

Effect of Daylighting and Artificial Lighting on Photosynthesis and Chlorophyll Contents of Indoor Plants

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Abstract

Countries around the world recognize the importance of the lighting energy saving. Many comparative studies on the daylighting and the artificial lighting were realized. However, these comparisons were not precise as the weather varied from hour to hour. The performance of the daylighting and the artificial lighting must be evaluated in the same condition. In this study, two experiment chambers consisting of daylight and artificial lighting were made. In order to make the same illuminance condition, 12 flourscent lamps (32W) were used with dimming-controller. The same illuminance of two chambers could enable the precise comparison experiment. In the photosynthesis, the increasing rate of the plants in daylighting chamber was higher than that in artificial chamber, and in the chlorophyll it was the same. The reason for this result is shown by the difference of spectrum energy. The light-absorbing pigments of plant need the spectrum of the large wavelength. The spectral energy of daylighting consists of ultraviolet, infrared and visible rays. However, the spectral energy of fluorescent lighting is high only at some specific wavelengths.

Keywords : Daylighting, Artificial Lighting, Lighting Control, Indoor Plants, Photosynthesis

1. Introduction

1.1 Background and purpose

Indoor landscaping, which introduces plants to indoor space, has come into the spotlight, not only because it improves aesthetic values of the indoor environment, but it also helps to produce environment-friendly space by providing people with psychological stability and creating productivity and/or comfortableness. Just as the control of indoor environment and maintenance of building are needed for comfortable human life, indoor

plants also need a careful maintenance for their healthy growth and for maintaining the effects of indoor afforestation.

In general, plants introduced to indoor space are used as a component of indoor interiors, rather than being passively located in a greenhouse or by the window. However, they are usually located in spare space as a room's function and effectiveness of space are considered, which makes the light environment insufficient for their healthy growth.

Most plants currently used in indoor landscaping are sciophytes (shade plants) or tropical foliage plants that are different from outdoor plants and can grow even at a low intensity of light. However, if the purpose is a long-term decoration, introduction of an auxiliary light source or daylight that are suitable for these plants should be considered.

In this aspect, two kinds of indoor plant were chosen in this study to examine the usefulness of daylighting and artificial lighting of the auxiliary light source, as well as its function of indoor lighting. Effects of daylighting and artificial lighting on plant

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This research was supported by environment-friendly construction research center, as a part of distinguished research center promotion project of the Ministry of Science and Technology, (R11-2005-056-02003-0)

growth were studied and compared, under the lighting condition of a duct-type daylighting system and fluorescent lamps, respectively. From this, we would like to verify the role and importance of choosing a light source in indoor landscaping space.

1.2 Methods and range

In this study, we have firstly examined the literatures on relationship of daylighting in indoor plants and verified that problems in setting the lighting environment and experiment conditions will give a wrong result. With precise procedures for research and experiment, we have made two chambers in order to compare and analyze the effects of daylighting and artificial lighting on indoor environment. In case of daylighting, the intensity of light coming into the chamber varied from hour to hour, depending the position of the sun and weather condition, while in artificial lighting the intensity remained relatively constant, with only small changes according to the characteristics of the light source and lighting time. Thus, in this study, we have constructed the lighting environment inside the chamber in a way that the output of artificial lighting can vary depending on the change of daylighting. The procedures and methods are described below in detail.

1) In order to assess the effects of daylighting and artificial lighting on the plants, two experiment chambers of the same size and environmental conditions were manufactured.

2) Monodraught's 300mm-diameter Sunpipe (light duct type daylighting system) was installed in the daylighting chamber, while twelve T8 fluorescent lamps (32W) were installed in the artificial lighting chamber.

3) In order to maintain a constant illuminance level in daylighting and artificial lighting chambers, each chamber was equipped with an illuminance sensor. Lighting controller was also installed to automatically control the **출력광속** from the fluorescent lamps in the artificial lighting chamber, according to the measured level of illuminance.

