AIR QUALITY IMPROVEMENT USING ORNAMENTAL PLANTS IN CLASSROOMS

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ABSTRACT

The purpose of this research is to investigate how indoor air quality might be improved by installing particular ornamental plants available in Thailand. Traditionally, ventilation fans have been used to encourage fresh air into living areas in order to reduce CO_2 levels. This consumes more energy than using ornamental plants. Our research screens three types of ornamental plants and selects one to investigate its potential for enhancing indoor air quality by reducing carbon dioxide levels. The three plants are epipremnum aureum, spathiphyllum wallisei, and dieffenbachia sp. The propensity to reduce carbon dioxide levels of each plant was preliminary screened using a closed flux chamber method over a 24-hour period. It was found that epipremnum aureum had the ability to absorb carbon dioxide better than the others. The epipremnum aureum was then put in a classroom to investigate variables in two further experiments. The ability to improve air quality in terms of sensitivity to various light concentrations and the number of plants in the room are explored. It was found that epipremnum aureum should be placed within a distance of 1.5 meters from windows to achieve the appropriate light concentration to enhance indoor air quality. It was also found that 150 pots of epipremnum aureum had the propensity to reduce CO_2 by 430 ppm in a classroom of 20 students for an 80-minute class. The use of sufficient amounts of epipremnum aureum can improve air quality in classrooms. A model to estimate numbers of such plants needed in classrooms is also presented.

KEYWORDS

building, carbon dioxide, classroom, indoor air, ornamental plants

1. INTRODUCTION

Carbon dioxide concentration in populated areas like classrooms increases as students stay inside for long periods without sufficient ventilation. Nine studies investigated pollutant from indoor CO_2 from 1999 to 2015 (Andrade and Dominski 2018). Classrooms in Thailand are usually comprised of air conditioning units and ventilation fans. A combination of natural and mechanical ventilation methods is able to provide sufficient indoor environmental quality (Irga and Torpy 2016). Reducing indoor air pollution represents a main consideration in terms of improving indoor air quality (Atarodi et al. 2018). Encouraging fresher air could potentially

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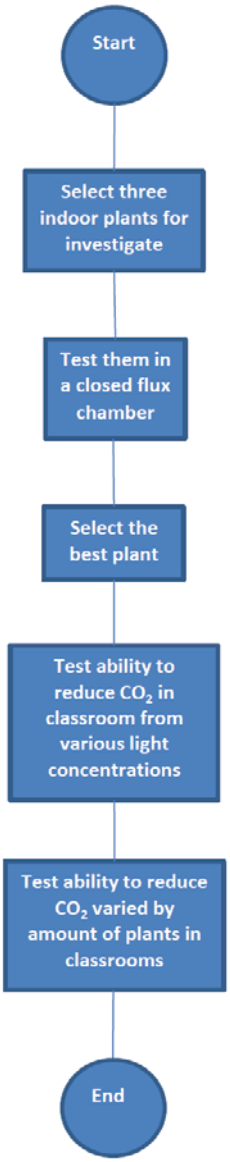
alleviate high concentrations of CO_2. However, ventilation fans bring hot air into rooms causing increased electricity consumption. Mechanical ventilation systems have been found to be able to ensure the highest outdoor air supply rates in classrooms, independent of seasonal variables (Gao et al. 2014). Indoor air quality has become a growing concern due to not only people spending increased time indoors, but also as a drive to reduce building ventilation in order to save energy (Pettit et al 2018). One method of reducing high concentration rates of CO_2 without employing ventilation fans is to use ornamental plants. Plants represent a sustainable but underexploited solution to enhance indoor air quality (Brilli et al. 2018). Husti et al. (2016) studied indoor air pollutants removal by introducing ornamental plants into the work environment and found 58.33% of the concentration of CO_2 was able to be removed. The amount of particulate matter accumulation on horizontal surfaces was found to be lower in rooms when plants were present (Lohr and Pearson-Mims 1996). Pettit et al. (2017) confirmed that green walls are able to remove particulate matters from the air. Yarn et al. (2013) indicated that spathiphyllum kochii was able to absorb CO_2 from human breathing. In another study, Su and Lin (2015) highlighted the ability of bird nest ferns to remove CO_2 at the rate of 1.984 ppm/hr in their research. Jamaludin et al. (2016) stated that both relative humidity and levels of TVOC, and CO_2 were considerably reduced by applying a landscape in a university classroom. In addition, Torpy et al. (2017) studied the reduction of high CO_2 concentration using two plants in a green wall application and revealed chlorophytum comosum and epipremmnum aureum to be effective in terms of CO_2 removal at specific light densities. Zuo et al. (2020) indicate that employing epipremmnum aureum is able to increase enthusiasm and willingness to work by 12.5% and 11.8%, respectively. Meanwhile, Torpy et al. (2014) found HL-acclimatised D. lutescens to be the most efficient species per unit of leaf area in removing high CO_2 concentrations from rooms, even those with low light levels. Tudiwer and Korjenic (2017) indicated that relative humidity in a green classroom was increased as well as the comfort level. People worry about potential fungal bio aerosol production from green walls. However, it was found that green walls do not contribute to airborne cultivable fungi in a test room (Irga et al. 2017). Green building initiatives are concerned with improving indoor air quality. Living in green buildings conventionally promises better health and lower electricity bills. It provides an enhanced indoor environment, while reducing energy demands. Wang et al. (2016) found that aesthetics is the top benefit of a green wall system. Many ornamental plants are available in Thailand. This research is interested in investigating the propensities of three ornamental plants to improve air quality by studying their CO_2 reduction or emissions, comparing them, and selecting one plant to be explored in greater detail by focusing on two particular variables, light sensitivity and the ability to remove CO_2 from real classrooms. Finally, models to estimate the number of ornamental plants used to improve air quality in classrooms are presented.

