Indoor Agriculture: Measurement of The Intensity of LED for Optimum Photosynthetic Recovery

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***Abstract*—Indoor agriculture has begun in urban areas. With the narrowness of land and the model of vertical house development, makes this method of indoor agriculture has become a trend in several big cities in the world. Meanwhile, the one that is always needed by every plant is photosynthesis, and every natural photosynthesis of plants continually requires abiotic components of visible light from sunlight. That's why the indoor agriculture requires a replacement source of the sun with artificial sunlight. We can make this artificial sunlight from several light sources, such as incandescent lamps, compact fluorescent lamps (CFL), or the latest with Light Emitting Diode (LED). In this paper, we measured the intensity of light generated from several LEDs with some radiation distance to obtain the optimal energy for plants photosynthesis.**

Keywords—component, formatting, style, styling, insert *(key words)*

I. Introduction

Because the more narrow and expensive in the urban land that can be used to create a house and its yards, it makes people prefer the concept of small home development or with the concept of vertical development.

The development of housing with such a concept makes the availability of land for planting plants becomes difficult, and people can no longer plant the plants in their yard. Moreover, this makes the indoor farming has been a big concern in urban areas these days.

The natural visible sunlight is one of the essential factors for plant growth. In locations where sunlight as a natural light source is not sufficient for optimum plant growth, a replacement light source may be used[1].

There are several ways to get traditional artificial light sources, such as the use of incandescent, halogen, fluorescent, mercury, High-Pressure Sodium (HPS) and Low-Pressure Sodium (LPS) lamps[2].

The use of these lamps can produce high light intensity but is very inefficient because it requires high electrical energy. Besides these types of lamps also produce high heat -so for indoor use, it will require adequate cooling.

In general, the lighting in an urban home needs averages 50% of the electricity consumption[3]. So when applied these traditional lamps -which require such tremendous power as a light source of the solar substitutes, it will increase the need for electrical energy very significant.

Meanwhile, the need for light intensity for photosynthesis of each plant is many. Some require high intensity, and some are not. Therefore, the selection of lamp power used should also be considered so that this artificial light source has high electrical energy efficiency.

II. Light Emitting Diode

Optoelectronic technology developed rapidly since the mid-1980s. One of these developments is that it has significantly improved the brightness and efficiency of LEDs.

LEDs are one type of the semiconductor diode, which consists of the semiconductor chip with a p-n junction -that formed when p-type and n-type p-type semiconductors are referred to as p-n junction diodes. The p-n junction diodes are made of semiconductor materials such as silicon, germanium, and gallium arsenide (figure 1).

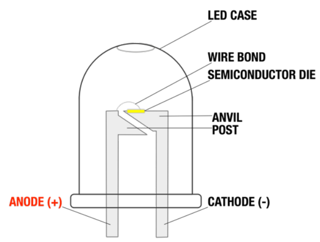

Fig. 1. Light Emitting Diode (LED)

With this p-n connection, the electric current will flow smoothly from the p-side (anode), to the n-side (cathode), and not in the backward direction. When electrified, the electrons and holes (the absence of the electron in a particular place in an atom) flow to the p-n junctions of the electrodes. Then, when the electron fills the hole, it falls to a lower energy level and releases energy in the form of photons[4].

The wavelength or color emitted by the photon on the LED has a relatively broad spectrum of possibilities. This wavelength depends on the bandgap energy on the substance that helps the p-n junctions. Some materials can radiate in near-infrared light, visible or almost ultraviolet light [4], [5].

At the beginning of the mid-1980s, GaAlAs (gallium aluminum arsenide) materials were developed to anticipate fast growth in LED use. The use of GaAlAs material provides better performance than previously available LEDs. The need for LEDs with lower voltages ultimately results in overall

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power savings. LEDs with low power can finally be easily connected with Pulse Width Modulation (PWM) to be multiplexed making it suitable for use as outdoor advertising boards.

During this 1980s development period, LEDs are also designed to be barcode scanners, data transmission at fiber optic systems, and medical devices.

The modern improvements in crystal growth and optical design have enabled LEDs in the primary color spectrum -red, green, and blue. So by using the PWM on these three primary colors of LEDs as the base colors, other colors can be made more easily. Therefore currently, the use of LEDs as the basis for the visual display of electronic devices is widespread to use. Telecommunication products, automotive applications, traffic control devices, and colorful message boards, even LED TVs are also commercially available.