4) Two plant species (*Codiaeum variegatum*, *Ardisia japonica*) were selected as targets. These plants have passed an one-month purification period to stabilize their growth status, and then two-week experiment periods in each chamber condition, after which growth reaction was evaluated by measuring chlorophyll contents and photosynthesis.

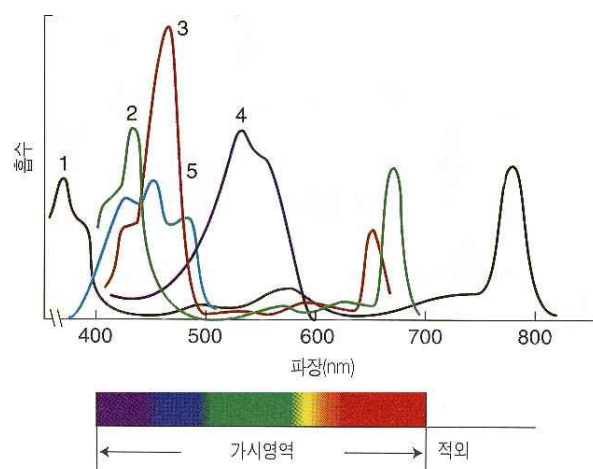
5) In order to exclude factors that may affect the plant growth during the experiment period, temperature, humidity and irrigation amount were set to be the

same. Illuminance, temperature and humidity in each chamber were continuously measured.

6) The intensity of light in each chamber was monitored by measuring illuminance at the same position to ensure the same lighting condition. Finally, through the measurement of light spectrum in visible range, the difference in lighting condition between daylighting and artificial lighting (fluorescent lamp) and the plants' growth status were compared and analyzed.

2. Growth reaction between light and the plants

Every life on earth ultimately depends on solar energy. Photosynthesis is biologically important in this respect, as it is the only process that can obtain such energy. Also, every energy source on earth originates from photosynthetic activity. Photosynthesis literally means 'a synthesis that makes use of light', and photosynthesis creatures use solar energy to synthesize organic materials that cannot be formed without energy. In fact, light energy is used to synthesize carbohydrates from carbon dioxide and water, with oxygen being produced. On the contrary, if light is not sufficient, the growth rate of trunk will be increased and chlorosis will occur.



1: germ chlorophyll a, 2: chlorophyll a, 3: chlorophyll b, 4: picoerythrobilin, 5: β -carotin

Fig. 1. Absorption spectrum of photosynthesizing pigments

The wavelength of light needed for plants is spread over all ranges including UV and IR, and the indoor, artificial lighting will make the plant growth poor. Thus, the influx of daylight into the chamber is the most crucial condition for the plant growth, and the direct lighting comes inevitable for improving the plant's function that affect human life environment.

3. Experiment chambers for daylighting and artificial lighting

In order to compare the effects of daylighting and indoor lighting by fluorescent lamps, experiment chambers of the same size were manufactured. These chambers were installed on the roof of the building of engineering at H university, with the same indoor environmental conditions and sufficient daylight.

The comparison experiment of the plants' growth had been conducted for 10 days, from 26th October to 7th November, 2007.

3.1 제원 of the experiment chamber

Both chambers were manufactured as a cube whose side is 1.15m long, as shown in the Fig. 1 and 2. In daylighting chamber, Monodraught's 300mm-diameter circular light duct was installed to aid a sufficient influx of daylight, and an 1.15m light duct and diffusion plate of indoor diffusing part in order to exclude the indoor shade by a direct ray of light.

Table 1. 제원 of the experiment chamber

Category	Daylighting chamber	Artificial lighting chamber
제원	1.15m(W)×1.15m(L)×1.15m(H)	
Diffusing part at the ceiling	300mm(R)	
Lighting method	Light duct	12 fluorescent lamps (32W)

In case of the artificial lighting chamber, the lighting was done through the 300m-diameter diffusion surface for a uniform lighting in the chamber. It was verified that the illuminance level at the measurement position in the daylighting chamber did not exceed 10,000 lux even at the clear sky condition, and the number of fluorescent lamps was set to be 12, in order to adjust the maximum output of artificial lighting to 10,000 lux at the measurement point.