2. RESEARCH METHODOLOGY

The methodology employed in this research project is shown in the flowchart in Figure 1. We investigate three popular ornamental plants available in Thai markets and first test them to ascertain their ability to improve air quality. Then, the most effective performing plant is tested in two further experiments focusing on light sensitivity and leaf area. Light concentration is a crucial factor in plants absorbing or emitting CO_2. Meanwhile, leaf area varies according to the number of pots of plants present in a room, which then has an impact on indoor air quality.

FIGURE 1. A flowchart of this research.



As a result, the number of pots in a room, denoting leaf area, are studied to reveal their ability to augment air quality.

3. SCREENING THREE PLANTS

The first stage involves selecting three potentially suitable ornamental plants based on previous research studies and their popularity in Thai markets. Epipremnum aureum was chosen based on previous research recommendations, while spathiphyllum wallisei and dieffenbachia sp., shown in Figure 2, were nominated based on their popularity as ornamental plants for indoor purposes in Thailand. The plants were examined in terms of their ability to absorb or emit

CO_2 during a 24-hour period using a closed flux chamber method, as shown in Figure 3. The size of the chamber was 50 centimeters in width, length, and height. CO_2 concentration was measured by a Lutron Air Quality Meter inside the chamber. Data collection for each plant started at 7:00 am and was recorded at 20-minute intervals throughout the day over 24 hours. The chamber was exposed to daylight in the morning and sunlight in the afternoon, given that the experiment room was facing west. The CO_2 levels recorded inside the chamber with the three plants are presented in Figure 4 (a). Since spathiphyllum wallisei used in this research has a larger leaf area compared to the other two plants, the CO_2 levels for each plant should be normalized by leaf area for comparison purposes. The leaf areas of each plant were measured using a data processing image application named Petiole. Their surface areas were measured as 1328, 2438, and 535 cm^2 for epipremnum aureum, spathiphyllum wallisei, and dieffenbachia sp., respectively. The CO_2 concentrations of the plants inside the chamber per one square centimetre are presented in Figure 4 (b). Data readings from Figure 4(b) were averaged. The CO_2 values per leaf area over a 24-hour period for each plant are presented in Table 1. Daytime CO_2 averages, from between 7am and 7pm and night CO_2 averages, taken between 7pm and 7am are also presented in table form. Epipremnum aureum performed better on the test than the other two plants as it yielded the lowest CO_2 per leaf areas. They are 0.28, 0.23, and 0.34 ppm/cm^2 for 24-hour, daytime, and nighttime averages, respectively.

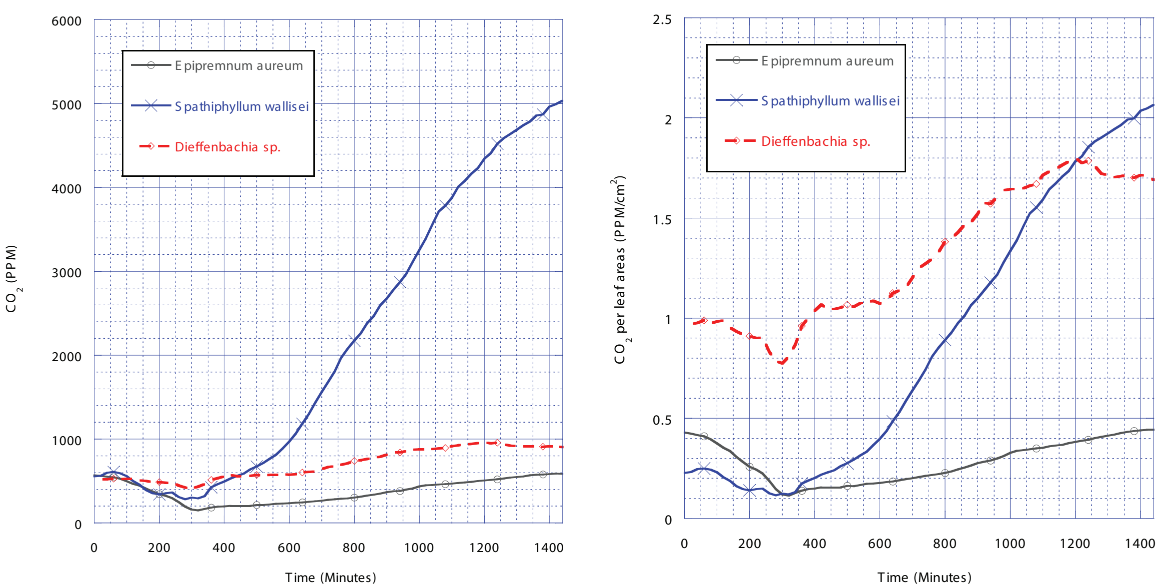
FIGURE 2. Plants used in this research.

Epipremnum aureum *Spathiphyllum wallisei* *Dieffenbachia sp.*

FIGURE 3. Plants were put in a closed flux chamber for 24 hours.