Table 1 is a list of some common LED types and the resulting colors [3], [4].

TABLE I. COMMONS TYPE OF LED

Wave Length	Color	Substrate
730 nm	Far-Red	GaP
700 nm	Red	GaP
660 nm	Red	GaAs
650 nm	Red	GaAs
630 nm	Orange-Red	GaP
610 nm	Orange	GaP
590 nm	Yellow	GaP
585 nm	Yellow	GaAs
565 nm	Green	GaP
450 nm	Blue	GaN/SiC

Why are the use LEDs preferred? Comparing with the light range of 8,000 hours of fluorescent lamps, exceedingly a 1,000 hours of incandescent light's, LEDs have a very much longer life of 100,000 hours. In addition to its long life, LEDs have many advantages over conventional light sources. These advantages include small size, a specific wavelength, low thermal output, customizable intensity and light quality, and high photoelectric conversion efficiency. These advantages make LEDs perfect for supporting plant growth in controlled environments such as plant tissue culture spaces and growth spaces.[4]

III. LED FOR ARTIFICIAL SUNLIGHT

The question that often arises when discussing the ideas of LED as a substitute for sunlight for the plant photosynthesis is, can LEDs replace the sunlight? The sunlight is polychromatic while light from LED is monochromatic, so is it can do the substitution?

A. The Sunlight and Plant photosynthesis

Sunlight reaches the earth in a vast spectrum. Starting from below 200 nm to more than 2000 nm[6]. This spectrum or wavelength of the sunlight generally can be divided into three areas (figure 2):

- Ultra Violet ray, which is an invisible light for human eyes, with wavelengths below 380 nm. This region of light spectrum consists of several types, namely:
  - Ultraviolet C, i.e., light with the wavelength of 200 nm to 280 nm. This light is harmful to plants because it has high toxicity. UVC from the sun usually never reach the surface of the earth because the ozone layer blocks it.
  - Ultraviolet B or light with the wavelength from 280 nm until 315 nm. Although this light is not harmful to plants, it can cause the color of the plants to fade.
  - The wavelength from 315 nm to 380 nm referred to as ultraviolet A (UVA), this light does not affect (both positive or negative) on plants.

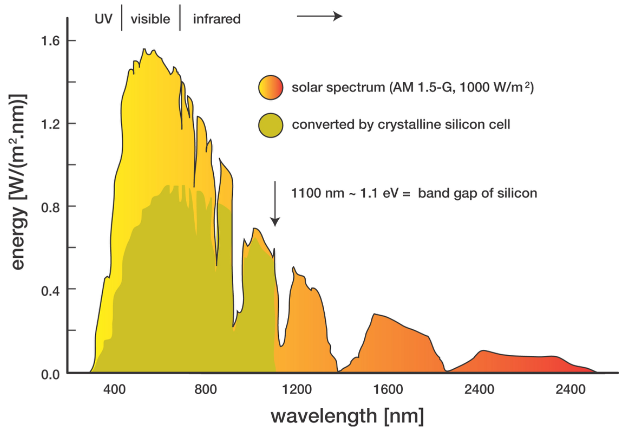

Fig. 2. Sunlight Spectrum[6]

- The visible light, which is the light that can see by the human eyes. For plants photosynthesis, is divided into several areas and benefits:
  - The wavelength from 380 nm to 400 nm as ultraviolet A or the beginning of visible light. At this wavelength, the process of light absorption by plant pigments (chlorophyll and carotenoids) begins.
  - Visible light at the wavelength of 400 nm to 520 nm containing purple, blue and green. At this spectrum peak absorption by chlorophyll occurs and this spectrum has a strong influence on vegetative and photosynthesis.
  - Visible light at the wavelength from 520 nm until 610 nm, that containing green, yellow, and orange light. At these wavelengths are less absorbed by plant pigments, the lesser effect on vegetative and photosynthesis.
  - The visible light at the wavelength of 610 nm to 720 nm contains the red light. Plants again absorb the light at this wavelength and considerably affects vegetative growth, photosynthesis, flowering, and proliferation.
- Infrared light, which is also a not visible light to the human eye with wavelengths higher than 720 nm.

- At the wavelength of 720 nm to 1000 nm, known as far-red or infrared light, this light affects the germination and flowering of plants, although only a small amount of absorption occurs in this band.
- Wavelengths above 1000 nm, all absorption at this spectrum will be converted into heat. So the plants do not use it.