In addition, by converting the illuminance level measured in two chambers to text and controlling Up and Down of the output from the fluorescent lamps according to the this difference, the lighting controller was manufactured such that the illuminance level in two chambers finally becomes the same. Two sensors, one to record the illuminance level and another to be used as input data, were integrated into one, eliminating the error in indoor illuminance level in two chambers. The structure of the lighting controller is shown in Fig. 5.

Circular diffusing part in each chamber, to which

daylight and artificial light flow in, was located at the middle of the chamber's ceiling. In addition, the chamber was built such that temperature and humidity inside it can be maintained constant without additional controlling devices, when ventilation by a fan occurs or the air comes in. Ventilation inside the chambers was set to be operated only when daylight is flowing in – that is, when the output artificial lighting is being controlled), so that the low-temperature air will not flow into the chamber at night to make the temperature disadvantageous for plant growth.

Procedures of the lighting controlling system are as following.

- 1) Illuminance is measured by an illuminometer in daylighting chamber.
- 2) The measured illuminance value is converted into an electric signal (current) and then sent to a controller.
- 3) The controller computes the 조광값 needed to maintain the same illuminance by selected algorithm.
- 4) The computed value is converted into voltage (0~10V), which is sent to 조광용 electric stabilizer.
- 5) This stabilizer controls the 광속량 of fluorescent lamps according to the voltage transmitted from the controller.

3.2 Measurement of indoor environment

The fundamental condition of this experiment is to maintain temperature, humidity, 광량 and 관수량 for plants located in two chambers to be the same. In order to compare the plant's growth status depending on the light source, temperature/humidity, illuminance and the light spectrum radiated from diffusing parts in each chamber were continuously measured and monitored throughout the experiment period.

The 제원 of a device used in measurement of environment inside the chamber is summarized in the table 1. In measuring the illuminance inside the chamber, indoor lighting was maintained for 8 hours from 9AM to 5PM. At other time, lighting inside these chambers was blocked so that their lighting condition will be kept the same at a low intensity.

As shown in Fig. 6-9, it turned out that the indoor illuminance level is affected by the weather change (status of the sky) and not kept constant. From the pattern of change in indoor illuminance, it turned out that the sky was partially clear in Fig. 6 and 7, while the clear sky was maintained in case of Fig. 8 and 9.

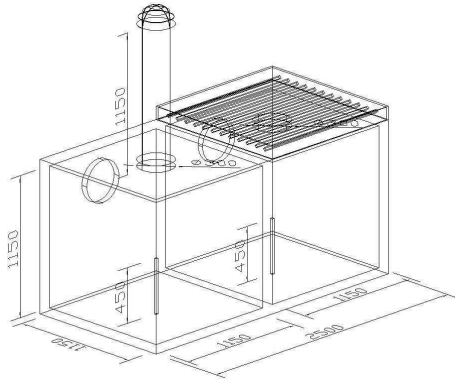


Fig. 2. 제원 of the laboratory



Fig. 3. Sunpipe installed at outside of daylighting chamber (left), fluorescent lamp installed in the artificial lighting chamber (right)



Fig. 4. Experiment chambers installed on the roof
(with the front cover opened)

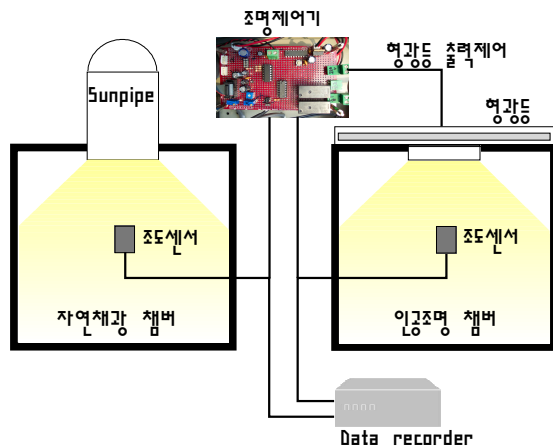


Fig. 5. Structure of the lighting controller

It could be verified that the change in illuminance by daylighting can precisely control the illuminance in artificial lighting chamber. Average relative error of the illuminance in these two chambers, measured during the 10-day experiment period, was 4.7%. From the measurement of the indoor illuminance, it turned out that the lighting environment in each chamber, which is necessary for plant growth, was the same.

