©2022 International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

TuEngr Group

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

Indoor Carbon Dioxide Reduction by Ornamental Plants: Comparison between Natural and Artificial Daylight

Itthi Plitsiri[1*], Wannawit Taemthong[1]

[1] *Faculty of Engineering, Department of Civil Engineering, King Mongkut's University of Technology North Bangkok, THAILAND.*

**Corresponding Author (Tel: 080 999 2491, Email: s6201081911015 @email.kmutnb.ac.th).*

Paper ID: 13A9B

Volume 13 Issue 9

Received 07 March 2022
Received in revised form 07 June 2022
Accepted 14 June 2022
Available online 21 June 2022

Keywords: Artificial daylight; Carbon dioxide; Indoor air quality; Natural daylight; Ornamental plant

Abstract

Indoor air quality is important to human health. Carbon dioxide (CO_2) concentration levels are one crucial factor. Higher indoor CO_2 concentration can increase detrimental health symptoms and decrease work performance. A closed environment with a large number of people can cause the build-up of CO_2 concentration. Plants are able to improve air quality. The objectives of this research are to study CO_2 reduction by plants in an experimental chamber. The experiment used six species of ornamental plants. The CO_2 reduction ability of plants was compared under both natural and artificial daylight. Each ornamental plant was planted in a ten-centimeter-diameter plastic pot which was installed inside the chamber. The results reveal that *Epipremnum aureum* and *Spathiphyllum spp*. plants are the most effective species in reducing CO_2 among the six studied. The recommended natural daylight and artificial daylights are 1,643 and 2,000 lux, respectively. Artificial daylight could only decrease CO_2 by approximately 56% of a plant's ability under natural daylight. This research recommends using *Epipremnum aureum* and *Spathiphyllum spp.* installed on green walls with natural daylight in the room to reduce CO_2 in enclosed premises with large numbers of inhabitants.

Disciplinary: Built Environment, Architecture (Botany & Landscape Architecture, Sustainable Architecture), Air Quality Management, Environmental Management

Cite This Article:

Plitsiri, I., Taemthong, W. (2022). Indoor Carbon Dioxide Reduction by Ornamental Plants: Comparison between Natural and Artificial Daylight. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 13*(9), 13A9B, 1-12. http://TUENGR.COM/V13/13A12B.pdf DOI: 10.14456/ITJEMAST.2022.170

1 Introduction

Currently, the world is facing unprecedented indoor pollution in enclosed environments with large numbers of inhabitants which can stimulate the build-up of carbon dioxide (CO_2). Humans produce and exhale higher concentrations of CO_2 in occupied indoor spaces than in concentrations outdoors (Satish et al. 2012). Occupants may suffer headaches, nausea, fatigue, and listlessness when exposed to high CO_2 concentrations for prolonged durations. Hence, the removal of CO_2 from enclosed environments is essential (Myhrvold et al. 1996; Sinha et al. 2018). The American Society of Heating, Refrigeration, and Air-Conditioning Engineers standard (ASHRAE 62.1. 2016) recommends that the maximum acceptable CO_2 concentration for comfort should be no greater than 700 ppm compared to outdoor CO_2 air levels. A CO_2 setpoint of a ventilation fan system has a massive impact on energy consumption (Taheri and Razban 2021). In a normal 30 m^2 office with 1–3 occupants, the indoor CO_2 concentration of a 100-plant-scale vertical farm could be decreased by 25.7%–34.3% causing about a 12.7%–58.4% building ventilating energy consumption reduction (Shao, et al., 2021). With the installation of indoor plants in certain areas, the relative humidity would increase, and CO_2 and carbon monoxide (CO) would reduce within these areas (Smith and Pitt, 2011). Green walls have great potential for improving building energy performance, acoustics, and indoor microclimatic comfort (Ascione et al., 2020). Many studies indicate that vertical plants walls could have the ability to remove indoor air pollution (Oh et. al., 2011; Bondarevs et al. 2015; Torpy et. al., 2016; Gubb et. al., 2018; Paull et. al., 2018; Pettit et. al., 2018; Cao et. al., 2019). Tudiwer and Korjenic (2017) found that using a mixed plant installation on a vertical wall in classrooms covering about 1 % of the volume of the room was able to reduce CO_2 concentrations in classrooms. In conclusion, plants can help improve indoor air quality with less energy used for heating, ventilation, and air conditioning systems. However, to what extent light impacts plants' ability to improve air quality by reducing CO_2 is less known. Therefore, this research objective is to study the indoor carbon dioxide reduction by ornamental plants comparing them under natural and artificial daylight by studying six ornamental plants under three different light conditions in an enclosed chamber.

2 Experimental Setup

In this research, CO_2 reduction levels in an experimental chamber involving six species of ornamental plants are compared under natural and artificial daylight conditions. The six ornamental plants are selected from previous research findings. They have the ability to reduce CO_2 concentrations within indoor climates. They are *Epipremnum aureum* (Torpy et. al., 2017), *Spathiphyllum* (Dominici et. al., 2021), *Ficus Lyrata* (Torpy et.al., 2014), *Syngonium podophyllum* (Torpy et.al., 2013), *Sansevieria trifasciata* (Treesubsuntorn and Thiravetyan, 2018), and *Calathea makoyana (E.Morr.)* (Suhaimi et. al., 2017). Six pots of each plant species, each with a diameter of 10 cm, were installed on a vertical plant wall and put inside an enclosed chamber, see Figure 1.