Readings for the accumulation of CO_2 for 24-hour, daytime and night-time periods also reveal that epipremnum aureum performs better than the other plants. Within the accumulation values in Table 1, negative and positive signs denote absorption and emission, respectively. The day time CO_2 accumulation value is –0.22. This means that the plant helps absorb the CO_2 in the air at a rate of 0.22 ppm/cm^2 of leaf area from 7am to 7pm. This represents a considerable benefit being derived from using this type of ornamental plant. Figure 4 (b) is enlarged for the period 7am until noon, or 0 to 300 minutes, and the readings replotted as shown in Figure 5 (a). This reveals that all plants absorb CO_2 during this period as all curves decelerate from minutes 0 to 300. They absorb CO_2 at rates of 0.31, 0.10, 0.19 ppm/cm^2 for epipremnum aureum, spathiphyllum wallisei, and dieffenbachia sp., respectively. Epipremnum aureum is able to absorb the CO_2 in the air at 0.31 ppm/cm^2 of leaf area. In our chamber study, a pot of epipremnum aureum has a leaf area of approximately 1,328 cm^2, indicating that it can absorb CO_2 at a rate of 412 ppm from 7am until noon. However, in the afternoon, Figure 5 (b) reveals that epipremnum aureum emits the least CO_2 compared to the other plants. It emits 0.06 ppm/cm^2 as shown in the last row of Table 1. In other words, it releases 76 ppm per one potted plant during noon to 5pm. With the other plants, spathiphyllum wallisei can absorb CO_2 at 0.1 ppm/cm^2 of leaf area. In our study, one pot of spathiphyllum wallisei has a leaf area of 2,438 cm^2 indicating that it can absorb CO_2 at 244 ppm in the morning. However, in the afternoon it emits CO_2 at 0.27 ppm/cm^2 or releases 667 ppm per one potted plant. Dieffenbachia sp. can absorb CO_2 in the air at 0.19 ppm/cm^2 of leaf area. In our study, one pot of dieffenbachia sp. has a leaf area of 535 cm^2 indicating that it can absorb CO_2 at 102 ppm in the morning. However, in the afternoon dieffenbachia sp. emits CO_2 at 0.3 ppm/cm^2 or releases 160 ppm per one potted plant.

FIGURE 4. CO_2 profile of three plants over 24 hours.



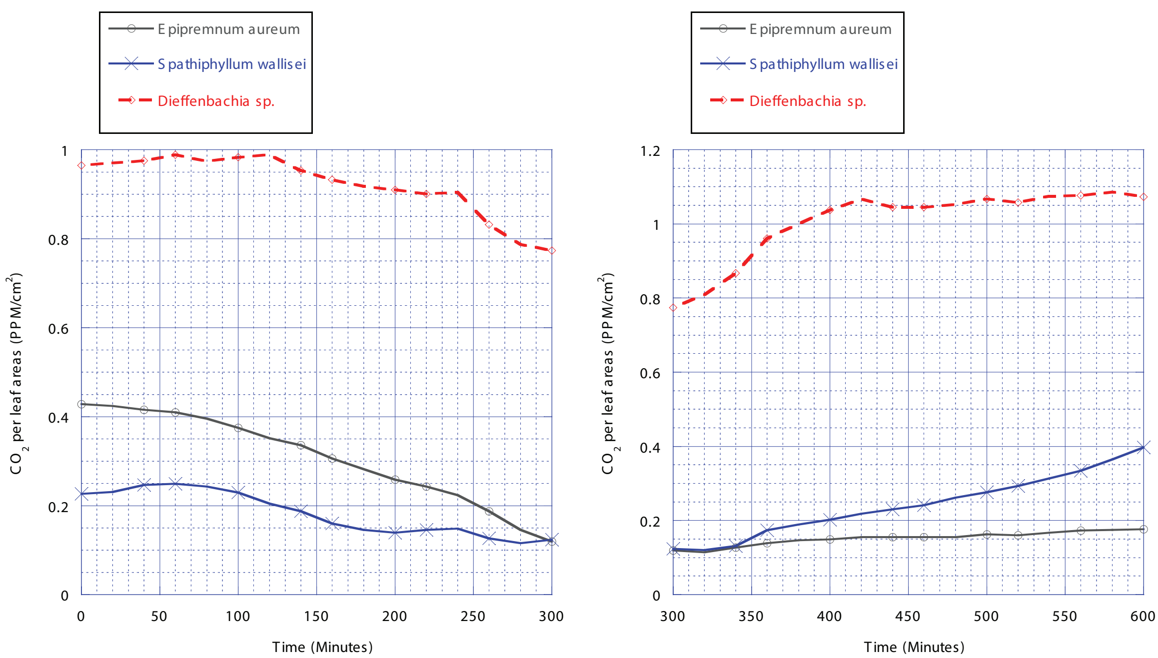
(a) Original

(b) Normalized by leaf area

TABLE 1. Carbon dioxide per leaf area in ppm/cm^2

Description Epipremnum aureum		CO_2 per leaf area (ppm/cm^2)		
		Spathiphyllum wallisei	Dieffenbachia sp.	
Leaf area (cm^2)		1,328	2,438	535
Average	24 Hour Average	0.28	0.90	1.32
	Day Time Average	0.23	0.27	1.00
	Night Time average	0.34	1.50	1.62
Accumulation	24 Hour Accumulation	0.01	1.84	0.73
	Day Time Accumulation	−0.22	0.46	0.29
	Night Time Accumulation	0.23	1.37	0.44
	5-hour Accumulation (7am-Noon)	−0.31	−0.10	−0.19
	5-hour Accumulation (Noon-5pm)	0.06	0.27	0.30

FIGURE 5. CO_2 profiles of three plants in morning and afternoon time periods.