3.3 Measurement of temperature and humidity in the chamber

During the 2-week experiment period from 25th October to 7th November 2007, temperature and humidity inside each chamber had been measured on a hourly basis, using a hygrothermograph (TH-101).

The temperature distribution during the period in each chamber is shown in Fig. 10. Temperature in these chambers was measured to be very similar, but from 12~5 PM when the illuminance is high, that of artificial lighting (fluorescent lamp) chamber was higher than that of daylighting chamber by 2°C at most. Radiation energy from the lamp and heat from electronic stabilizer are considered to have affected the indoor temperature.

The humidity distribution during the period in each chamber is shown in Fig. 11. Humidity in these chambers was measured to be very similar, but in the afternoon, that of daylighting chamber was measured to be higher than that of artificial lighting chamber by 15% at most. This is thought to be due to the high temperature of the latter in that time that decreases the relative humidity.

Aside from indoor illuminance level, temperature and humidity in these chambers showed some difference. However, considering the distribution and change with time of temperature and humidity measured during the experiment period, the difference is not too large to bring a large effect to growth of the plants inside the chamber, although artificial chamber had a slightly better environment.

Table 2. Devices for measuring indoor environment and the plants' growth status

Category		Product name	Manufacturer	Quantity
Temperature and humidity		TH-101	Microtechno	2
Illuminance	Illuminance sensor	LI-210	LI-COR	2
	Data logger	NetDAQ2640A	Fluke	1
Light spectrum		Avaspec 2048	Avantes	2
Chlorophyll contents		SPAD-502	Minolta	1
Amount of photosynthesis		LI-6400	LI-COR	1

3.4 Light spectrum analysis

Using a spectrum analyzer (Avaspec-2048-2-SPU), we have measured the spectrum of daylight and fluorescent lamp at illuminance of 2500lx. Fig. 12 shows the spectral distribution of light radiated from diffusing part, measured in each chamber.

As can be shown in the figure, fluorescent lamp showed a relatively high 광량 at specific wavelengths (435nm, 545nm, 610nm), while daylight showed a uniform spectral distribution throughout all wavelengths of visible ray.

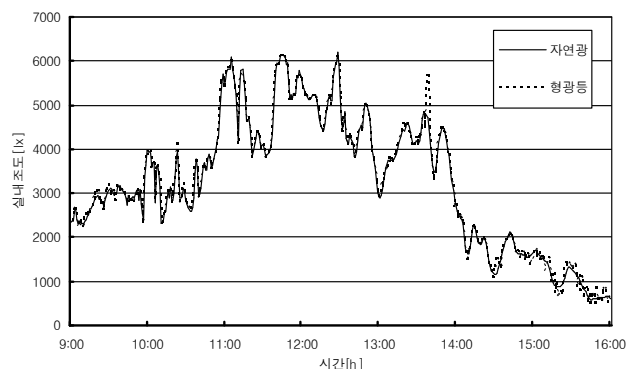


Fig. 6. Measured illuminance data (25th Oct, 2007)

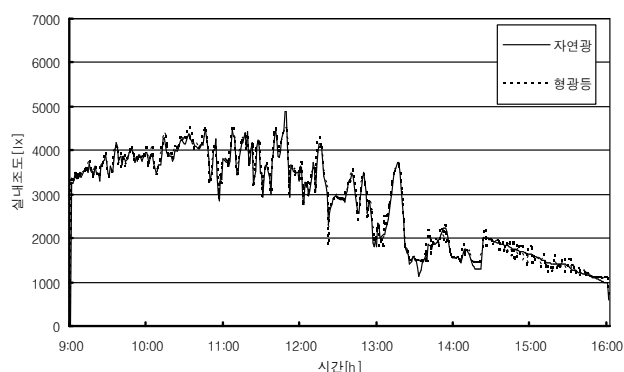


Fig. 7. Measured illuminance data (26th Oct, 2007)

