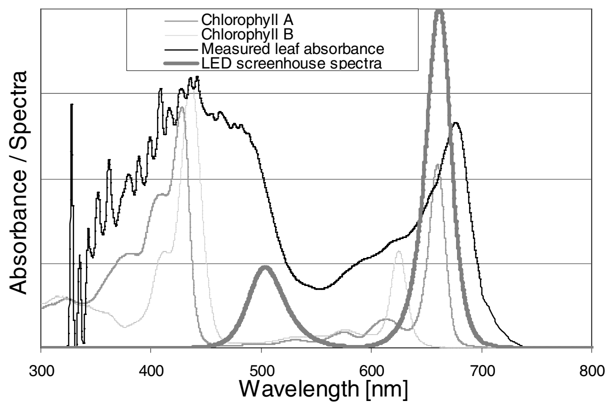

Figure 5. Theoretical absorbance curves of chlorophyll A and B, and the measured absorbance of the cucumber leaf and the spectral curve of our LED greenhouse illumination.

Our greenhouse has been very popular stop in the exhibitions and it has raised a lot of conversations. Also some newspaper reporters in the exhibitions have wanted to write article with our interview about this project and the pictures of the prototype [17], [18].

3 CONCLUSIONS, DISCUSSION AND FUTURE

Due the lower energy demand and therefore also lower cost and other benefits of using LED lighting in the greenhouse the number of studies in this area are expected to expand greatly in the near future. Hopefully our research project will also provide some meaningful knowledge for this area in the future.

Based on our experiments we have think that the optimum lighting conditions for plants might be the one, where the plants would look like black. Because, that would mean that they absorb all the light directed to them, and would not reflect any wasted light.

The light should also penetrate inside the plant, but if the lighting would be just so intense, that the minimal percentage of the original light would pass through the leaf, we would have optimal lighting (total absorbance). Of course this requires the condition that leafs do not shade each other. If they shade, then more light intensity is needed.

Another use for LEDs in the greenhouse might be guiding the bees [19]. The greenhouse farmers have figured out that bees are blind during the winter, when the greenhouse lacks the natural light from outside. This is considered to be due that insect's eye sees more ultraviolet light than the human eye. The high-pressure sodium lights currently used in the greenhouses do not emit light in the wavelengths that bees require for seeing.

Some plants do require the pollination by the bees; therefore LED lighting might be an answer, if ultraviolet LEDs are installed in the greenhouse. However UV light is generally harmful for plants and animals, therefore the less ultraviolet light is usually hoped. Normal LEDs do not emit UV light, which is good in the normal illumination. In the greenhouse some UV light might be helpful for bees, at least in the pollination period.

Another benefit of LEDs is that they can be much closer to the plants than the high-pressure sodium light pulps, because LEDs are not as hot. Sodium lamps will dry or burn the plants, if they are too close.

Due the same reason with LEDs we can install illumination elements between the plants [9], so that more of their leafs gets light energy, also the lower leafs in the sides, not just the top.

So far we have not considered how actually install the LED illumination system in the full-scale greenhouse. Later in the project we will also consider these issues.

ACKNOWLEDGMENTS

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