The leaf areas were measured by a CI-203 Laser Area Meter, as shown in Figure 2. The total leaf areas of the six pots are 1,814, 1,796, 1,840, 1,791, 1,771, and 1,665 cm^2 for *Epipremnum* *aureum*, *Spathiphyllum spp.*, *Ficus Lyrata*, *Syngonium podophyllum*, *Sansevieria trifasciata prain*, and *Calathea makoyana (E.Morr.)*, respectively. The closed chamber has a size of 0.40 x 0.60 x 0.80 m and a volume of 0.192 m^3, as shown in Figure 3.

The chamber is made of a clear acrylic sheet with a separated wall inside designed for holding a vertical green wall. A small fan was installed on the wall for air circulation purposes. Light bulbs are installed in the chamber which is placed opposite the vertical green wall. The bulbs' powers are 15 and 30 Watts, generating 1,000 and 2,000 lux, respectively.

A drilled hole is on the top side of the chamber to fill it with CO_2 gas, which was emitted from a CO_2 tank. During experiments, CO_2 concentration data are measured by a Xiaomi Mijia Clear Grass Air Detector. It was connected to Wi-Fi for recording data every 15 minutes. Light intensity in lux was measured by a Xiaomi Mijia GZCGQ01LM sensor and connected to the Wi-Fi via a Mi Home application in real-time during experimentation.

3 Research Methodology

Six ornamental plants were selected from the literature review based on their superior CO_2 absorption abilities. The experiments in this research are designed to study the ability of plants to absorb CO_2 for indoor purposes. Six plants were put in a closed chamber in three light situations, which are natural light, and artificial light at 1,000 and 2,000 lux. As a result, they can be grouped into three categories as shown in Table 1. Three tests were performed in each group. Therefore, a total of 57 experiments were conducted including empty chamber procedures.

Figure 1: Six ornamental plants used in this research.

Figure 2: Leaf area measuring instrument.

Figure 3: Experimental chamber and related equipment.

Table 1: Details of all 57 experiments.

Category of Experiment	Description	Plants tested	Repeated Experiments	Number of Experiments
1	Six Plants under natural daylight	6	3	18
2	Six Plants under 1,000 lux artificial light	6	3	18
3	Six Plants under 2,000 lux artificial light	6	3	18
4	Empty chamber	-	3	3
Total Experiments				57

The first experiment category involves a study of plants under natural daylight which was performed during the daytime starting from 9 am to 5 pm. Plants are installed facing south to receive natural daylight. It was distanced about 50 cm from the window. Meanwhile, the second and third experimental categories were performed during nighttime in order to reduce the impact of natural daylight. Finally, the last category comprised of tests in the empty chamber which is used as a controlled benchmark. Artificial light experiments were performed between 7 pm and 3 am. The LED bulbs were turned on, giving the light intensity of 1,000 or 2,000 lux. In every experiment, six ornamental plants were installed on the vertical wall inside the chamber, as shown in Figure 4. The lid of the chamber is closed during experiments. The CO_2 gas was released through a hole on the lid at the top of the chamber, as shown in Figure 5. The lid of the chamber is closed from the top and the joints are sealed with clear adhesive tape and clear silicone to seal the holes for the power supply. The average values from 3 iterations were used to analyze the results.

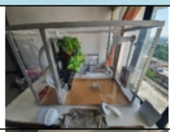
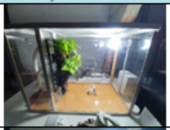
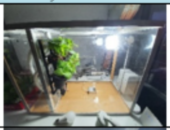
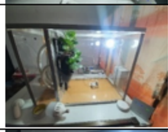
Plant Species	Natural Daylight	LED Intensity 1,000 lux	LED Intensity 2,000 lux
Epipremnum aureum			
Spathiphyllum spp.			
Ficus Lyrata			
Syngonium podophyllum			
Sansevieria trifasciata prain			
Calathea makoyana (E.Morr.)			

Figure 4: Six ornamental plants in three different light situations.

Figure 5: Experimental chamber and related equipment.

4 Results

The results in this section are separated into three parts involving the experiments using natural daylight, and artificial daylight at 1,000 and 2,000 lux. All experiments start when CO_2 concentrations in the chamber reach 2,000 ppm, then the gas release is stopped. Data were recorded every 15 min for all six plants with three different lighting situations. The CO_2 profile results of six plants under the natural daylight experiments are shown in Figures 6 (a) to (c). They were recorded on three different days. Natural daylight intensity varied on each experimental day for the six plants, as shown in Figures 7 (a) to (c). Figure 8 (a) to (c) shows CO_2 profiles in the chamber under artificial light at 1,000 lux, which were repeated three times. The results of the artificial light at 2,000 lux experiments are shown in Figures 9 (a) to (c).