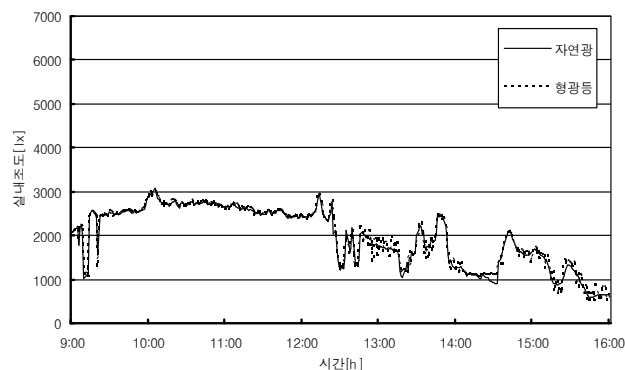


Fig. 8. Measured illuminance data (2nd Nov, 2007)

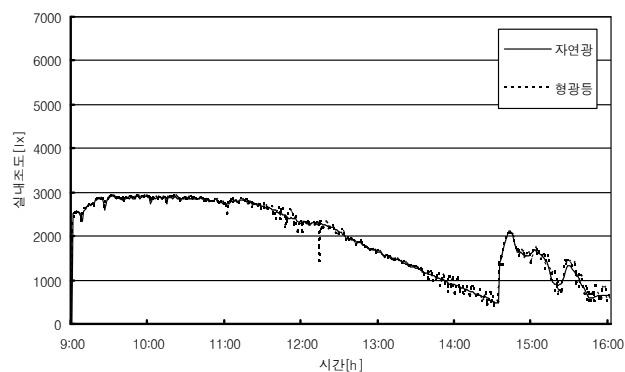


Fig. 9. Measured illuminance data (7th Nov, 2007)

Although both chambers showed the same 광량, the absorption spectrum of photosynthesizing pigments has a uniform distribution in each wavelength ranges, implying that the condition of these chambers differ in 광량 needed for the plant growth. This distribution is considered to have a significant effect on the plant growth.

4. Measurement of growth status of indoor plants

Two plant species that are widely used as garden plants, Codiaeum variegatum and Ardisia japonica, were selected as experiment targets. Experiments were done after these plants passed an one-month purification period. The former is a 무늬종 foliage plant that is sensitive to light, while the latter is a Korean autochthon that grows well in indoor conditions and is especially strong at low light. Fig. 13 shows the photo of these two plants.

After these plants have grown for 10 days in daylighting and artificial lighting chamber, the amount of photosynthesis was measured at light intensity of 100, 300, 500, 700 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$. As a result, Codiaeum

variegatum showed an increase in photosynthesis amount from $0.21 \pm 0.13 \mu\text{mol} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ to $0.19 \pm 0.14 \mu\text{mol} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ as the light intensity goes up, while a decrease was observed in the artificial lighting chamber, from $0.19 \pm 0.14 \mu\text{mol} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ to $0.08 \pm 0.65 \mu\text{mol} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ (Table 3). It is thought that, as the light intensity is changed, cell components including chloroplast are reduced to inhibit the production of chlorophyll and reduce the photosynthesis amount. In case of *Ardisia japonica*, too, photosynthetic efficiency was the highest at $700 \mu\text{mol} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$, recording $1.31 \pm 0.12 \mu\text{mol} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ (Table 4). Hence, daylighting is considered to be better than fluorescent lighting for the growth of these plants.