(a) 7am to Noon

(b) Noon to 5pm

4. LIGHT SENSITIVITY TESTS

After epipremnum aureum was found to perform best in terms of reducing indoor CO_2, plants were arranged in a classroom to test for what effect light sensitivity plays in reducing CO_2. The classroom used was 6 × 11 meters with its ventilation system turned off during the experiments. Twenty pots of epipremnum aureum, or approximately 20,000 cm^2 in leaf area, were put on tables with 0.5, 1.0, 1.5, and 2.0 meters distance from windows, as shown in Figure 6.

Light density was measured and recorded by a lux meter made by Extech instruments. Experiments started right after classes were over. Left over CO_2 levels from students in classes were used as beginning CO_2 readings and then subsequent readings were recorded over one hour using the air quality meter placed in the center of the room. Data was recorded for five experiments at the same time of day in all experiments. They involved a vacant room without plants, and then with plants placed 0.5, 1.0, 1.5, and 2.0 meters from windows. The first experiment involved studying the behaviour of CO_2 decreasing naturally after students had left the room. The other four experiments went on to study how the rate of CO_2 decrease was affected by plants being placed at varying distances from the windows. The light density on the table where the plants were placed was recorded at 1471, 1065, 1008, and 628 lux, for the 0.5, 1.0, 1.5, and 2.0 meters distances, respectively, as shown in Table 2. Data was recorded in four-minute intervals over one hour, as shown in Table 3. The ability to absorb CO_2 for the epipremnum aureum varied in response to different light densities. The values in the table are original data as recorded. However, starting CO_2 points differed on each testing day. Data is

FIGURE 6. Epipremnum aureum were placed different distances from windows to test the sensitivity of light density to CO_2 levels.

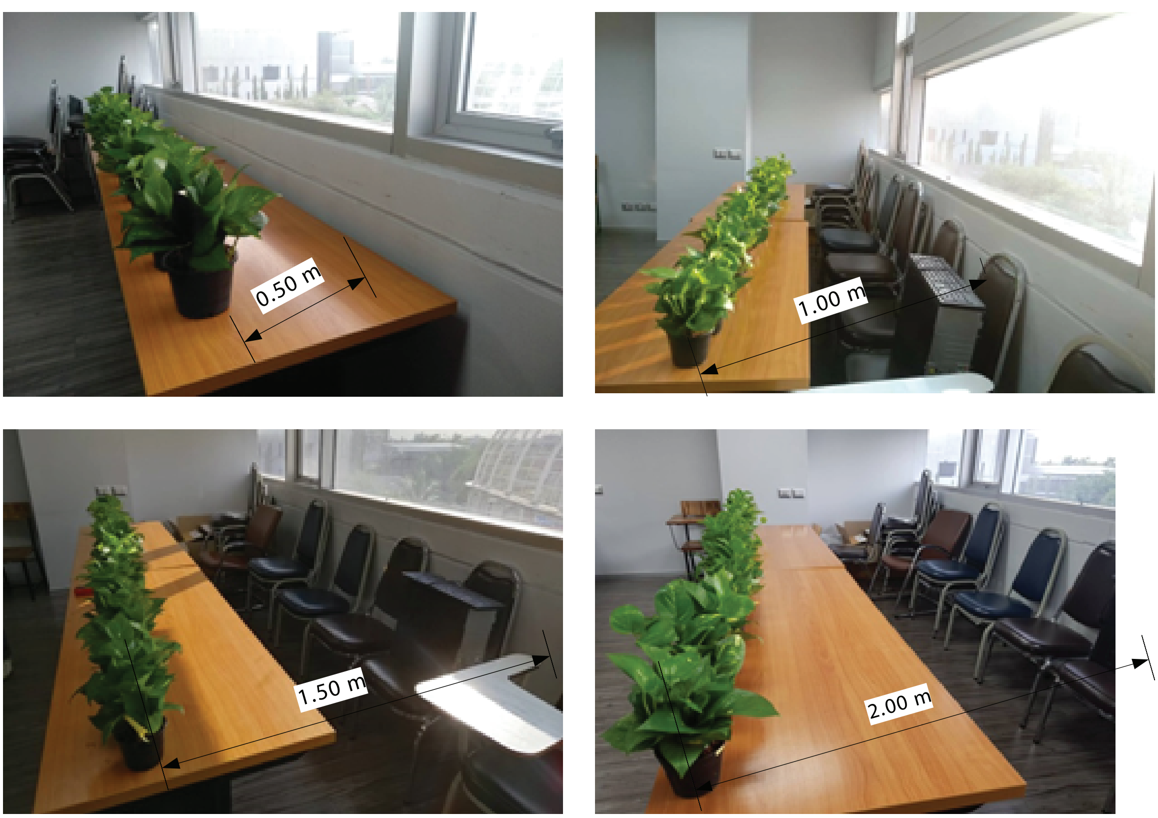


TABLE 2. Light density on the table with plants at different distances from the windows.