B. *LEDs and photosynthesis of plants*

Plants always need light throughout their lives. Starting from the first time when it is yet a sprout, until becoming a flowering and producing as an adult plant. There are three light parameters required by all plants, namely quality, quantity and duration[1], [7]:

- The quantity of light or intensity is the primary parameter that affects photosynthesis. Photochemical reactions within the plant cells require the energy of that light to convert CO_2 to carbohydrates. So the intensity of the lights will determine the success of this reactions.
- The quality of light or spectral distribution refers to the distribution of the light spectrum, i.e., which part of the emission is in the wavelength region of light. These wavelength regions are divided into blue, green, red regions and invisible wavelength regions. The quality of light also affects the shape of plants, development, and flowering (photomorphogenesis)[7].
- The duration of light or photoperiod is how long the plant accepts the light with a certain quantity and quality as above. This duration especially needed at the time of plants in the flowering phase, so the flowering time on plants can be controlled by arranging photoperiod [7].

Light sourced from the LEDs can meet the first parameter and the second parameter required by the plant as above. The intensity of light can be generated by using a substantial LEDs power to produce sufficient light intensity. Alternatively, it could also by using some LEDs light sources.

Meanwhile, the photoperiod is very easy to set. Since the LEDs as a light source is dependent on the presence of electric current, so long as there is an electric current in the house, the photosynthesis of agriculture in this room can also be done.

Which then becomes the question is, whether the LEDs can replace the quality of light such as sunlight?

In some studies, it was found that in conducting photosynthesis, plant chlorophylls responded most strongly to red and blue regions. Although plants receive all the spectrum of sunlight, plants do not use the entire spectrum for photosynthesis. Photosynthesis absorbs only light with a wavelength of 400nm up to 700 nm -which is part of human-visible light[1], [5],[7].

Chlorophylls (chlorophyll a and b) are the essential actors in photosynthesis (figure 3), although they are not the only chromophores. Plants also have other photosynthetic pigments, known as antenna pigments (such as carotenoid β-carotene, zeaxanthin, lycopene, and lutein), which participate in the absorption of light and play an essential role in photosynthesis[8],[9],[10].

From figure 3 and Table II, can be seen that in the photosynthesis plants not all spectrum of light is needed, also not all the visible light spectrum is absorbed by chlorophyll and antenna, only a part is required.

TABLE II. WAVE LENGTH OF LIGHT FOR PHOTOSYNTHESIS

Wave Length (nm)		Known As	V/I	Absorb by Plant
200	280	Ultraviolet C	I	N
280	315	Ultraviolet B	I	N
315	380	Ultraviolet A	I	N
380	400	Ultraviolet A	V	Y
400	520	Purple, Blue, Green	V	Y
520	610	Green, Yellow, Orange	V	Y (but lesser)
610	720	Orange, Red	V	Y
720	1000	Infrared	I	N

(V)isible, (I)nvisible, (Y)es, (N)o

The chlorophyll A absorb more in purple, blue, and red. Meanwhile, the chlorophyll B absorb more in blue and red. Last, the antenna absorbs the purple, blue, and a little green.

As we know above, that the photosynthesis process does not require a full-spectrum visible light, that is why the light from LED can be used as artificial sunlight for photosynthesis. Meanwhile, the LEDs can generate sufficient light at specific wavelengths, turn on and turn off very quickly, then the photosynthesis of plants linked with the solid state LED characteristics is an energy-saving way to indoor agriculture with the low power consumption.

Other artificial light sources do not easily achieve this way.

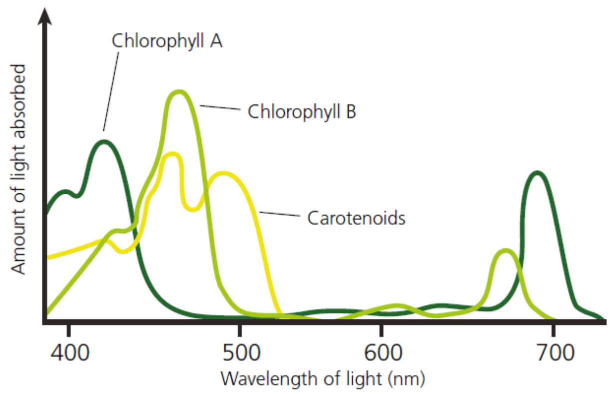

Fig. 3. Spectral Absorption by Plants[6]

IV. MEASUREMENT OF LED LIGHT INTENSITY

Our experiment on Automatic Plant Acclimatization Chamber (APAC) uses LEDs as the light source -for replacement of sunlight[11]. This experiment aims to create a smart Plant Growth Chamber, which can simulate a specific micro-climate in a specified location and period automatically.