Table 3. Change in amount of photosynthesis of *Codiaeum variegatum*

Light intensity	Amount of photosynthesis ($\mu\text{mol} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$)		
	Before experiment	After experiment	
		Daylight	Fluorescent lamp
100	1.21 $\pm$ 0.66	0.21 $\pm$ 0.18	0.19 $\pm$ 0.14
300		0.47 $\pm$ 0.06	0.44 $\pm$ 0.10
500		0.72 $\pm$ 0.12	0.5 $\pm$ 0.30
700		0.85 $\pm$ 0.30	0.08 $\pm$ 0.65

Table 4. Change in amount of photosynthesis of *Ardisia japonica*

Light intensity	Amount of photosynthesis ($\mu\text{mol} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$)		
	Before experiment	After experiment	
		Daylight	Fluorescent lamp
100	1.39 $\pm$ 0.24	0.26 $\pm$ 0.07	0.26 $\pm$ 0.12
300		0.65 $\pm$ 0.06	0.64 $\pm$ 0.11
500		1.01 $\pm$ 0.15	0.97 $\pm$ 0.14
700		1.31 $\pm$ 0.42	1.05 $\pm$ 0.36

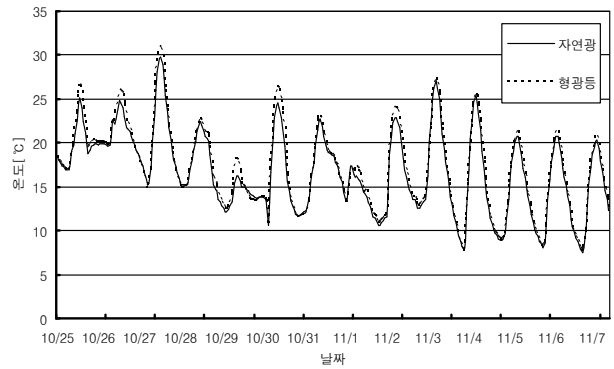


Fig. 10. Measured temperature data

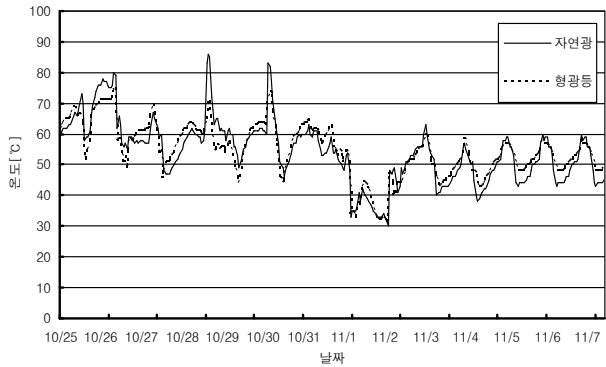


Fig. 11. Measured humidity data

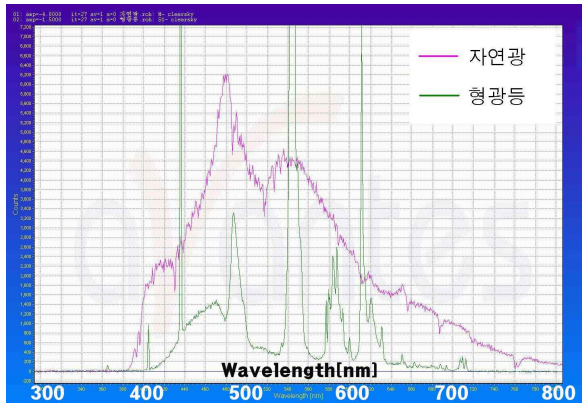


Fig. 12. Measured spectrum data



Fig. 13. Plants used in the experiment (Left: *Codiaeum variegatum*, Right: *Ardisia japonica*)

Chlorophyll contents before and after experiment were measured. In case of *Codiaeum variegatum*, chlorophyll contents were increased by 16.3 SPAD in daylighting chamber and 4.1 SPAD in artificial lighting chamber. In *Ardisia japonica*, they were increased by 2.7 SPAD in daylighting chamber and 0.9 in artificial lighting chamber.