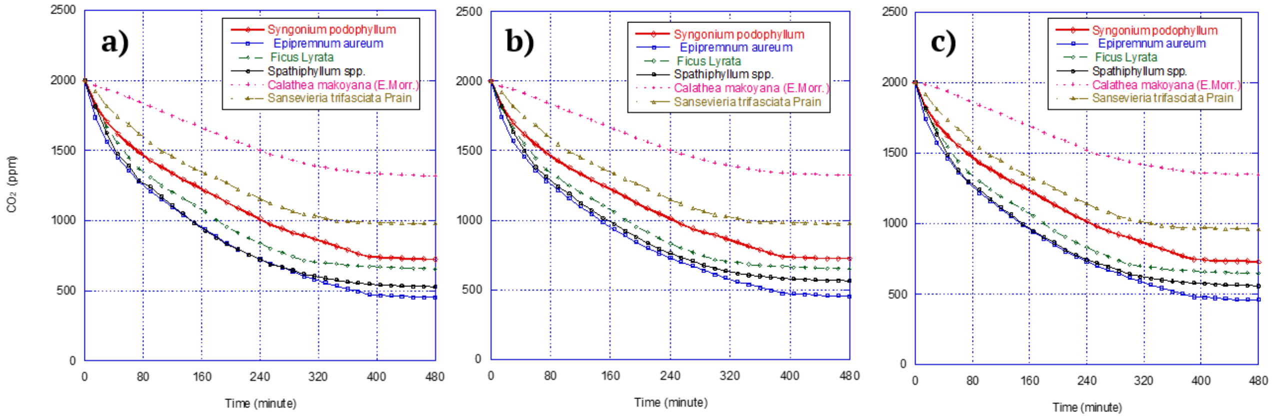


Figure 6: CO_2 profile of the first category experiment under natural light conditions

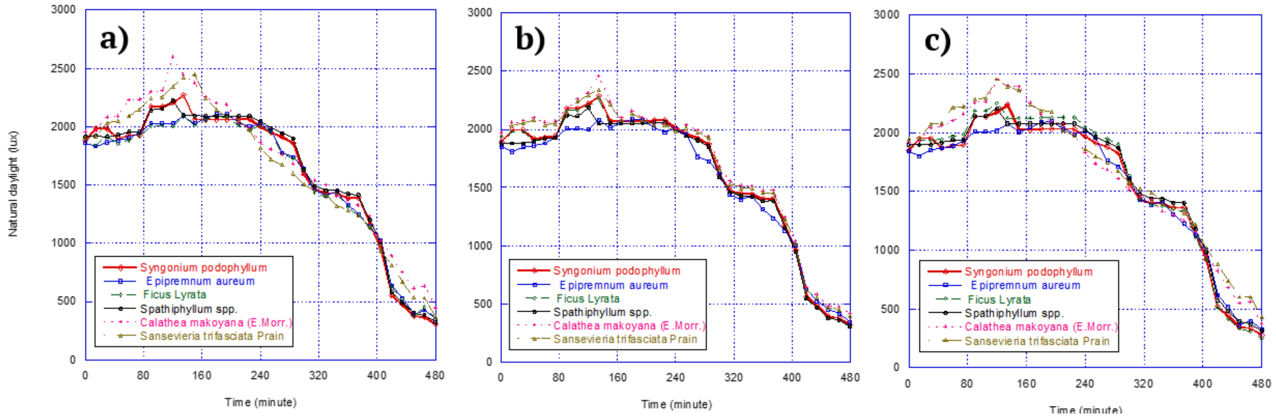


Figure 7: Light intensity profile under natural light conditions

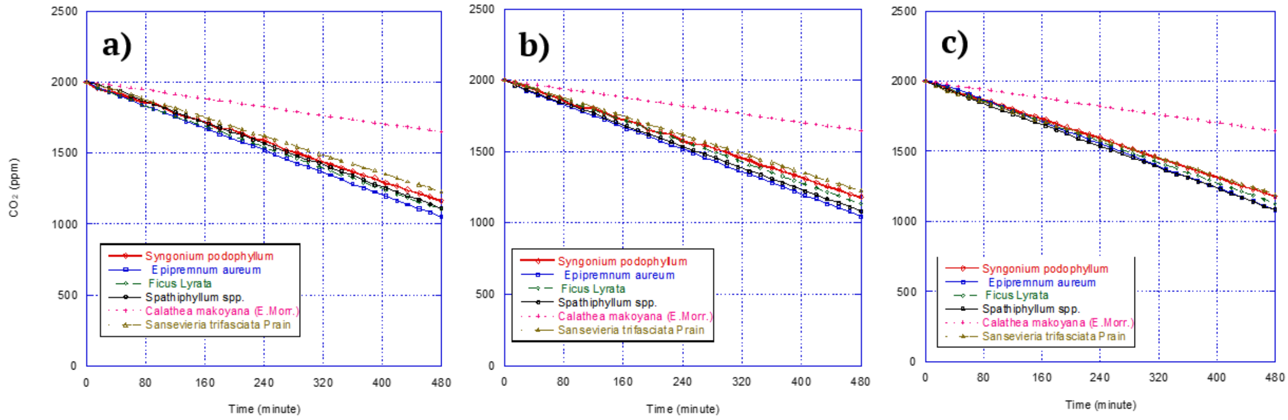


Figure 8: CO_2 profile of the second category experiment under the artificial light of 1,000 lux.