The use of LEDs in this experiment becomes mandatory because only LEDs can be used as artificial light sources with the ability to turn on and turn off quickly. Other light sources take time to reach the maximum of intensity that can be generated.

Besides, only LEDs that can reduce the intensity of light with a simple microcontroller. The intensity reduction in this experiment uses Pulse Width Modulation (PWM) and then reduce the LED duty cycle to decrease the intensity of the generated light and increase the duty cycle to raise it -up to 100% duty cycle for maximum LED light intensity.[12]

This APAC Experiment uses High Power LEDs (HP-LED) with the following specifications:

- light color : 6000 - 6500 Kelvin
- voltage : 9.5 - 12 volts DC
- input current : 900 mA
- light intensity : 800 - 1000 lumens
- view angle : 120 degrees

HP-LED is one type of LED that has higher power and brightness compared to conventional LEDs that require little power and produce less brightness. The conventional LED has an input current 20 mA and principally LED with input current higher than 20 mA is called as HP-LED. Currently, HP-LED widely applied to the headlamp of the car, flashlight, lighting fixtures, and so forth.[13]

HP-LED is an energy-efficient building block that produces ideal lumen output for the latest lighting applications. HP-LED offers the best possible solid-state light source[14].

A. Experiment Setup

For this measurement of the intensity of HP-LED, we prepare a chamber of 2 meter by 2 meter as the place of the experiment. This chamber is designed not to reflect the inner-sourced light, and also can not penetrate the light from outside sources. Therefore, the chamber gives the black color of the inner walls (figure 4)

Fig. 4. Darkbox Design

HP-LED will be placed right at the top center of the box as a light source. Some TSL2561 sensors packaged in an array of sensors, placed on board as a luminosity sensor. This boards can be raised or lowered as needed near or away from light sources. Before the actual measurement, the reading results of each TSL2561 sensor were recorded first as a comparison when reading TSL2561.

B. LED Radiation Pattern

The specifications of the HP-LED makers that used in this experiment said that its view angle is 120 degrees. So, that when HP-LED is installed in height 1 meter from the sensor so that when described in triangle form will be like in figure 5

The calculation of the width of light to be received from

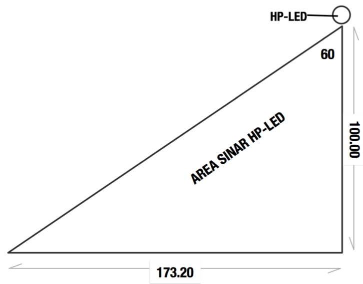

Fig. 5. 2D of Light Area

HP-LED can be calculated by the trigonometric formula: tangent (equation 1).

$$\tan\theta = \frac{Opposite}{Adjacent} \qquad (1)$$

So if the HP-LED is at an altitude of 1 m (100 cm), then the spread of the light of the HP-LED has the radius of 173.20 cm or a diameter of 336.40 cm.

The measurement with the TSL2561 sensor produces an image of the radiation pattern as shown in Figure 6.

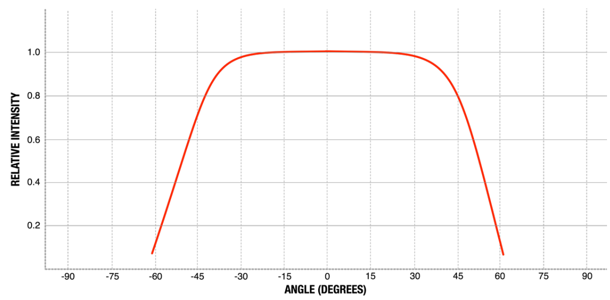

Fig. 6. HP-LED Radiation

C. LED Intensity

The intensity of the light is measured by how many luminous fluxes are scattered in specific areas. The amount of light generated by the light source will illuminate the surface fainter if spread over a larger area, so the illumination is inversely proportional to the area where the luminous flux is maintained constant[15].

One lux equals one lumen in square meters or 1 lx = 1 lm/m^2. The flux of 1,000 lumens, if concentrated in an area of 1-meter square, then it illuminates the area of the square meter with the illumination of 1,000 lux. However, the same 1,000 lumens, if spread over 10 square meters, will produce only 100 lux illuminations.