Distance from Windows (m.)	0.5	1.0	1.5	2.0
Light Density (Lux)	1471	1065	1008	628

then was normalized to start at 1770 ppm as presented in Table 4. Readings were plotted as a function of light density versus CO_2 concentration in the room to allow a visual comparison, as shown in Figure 7.

The average CO_2 levels over one hour are calculated as 1339, 1357, 1363, and 1405 for the 0.5, 1.0, 1.5, and 2.0 meters distances, respectively, as shown in Table 4. They are compared using the average CO_2 of a room without any plants as a base reading. The 0.5-meter variable of distance of plants from the windows records the best performance level at 347 ppm. The ability to reduce CO_2 decreases as the distance from the windows increases. The 2.0-meter

TABLE 3. Original room CO_2 as recorded.

Time (Minute)	Room CO_2 without plants (PPM)	Room CO_2 effected by epipremnum aureum for different distances from windows (PPM)			
Distance from Windows (m.)		0.50	1.0	1.5	2.0
Light Density (Lux)		1471	1065	1008	628
0	1279	1770	1586	1510	1453
4	1263	1681	1504	1419	1363
8	1258	1604	1437	1340	1285
12	1240	1525	1359	1278	1231
16	1222	1455	1294	1217	1176
20	1219	1416	1227	1157	1133
24	1205	1368	1175	1117	1104
28	1188	1311	1122	1064	1051
32	1180	1264	1092	1032	1032
36	1175	1231	1078	1005	1005
40	1166	1199	1062	980	992
44	1162	1167	1031	954	965
48	1162	1135	987	935	937
52	1136	1119	963	909	924
56	1134	1096	936	878	894
60	1128	1088	914	851	863

distance variable accounted for the lowest performance reading, decreasing CO_2 at only 281 ppm. In these experiments, it was found that the ability to reduce CO_2 of tables with plants at 1.0, 1.5, and 2.0 meters distance from windows are different from that of tables at 0.5 meters by rates of 1%, 2%, and 4%, respectively. Based on these discrepancies, this research would recommend placing epipremnum aureum as close to windows as possible within a range of 1.5 meters. Within this range, it can absorb CO_2 at similar levels of performance.

Without plants, CO_2 in a room would be 1686 ppm on average. With epipremnum aureum in a room, CO_2 would come down as a function of light density shown in Figure 8 based on a 60-minute experiment duration. Twenty pots of epipremnum aureum could help decrease CO_2 from 281 to 347 depending on particular light densities.

TABLE 4. Normalized as starting at 1770 ppm for comparison purposes.

Time (Minutes)	Room CO_2 without plants (PPM)	Room CO_2 effected by epipremnum aureum for different distanced from windows (PPM)			
Distance from Windows (m.)		0.50	1.0	1.5	2.0
Light Density (Lux)		1471	1065	1008	628
0	1770	1770	1770	1770	1770
4	1754	1681	1688	1679	1680
8	1749	1604	1621	1600	1602
12	1731	1525	1543	1538	1548
16	1713	1455	1478	1477	1493
20	1710	1416	1411	1417	1450
24	1696	1368	1359	1377	1421
28	1679	1311	1306	1324	1368
32	1671	1264	1276	1292	1349
36	1666	1231	1262	1265	1322
40	1657	1199	1246	1240	1309
44	1653	1167	1215	1214	1282
48	1653	1135	1171	1195	1254
52	1627	1119	1147	1169	1241
56	1625	1096	1120	1138	1211
60	1619	1088	1098	1111	1180
Average	1686	1339	1357	1363	1405
CO_2 comparison with naturally decreasing readings without any plants (ppm)		347	329	323	281
Percentage Comparison		21%	20%	19%	17%

The CO_2 reduction values derived from the 60-minute experiment, which are displayed in the second row from the bottom of Table 4, are plotted versus different light densities, as shown in Figure 8. The four coordinates in black dots in Figure 8 were curve fitted by a log function. A model is obtained as shown in Equation 1 with an R^2 of 0.99. This equation is recommended to be used within test ranges or between 628 to 1471 lux. Any extrapolation beyond the test ranges could be made, but would need to be interpreted with caution. The equation 1 model can estimate the CO_2 values reduction at the 60th minutes with desired light density values within the test ranges by the 20 pots of epipremnum aureum.

$$y = 182 \log(x) - 225 \qquad \text{Equation 1}$$

where x = light density in lux
y = carbon dioxide in ppm

5. LEAF AREA TESTING

Epipremnum aureum was found to be the best plant in terms of reducing indoor CO_2 and should be placed as close to windows as possible, or not more than 1.5 meters away, to generate positive outcomes. Our next question concerns how many pots of epipremnum aureum would be required to help reduce CO_2 to within the generally acceptable value of 1,000 ppm to ensure acceptable indoor air quality. To examine this, four experiments were performed. They comprise experiments of eighty minutes duration conducted in a classroom with 20 students present. Each experiment was held between 13.00 and 15.00. The first session was conducted

FIGURE 7. Effect of light density on epipremnum aureum in decreasing room CO_2.