Table 5. Comparison of chlorophyll contents in *Codiaeum variegatum* and *Ardisia japonica*

Plant	Light source	Chlorophyll contents [SPAD]		Increase in chlorophyll contents [%]
		Before experiment	After experiment	
<i>Codiaeum variegatum</i>	Daylight	29.3	45.6	55.6
	Fluorescent light	30.3	34.3	13.2
<i>Ardisia japonica</i>	Daylight	39.1	41.8	6.9
	Fluorescent light	39.5	40.4	2.3

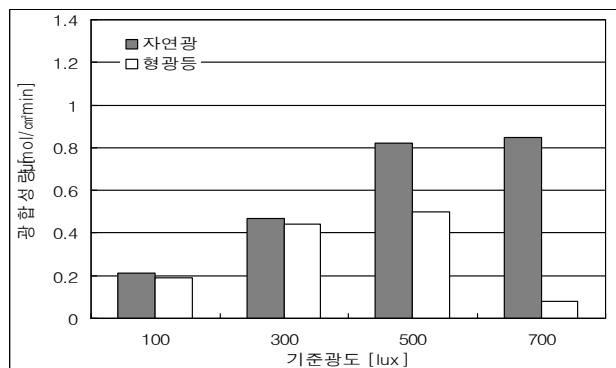


Fig. 14. Amount of photosynthesis by *Codiaeum variegatum* at reference 광량s

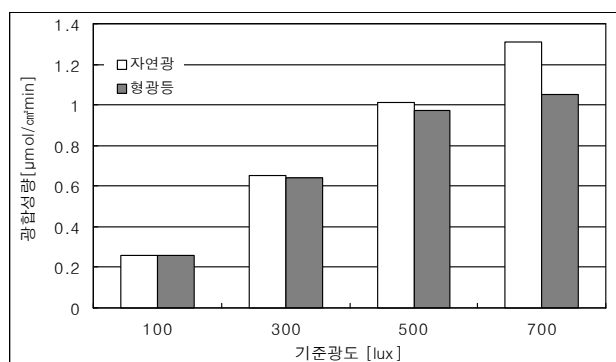


Fig. 15. Amount of photosynthesis by *Ardisia japonica* at reference 광량s

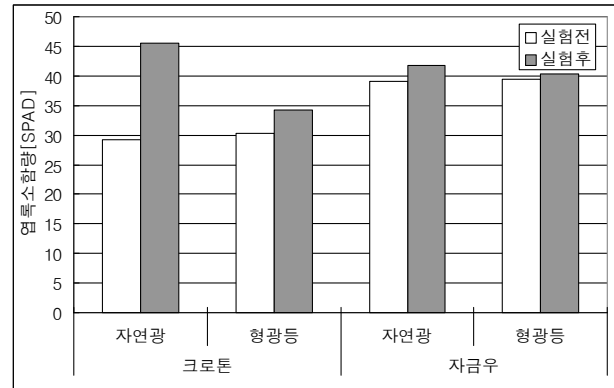


Fig. 16. Chlorophyll contents in *Codiaeum variegatum* and *Ardisia japonica*

5. Conclusion

In order to analyze the daylighting and artificial lighting on indoor plants, we have conducted experiments to explore the physiological reaction of two indoor plant species, *Codiaeum variegatum* and *Ardisia japonica*, under each light source. Two such chambers of the same size were manufactured, and these plants' physiological reaction was compared while the temperature, humidity and 광량(illuminance) were maintained to be the same. Our conclusion is as following.

1) When the chlorophyll contents and the amount of photosynthesis of these two plants under daylighting and artificial lighting conditions were compared, *Codiaeum variegatum* in the daylighting chamber showed chlorophyll contents and photosynthesis amount higher than those in the artificial chamber by 32.9% and 48.5% (averaged), respectively. *Ardisia japonica* showed the same trend, but the differences were much smaller - 3.5% and 9.6%, respectively. Although the growth status varies with the plant, it turned out that daylighting was, in general, preferable to lighting by fluorescent lamps.

2) It is not easy to compare the environment for the plants' growth because the characteristics of two light sources are different: daylight exhibits a continuous change of light intensity, while the intensity of artificial light can be kept constant throughout the period. However, if the conditions are the same, daylighting is preferable for the plants' growth as it has a richer spectral distribution. This should be taken into consideration when artificial lighting is planned.