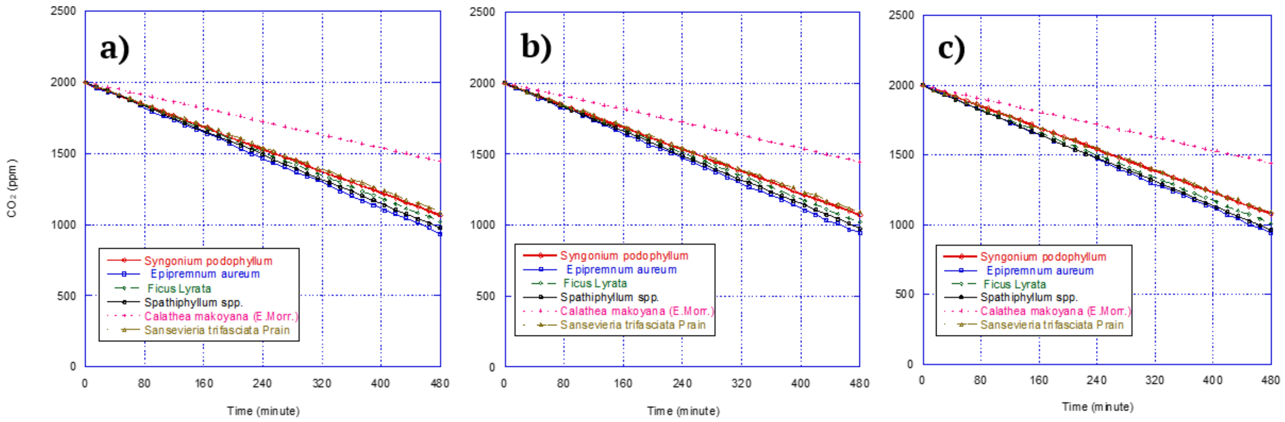


Figure 9: CO_2 profile of the third category experiment under the artificial light of 2,000 lux.

Three tests to determine decreasing rates of CO_2 in the empty chamber without plants are presented in Figure 10. Light differed on different testing days. Therefore, the average light intensity from Figure 7 (a) to (c) can be determined and used for normalizing comparison purposes as shown in Figure 11.

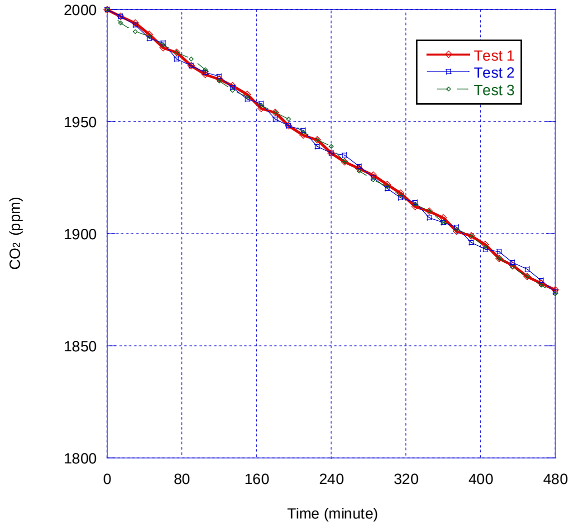


Figure 10: Decreasing CO_2 inside an empty chamber without a plant in three tests.

Figures 12, 13, and 14 present the average levels of CO_2 in the chamber for natural light, and artificial light at 1,000 and 2,000 lux, respectively. For natural daylight experiments, the ability to remove CO_2 of Epipremnum aurerum is the best when compared to the others. It was found generally that the brighter the artificial light, the better the ability to remove CO_2 by plants. With both lighting levels, the *Epipremnum aurerum* performs best among all plants. *Epipremnum aureum* absorbs CO_2 better than other plants for both natural daylight and artificial light. *Spathiphyllum spp.*, *Ficus lyrata*, *Syngonium podophyllum*, *Sansevieria trifasciata*, and *Calathea makoyana (E.Morr.)* are in the second to the sixth ranks, respectively.

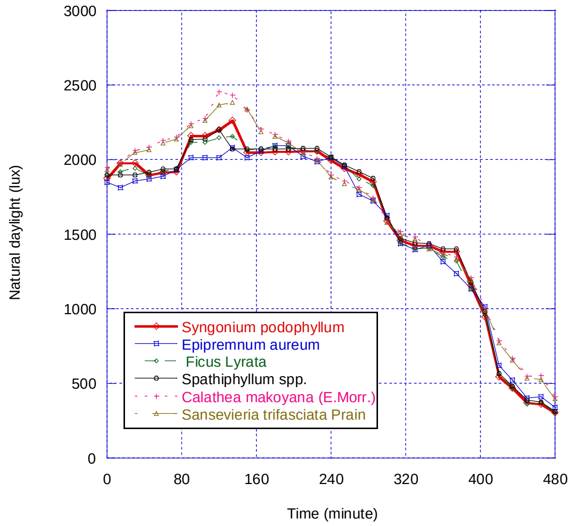


Figure 11: Averaged light intensity from Fig. 7 (a) to (c) during natural experiments.