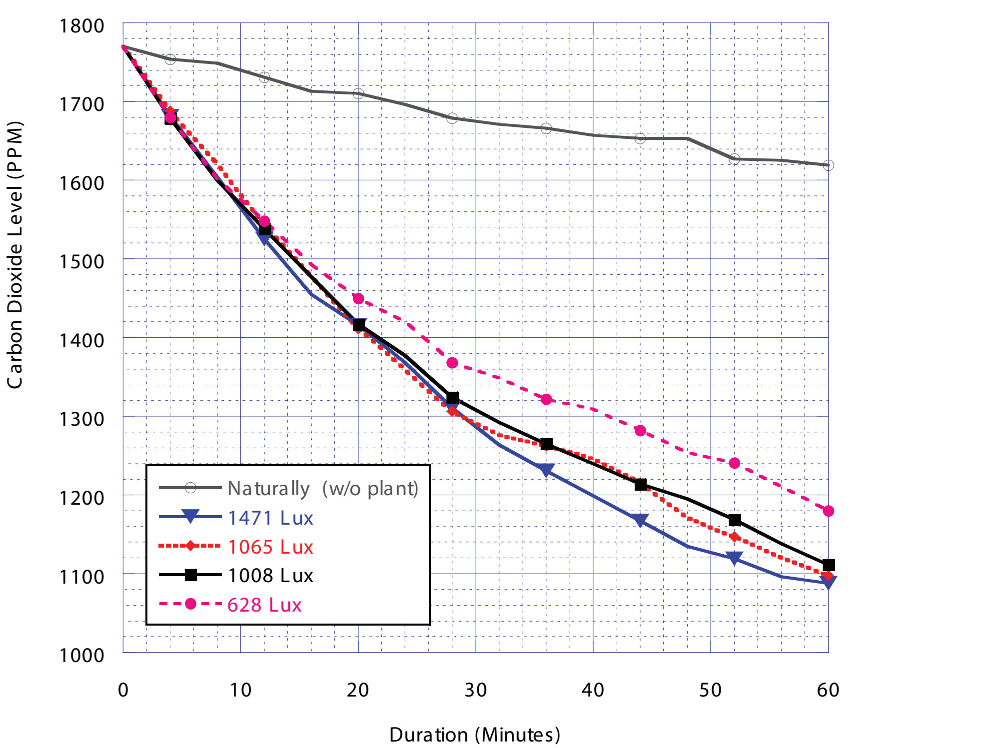
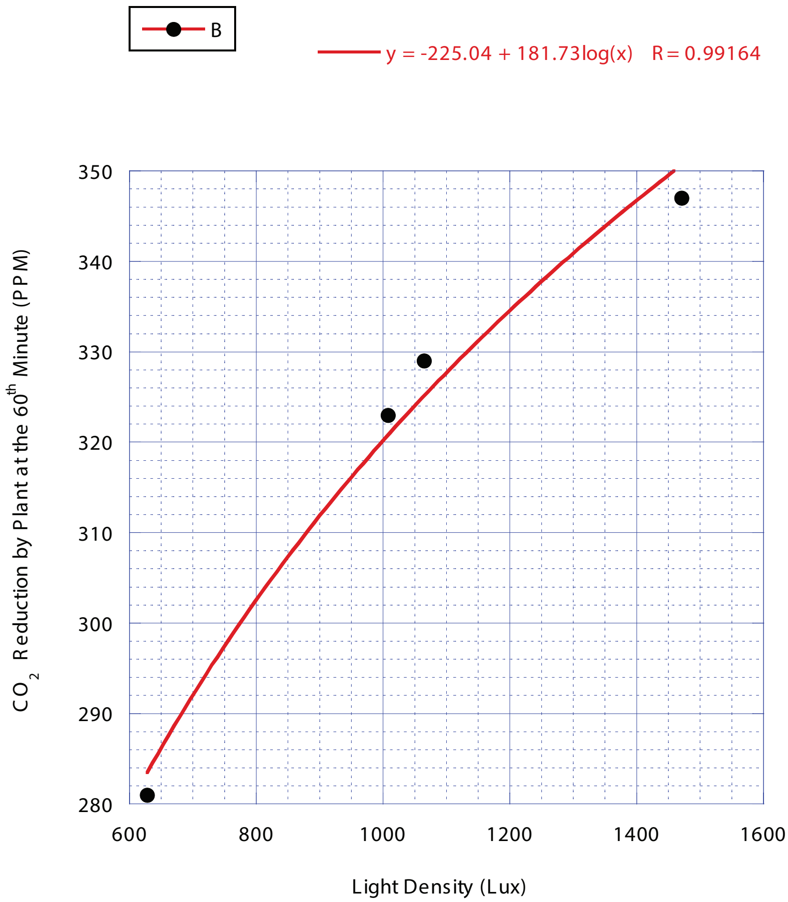


FIGURE 8. Effect of light density on room CO_2 reduction at the 60th minute.



in a room with no plants present. The other experiments were carried out in the same classroom filled with students, but with varying amounts of epipremnum aureum plants with leaf areas approximately of 33,000, 66,000, and 150,000 cm^2. By using a data processing image application named Petiole, the leaf areas from 15 pots of epipremnum aureum were measured and the total leaf areas were found to be between 800 and 1,200 cm^2 per pot, with an average of approximately 1,000 cm^2. The leaf areas used in experiments were, therefore, calculated in terms of 1,000 cm^2 per one pot of epipremnum aureum. Consequently, the 33,000, 66,000, and 150,000 cm^2 leaf experiments used 33, 66, and 150 pots, respectively. They were placed on tables next to windows at the back of the classroom, as shown in Figures 9 and 10.