Regarding calculating the extent of this HP-LED ray, since the rays creating a form of a circular area, the counting base used is the circle area (equation 2).

$$L = \pi . r^2 \qquad (2)$$

Since the radius of the light depends on the distance between the HP-LED and the floor, by decreasing equation 1, r can be obtained by equation 3.

$$r = \tan\frac{\theta}{2} . t \tag{3}$$

So the formula of this area of the HP-LED ray can be calculated directly with equation 4.

$$L = \pi . \left(\tan\frac{\theta}{2} . t\right)^2 \tag{4}$$

Finally, the HP-LED Illuminance at a certain height can be calculated by equation 5.

$$lx = \frac{lm}{\pi . \left(\tan\frac{\theta}{2} . t\right)^2} \tag{5}$$

Where lm is the flux produced by HP-LED, θ is the angle of the HP-LED light beam and *t* is the HP-LED height from the base (in meter).

Figure 7 shows the results of the measurement of light intensity compared with the calculation using the formula above.

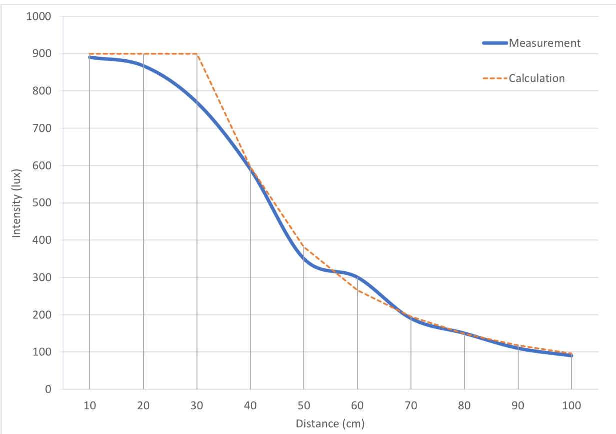

Fig. 7. Lux Calculation (red) and Experiment (blue)

D. Tropical Illuminance vs LEDs

In some research reports the average sunlight illumination that occurs around Indonesia can reach 60,000 lux[16], [17]. This magnitude can rise or fall depending on the weather and the position of the sun on the location where the measurement has been done.

However, for the needs of plant photosynthesis, some studies note that it takes around 400 to 600 lux[18].

To be able to achieve the needs of photosynthesis, it is enough to need an LED with a power of 10 watts and placed at an altitude of 40 to 50 cm above the plant. However, this amount will -of course, increasing when the placement of LEDs is more than 50 cm, and plants that require lighting are in the area more than 2.35 square meters.

This means, the need for electric power for photosynthesis needs of plants in the room can be regulated by increasing or decreasing the distance of the LED from the plant. This power requirement will also decrease if the transmitting angle of the LED beam can be reduced and directed to the required location.

V. Conclusion And Future Works

Plants do not require the entire spectrum of light obtained from sunlight. Plants require only light with a wavelength of 400-700 nm, known as photosynthetically active radiation (PAR). While the LEDs can emit light with a specific wavelength -according to the base material that the manufacturer is making. Therefore, LED is the first artificial light source which can be controlled by an actual spectral composition for the plant.

By using LEDs, the wavelength of light required by plants in it photoreceptors will always be met with the artificial light. Adjustment of the intensity and wavelength of light from these artificial sunlight sources will be able to optimize production as well as to influence the morphology and composition of the plants.

The placement of LEDs positions for specific plants can also be easily arranged, tailored to the specific needs of the plant. Besides LEDs can also be easily integrated into a digital control system, facilitating complex lighting programs such as various spectral compositions during the photoperiod or by the plant development stage.

This experiment needs to be strengthened by the measurement of the light intensity generated by the LED array (multiple LEDs) in some radiation area. The addition of LEDs at a certain distance, of course, does not increase the intensity of light in areas with linear quantities.

For electric power savings, this study should also be followed by conducting another experiment to measure the impact of increasing the voltage and the need of electric current by the LED compared to the intensity of the light generated. Optimizing the use of electric power by LEDs can be achieved by providing a specific voltage for specific intensity needs as well.

Also on the use of PWM to reduce the intensity of LED light. There are still unanswered questions as to whether reducing the duty cycle to reduce the intensity of this light further saves the power than reducing the voltage as the plan above.

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