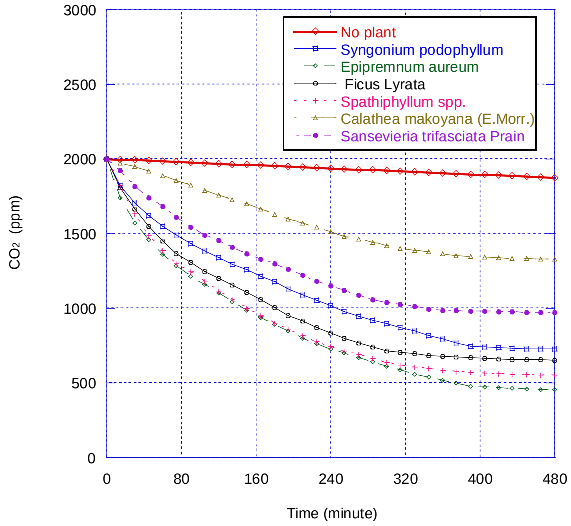


Figure 12: CO_2 profiles of six plants in the chamber under natural light experiments

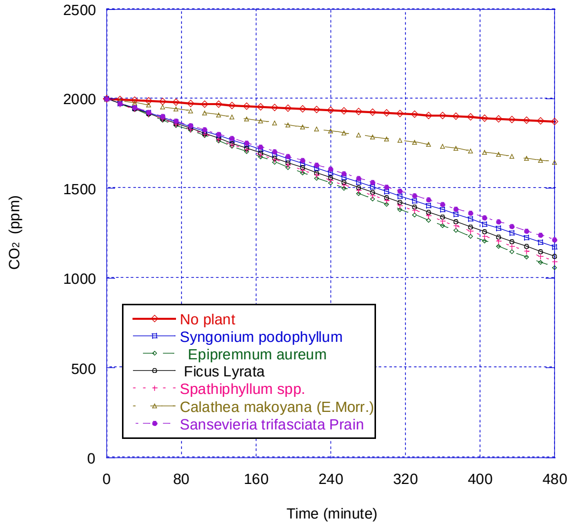


Figure 13: CO_2 profiles of six plants in the chamber under 1,000 lux artificial light experiments

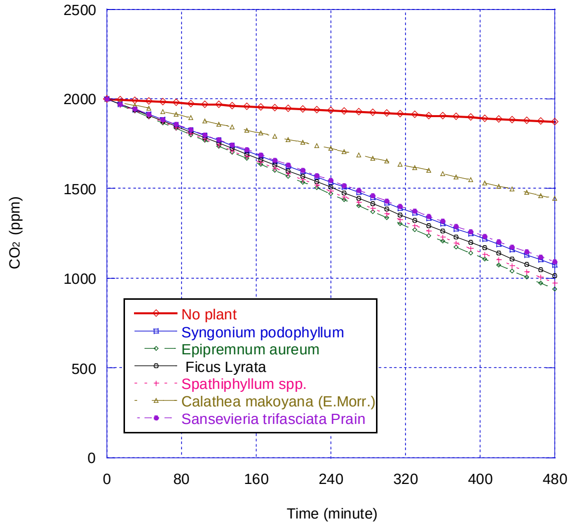


Figure 14: CO_2 profiles of six plants in the chamber under 2,000 lux artificial light experiment

5 Analysis

In order to determine the ability of plants in absorbing CO_2 in six plant experiments, the area under the curve was calculated by an integration method. The lower the areas, the better the ability in absorbing CO_2 by plants. They are shown in Column 3 of Table 2. Since natural daylight varied on each experimental day during the six plant experiments, as shown in Figure 11. The CO_2 values were normalized to a specific light intensity of 1,643 lux, which is an averaged value, as shown in Column 5 of Table 2.

Table 2: Area under the curve of each plant under natural daylight intensity by integration method.

Plant Species	Time (min)	The area under Curve by Integrations (lux·min)	Average Natural Daylight (lux)	Average Natural Daylight of 6 Experiments (lux)
Epipremnum aureum	480	761,963	1,587	1,643
Spathiphyllum spp.	480	781,965	1,629	
Ficus Lyrata	480	775,703	1,616	
Syngonium podophyllum	480	780,585	1,626	
Sansevieria trifasciata prain	480	811,688	1,691	
Calathea makoyana (E.Morr.)	480	820,200	1,709	

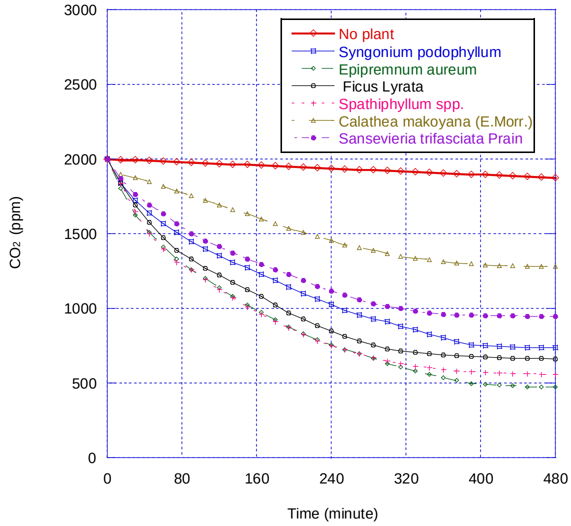


Figure 15: CO_2 profiles of six plants in the chamber under natural light experiments after the normalization process