The experiment room comprised a classroom with a size of 6×11 meters. A CO_2 meter was placed in the middle of the room to record CO_2 concentration during the experiments. The CO_2 concentrations of all four experiments after normalization are presented in Figure 11. Without plants, the CO_2 level rose to 1743 ppm at the 80th minute, creating an uncomfortable and unproductive environment for studying. In school buildings, poor indoor air quality can cause a reduction in students' performance levels as confirmed by short-term, computer-based tests, whereas more suitable air quality in classrooms can enhance students' concentration levels and also teacher productivity (Clements-Croome et al. 2008). At the 80th minute, in the experiment involving 150,000 cm^2 of leaf area, the CO_2 level was able to be reduced to 1313 ppm level.

FIGURE 9. Plants placed in the back of the room with the CO_2 meter in the center of the room.

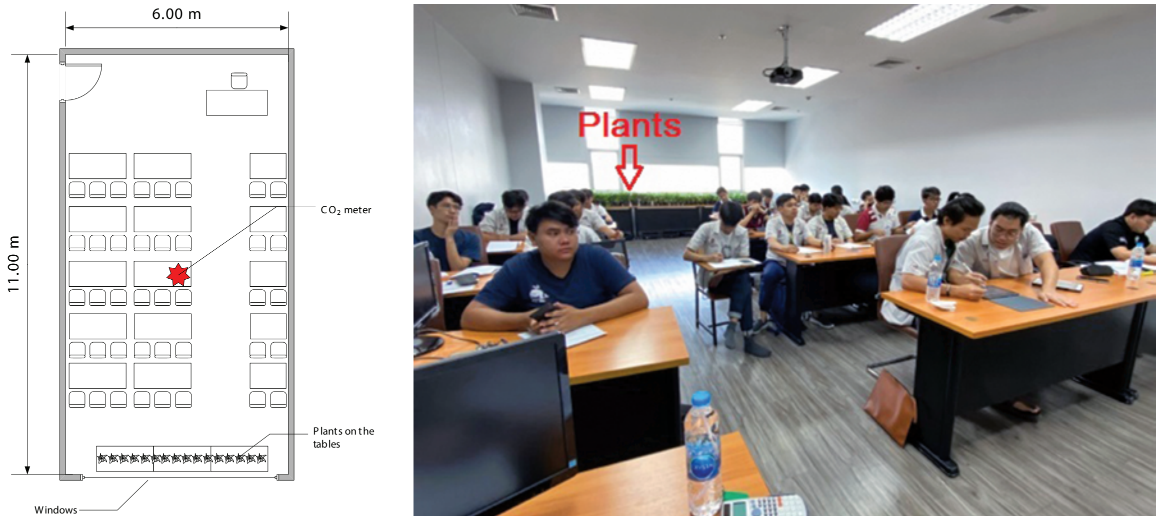
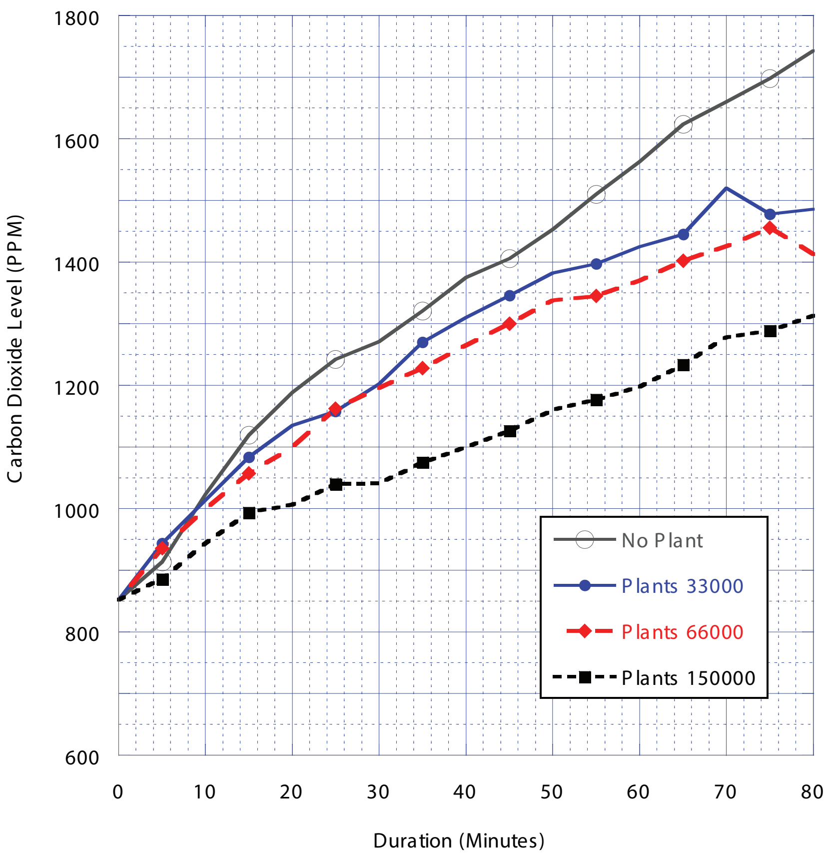


FIGURE 10. Plants placed in the back of the room and varyied by leaf area in cm^2.