They were plotted in Figure 15 together with the empty chamber without plants. CO_2 values decrease gradually from time zero to 480 minutes. This means that CO_2 can diminish itself as time passes without the help of any plant at a rate of 0.26 ppm per minute. This rate is obtained by fitting the no plant line in Figure 15 to a straight-line model using a linear regression method. The model is shown in Equation 1, where y is CO_2 in ppm and x is time in minutes.

$$y = 2{,}000 - 0.26x \quad (1)$$

From Figure 15, the area under each line can be determined by an integration method. The area is 929,775 ppm·min, which is the amount of CO_2 cumulates 480 minutes after stopping releasing CO_2 gas into the chamber. The CO_2 amount which is absorbed by each plant can be determined by subtracting the areas under the line of each plant from the area under the no-plant line. Then, dividing the subtracted area by 480 minutes or the duration of the test to obtain the CO_2 amount absorbed by the plant. For example, *Epipremnum aureum* has an area under the line equal to 421,958 ppm·min. Therefore, *Epipremnum aureum* absorbs $\frac{929{,}775-421{,}958}{480} = \frac{507{,}817}{480}$ = 1,058 ppm, as shown in Column 4 of Table 3.

Table 3: Ability in absorbing CO_2 by plants under natural daylight intensity.

Plant Species	The area under Curve by Integrations (ppm·min)	Differentiated Areas from No Plant Test (ppm·min)	CO_2 absorbed (ppm)	CO_2 reduction per minute (ppm/min)
No plant	929,775	-	-	-
Epipremnum aureum	421,958	507,817	1,058	2.20
Spathiphyllum spp.	432,420	497,355	1,036	2.16
Ficus Lyrata	475,403	454,373	947	1.97
Syngonium podophyllum	532,770	397,005	827	1.72
Sansevieria trifasciata prain	585,120	344,655	718	1.50
Calathea makoyana (E.Morr.)	725,468	204,308	426	0.89

Figures 13, and 14 present the CO_2 amount absorbed by artificial light 1,000 and 2,000 lux of each plant. It was found generally that the brighter the artificial light, the better ability to remove CO_2 by plants. With both lighting levels, the *Epipremnum aurerum* performs best among all plants. as shown in Table 4 and Table 5, respectively.

Table 4: Ability in absorbing CO_2 by plants under the artificial light of 1,000 lux.

Plant Species	The area under Curve by Integrations (ppm·min)	Differentiated Areas from No Plant Test (ppm·min)	CO_2 absorbed (ppm)	CO_2 reduction per minute (ppm/min)
No plant	929,775	-	-	-
Epipremnum aureum	734,430	195,345	407	0.85
Spathiphyllum spp.	742,575	187,200	390	0.81
Ficus Lyrata	749,295	180,480	376	0.78
Syngonium podophyllum	761,775	168,000	350	0.73
Sansevieria trifasciata prain	771,468	157,815	329	0.68
Calathea makoyana (E.Morr.)	875,055	204,308	114	0.24

Table 5: Ability in absorbing CO_2 by plants under the artificial light of 2,000 lux.

Plant Species	The area under Curve by Integrations (ppm·min)	Differentiated Areas from No Plant Test (ppm·min)	CO_2 absorbed (ppm)	CO_2 reduction per minute (ppm/min)
No plant	929,775	-	-	-
Epipremnum aureum	705,848	223,928	467	0.97
Spathiphyllum spp.	713,775	216,000	450	0.94
Ficus Lyrata	723,900	205,875	429	0.89
Syngonium podophyllum	737,528	192,248	401	0.83
Sansevieria trifasciata prain	741,848	187,928	392	0.82
Calathea makoyana (E.Morr.)	826,808	102,968	215	0.45

Epipremnum aureum absorbs CO_2 better than other plants. *Spathiphyllum spp.*, *Ficus lyrata*, *Syngonium podophyllum*, *Sansevieria trifasciata*, and *Calathea makoyana (E.Morr.)* are in the second to the sixth ranks, respectively. The CO_2 amounts absorbed by *Epipremnum aureum* under natural daylight are 56% better in artificial daylight conditions. This can be seen by calculating from CO_2 absorbed values of *Epipremnum aureum* in Column 4 of Table 3 and Column 4 of Table 5 or $\frac{1{,}058-467}{1{,}058}$ = 56%. Natural daylight at 1,643 lux shows better performance than artificial light at 2,000 lux.

Ornamental plants on a green wall that are cultivated in natural daylight do not consume as much energy compared to those in artificial light. Thus, natural daylight helps a plant's ability to absorb CO_2 in a room better than artificial light.

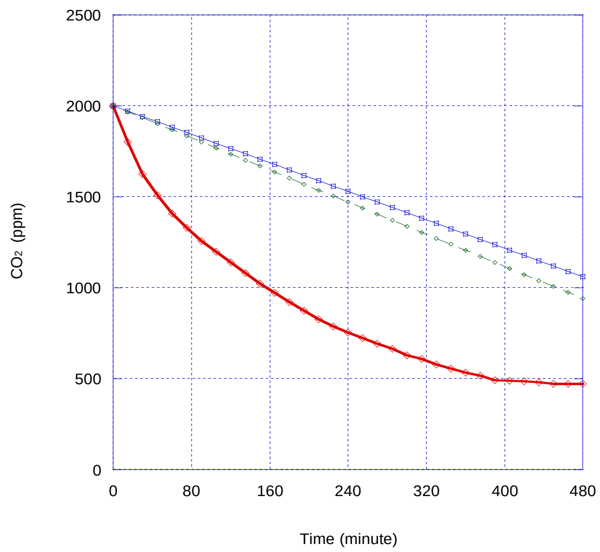


Figure 16: CO_2 profiles of *Epipremnum aureum* in the chamber for natural daylight at 1,643 lux and artificial light at 1,000 and 2,000 lux experiments

From Figure 16, *Epipremnum aureum* under average natural daylight conditions absorbed CO_2 in the chamber better than in the experiments of artificial light at 1,000 and 2,000 lux. From this, it may be concluded that areas close to windows in which a green wall is placed are suitable for placing a green wall to minimize energy usage in the building. Since each plant species tested in the experiments has different leaf areas, Table 6 shows the ability of plants to absorb CO_2 per leaf area in ppm per cm^2. *Epipremnum aureum* and Spathiphyllum spp. have an equal ability to absorb CO_2 which is 0.58 ppm/ cm^2.

The CO_2 concentrations were below the ASHRAE standard at 1,000 ppm within 2:30 hours, 3:15 hours, and 4:15 hours, for *Epipremnum aureum and Spathiphyllum spp.*, *Ficus lyrata*, and *Syngonium podophyllum*, and *Sansevieria trifasciata prain,* respectively. While *Calathea makoyana (E.Morr.)* inside the chamber was unable to reduce CO_2 concentrations below the ASHRAE standard within eight hours. In terms of artificial light from LED daylight, only two species at a light intensity of 2,000 lux were able to reduce CO_2 concentrations below the standard within eight hours. They are *Epipremnum aureum* and *Spathiphyllum spp.*

Table 6: Analysis of CO_2 amount absorbed by different plants per leaf area in ppm·cm^2

Plant Species	Natural Daylight Intensity (lux)	CO_2 amount absorbed by each plant (ppm)	Leaf area (cm^2)	Ability to Absorb CO_2 per leaf area (ppm/cm^2)	Ability to Absorb CO_2 per hour by 6 plant pots (ppm/hr)
Epipremnum aureum	1,643	1,058	1,814	0.58	132
Spathiphyllum spp.	1,643	1,036	1,796	0.58	130
Ficus Lyrata	1,643	947	1,840	0.51	118
Syngonium podophyllum	1,643	827	1,791	0.46	103
Sansevieria trifasciata prain	1,643	718	1,771	0.41	90
Calathea makoyana (E.Morr.)	1,643	426	1,665	0.26	53

6 Conclusion

This study on the ability to reduce CO_2 of ornamental plants in a closed chamber found that natural daylight helped reduce CO_2 better than artificial daylight. Different plant species and light intensities affect the ability to absorb CO_2 and result in different reduction rates. The number of plants, the volume of the room, and the number of people living inside are crucial factors. *Epipremnum aureum* and *Spathiphyllum spp.* can reduce indoor CO_2 below the ASHRAE standard at 1,000 ppm inside the chamber of 0.192 m^3 using six pots of plants. This figure can be used as a guideline to estimate the number of plant pots required to be installed on a green wall in building areas. *Epipremnum aureum* and *Spathiphyllum spp.* were able to reduce CO_2 below the standard within 2:30 hours in average natural daylight. Meanwhile, for artificial light at 2,000 lux the *Epipremnum aureum* and *Spathiphyllum spp.* were able to reduce CO_2 below the standard at 7:30 hours and 7:45 hours, respectively. In artificial light situations, building designers may increase the light intensity to achieve better reduction rates of CO_2. From the natural daylight experiments, six pots of *Epipremnum aureum* and *Spathiphyllum spp.* were able to reduce indoor CO_2 at totals of 1,058 ppm and 1,036 ppm, respectively. Therefore, *Epipremnum aureum* and *Spathiphyllum spp.* in an appropriate number of pots are recommended for putting on green walls inside living areas to reduce the high CO_2 generated by people. This research recommends either *Epipremnum aureum* or *Spathiphyllum spp.* be installed on vertical plant walls to reduce CO_2 in enclosed premises with large numbers of inhabitants. The average natural daylight intensity is recommended to be more than 1,643 lux. If rooms are not connected to windows, the artificial light intensity of LED should be more than 2,000 lux to increase the CO_2 reduction potential.

7 Availability of Data and Material

Data can be made available by contacting the corresponding author.

8 References

Ascione, F., De Masi, R. F., Mastellone, M., Ruggiero, S., and Vanoli, G. P. (2020). Green walls, a critical review: knowledge gaps, design parameters, thermal performances and multi-criteria design approaches. *Energies, 13,* 2296.

ASHRAE 62.1. (2016). Ventilation for Acceptable Indoor Air Quality.

Bondarevs, A., Huss, P., Gong, S., Weister, O., and Liljedahl, R. (2015). Green Walls Utilizing Internet of Things. *Sensors & Transducers, 19 2(9),* 16–21.

Cao, Y., Li, F., Wang, Y., Wang, Z., Lui, X., and Ding, K. (2019). Assisted Deposition of PM2.5 from Indoor Air by Ornamental Potted Plants. *Sustainability, 11*(9), 2546.

Dominici, L., Fleck, R., Gill, R. L., Pettit, T. J., Irga, P. J., Comino, E., and Torpy, F. R. (2021). Analysis of lighting conditions of indoor living walls: Effects on CO_2 removal. *Journal of Building Engineering, 44,* 102961.

Gubb, C., Blanusa, T., Griffiths, A., and Pfrang, C. (2018). Can houseplants improve indoor air quality by removing CO_2 and increasing relative humidity?. *Air Quality, Atmosphere & Health, 11*(4), 1191–1201.

Myhrvold, A. N., Olsen, E., and Lauridsen, Ø. (1996). Indoor Environment in Schools Pupils Health and Performance in regard to CO_2 Concentrations. *Proceedings of Indoor Air 96: the 7th International Conference on Indoor Air Quality and Climate, 4,* 369-374.

Oh, G. S., Jung, G. J., Seo, M. H., and Im, Y. B. (2011). Experimental study on variations of CO_2 concentration in the presence of indoor plants and respiration of experimental animals. *Horticulture, Environment and Biotechnology, 52(3),* 321–329.

Paull, N. J., Irga, P. J., and Torpy, F. R. (2018). Active green wall plant health tolerance to diesel smoke exposure. *Environmental Pollution, 240,* 448–456.

Pettit, T., Irga, P. J., and Torpy, F. R. (2018). The in situ pilot-scale phytoremediation of airborne VOCs and particulate matter with an active green wall. *Air Quality, Atmosphere & Health, 12*, 33-44.

Satish, U., Mendell, M. J., Shekhar, K., Hotchi, T., Sullivan, D., Streufert, S., and Fisk, W. J. (2012). Is CO_2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO_2 Concentrations on Human Decision-Making Performance. *Environmental Health Perspectives, 120(12),* 1671-1677.

Shao, Y., Li, J., Zhou, Z., Hu, Z., Zhang, F., Cui, Y., and Chen, H. (2021). The effects of vertical farming on indoor carbon dioxide concentration and fresh air energy consumption in office buildings. *Building and Environment 195*, 107766.

Sinha, A., Thakkar, H., Rezaei, F. Kawajiri, Y., and Realff, M. J. (2018). Direct Air Capture of CO2 in Enclosed Environments: Design under Uncertainty and Techno-Economic Analysis. *Computer Aided Chemical Engineering, 44,* 2179-2184.

Smith, A., and Pitt, M. (2011). Healthy workplaces: plantscaping for indoor environmental quality. *Facilities, 29(3/4),* 169–187.

Suhaimi, M. M., Leman, A., Afandi, A., Hariri, A., Idris, A. F., Dzulkifli, S. N. M., and Gani, P. (2017). Effectiveness of Indoor Plant to Reduce CO_2 in Indoor Environment. *MATEC Web of Conferences, 103(7),* 05004.

Taheri, S., and Razban A. (2021). Learning-based CO_2 concentration prediction: Application to indoor air quality control using demand-controlled ventilation. *Building and Environment, 205,* 108164.

Torpy, F. R., Irga, P. J., and Burchett, M. D. (2013). Can hydroculture be used to enhance the performance of indoor plants for the removal of air pollutants?. *Atmospheric Environment, 77,* 267–271.

Torpy, F. R., Irga, P. J., and Burchett, M. D. (2014). Profiling indoor plants for the amelioration of high CO_2 concentrations. *Urban Forestry & Urban Greening, 13(2),* 227–233.

Torpy, F. R., Zavattaro, M., and Irga, P. (2016). Green wall technology for the phytoremediation of indoor air: a system for the reduction of high CO_2 concentrations. Air Quality, Atmosphere & Health, 10(5), 575–585.

Torpy, F. R., Irga, P. J., Abdo, P., and Zavattaro, M. (2017). An assessment of the potential fungal bioaerosol production from an active living wall'. *Building and Environment, 111,* 140-146.

Treesubsuntorn, C., and Thiravetyan, P. (2018). Botanical biofilter for indoor toluene removal and reduction of carbon dioxide emission under low light intensity by using mixed C3 and CAM plants. *Journal of Cleaner Production, 194,* 94–100.

Tudiwer, D., and Korjenic, A. (2017). The effect of an Indoor Living Wall System on humidity, mould spores and CO_2 concentration. *Energy and Buildings, 146,* 73-86.

Itthi Plitsiri is a Ph.D. candidate at the Department of Civil Engineering, King Mongkut's University of Technology North Bangkok, Thailand. He got a Master's degree in Engineering and Construction Management from King Mongkut's University of Technology Thonburi, Thailand. His research focuses on Construction Management and Air Quality Improvement.

Dr. Wannawit Taemthong is an Associate Professor at the Department of Civil Engineering, King Mongkut's University of Technology North Bangkok, Thailand. He got his Master's degree in Construction Management from the Asian Institute of Technology and his Ph.D. degree in Civil Engineering from the University of Michigan. His research focuses on Construction Management, Green Building, and Indoor Air Quality.