If we consider CO_2 levels throughout the 80 minutes, average CO_2 readings were 1351, 1262, 1226, 1101 ppm, as shown in the second row of Table 5. Rooms with plants showed a decrease in CO_2. Plants with leaf areas of 33000, 66000, and 150000 cm^2 were able to absorb CO_2 at rates of 89, 125, and 250 ppm, respectively. From these figures, the CO_2 absorption rates per one pot of epipremnum aureum can be calculated at 2.7, 1.9, and 1.7 ppm per 1000 cm^2. Given that the price of one pot of epipremnum aureum is 15 Baht, or 0.43 Euros, the cost of the plants used in the experiments outlined above are 14.3, 28.6, and 65 Euros, obtained by multiplying 33, 66, and 150 pots by 0.43 Euro. Thus, the cost effectiveness of using these plants to remove CO_2 comprises 0.16, 0.23, and 0.26 Euro/ppm. Using large amounts of plants is not as effective as using small amounts since plants also emit CO_2 during the afternoon, as we found earlier from the light sensitivity testing. However, large amounts of plants still reduce CO_2 much more efficiently than small amounts and are effective in improving indoor air quality.

If we want to predict the number of plants that would be able to bring down the CO_2 level to 1,000 ppm, a prediction model is required. Data from the first and second rows of Table 5 is

FIGURE 11. CO_2 profiles during 80 minutes for all four experiments.



used to enable curve fitting by the linear regression method using a straight-line model. Three coordinates are used, 33000, 66000, and 150000 cm^2 versus the 80-minute averages from Table 5. These are plotted as shown in Figure 12. The straight line in Figure 12 represents a model obtained by the linear regression method. The line represents the three coordinates at R^2 of 0.99 and reflects the model shown in Equation 2. For example, we can predict the amount of leaf area or pots of epipremnum aureum required to reduce CO_2 to 1,000 ppm at the 80th

TABLE 5. Absorption ability and cost effectiveness varies according to leaf area.

Leaf areas (cm^2)	No Plants	33,000	66,000	150,000
80 minutes averaged CO_2 (ppm)	1,351	1,262	1,226	1,101
Plants absorb CO_2 (ppm)	—	89	125	250
CO_2 absorption per a pot (ppm/1,000 cm^2)	—	2.7	1.9	1.7
Cost of plants in Thai market (€, Euro)	—	14.3	28.6	65.0
CO_2 absorption cost (Euro/ppm)	—	0.16	0.23	0.26

minute by following Equation 2. By substituting y with 1000 ppm, a leaf area of 222,857 cm^2 is obtained. Such a leaf area is equivalent to approximately 223 pots of epipremnum aureum.

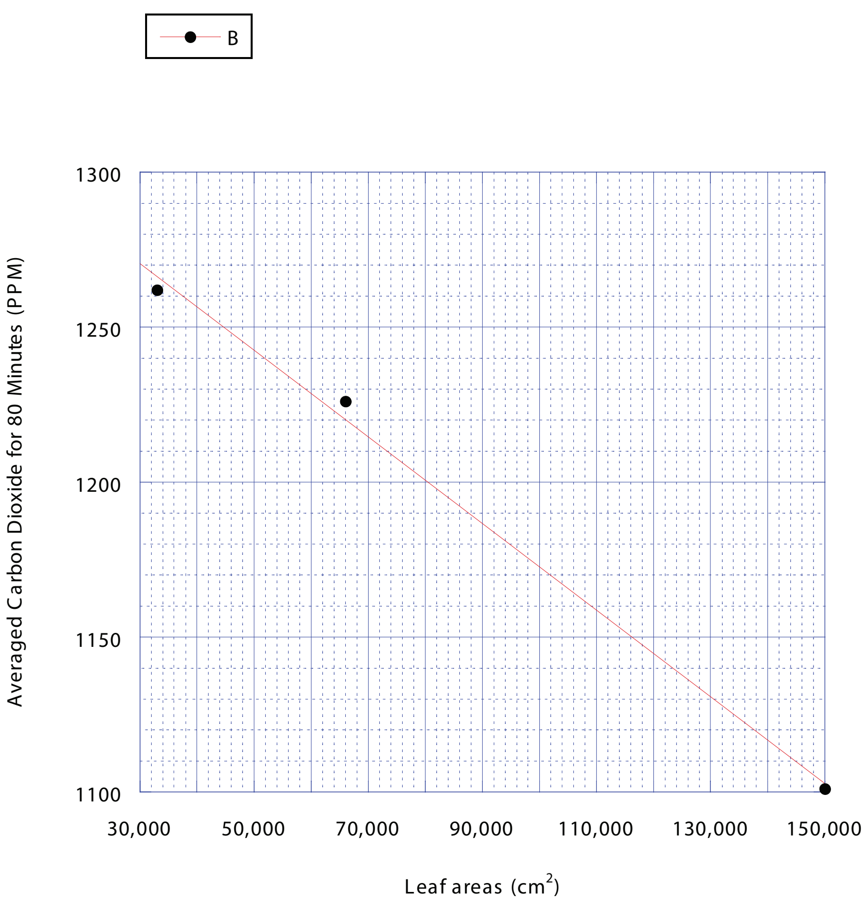
$$y = 1312 - 0.0014x \qquad \text{Equation 2}$$

where x = leaf area in cm^2
y = carbon dioxide in ppm

6. CONCLUSIONS

From our findings, epipremnum aureum is able to improve indoor air quality better than spathiphyllum wallisei and dieffenbachia sp. In our experiments epipremnum aureum recorded lower average CO_2 readings in a closed flux chamber than the other plants during 24-hours, morning and afternoon periods. All plants were able to absorb CO_2 relatively efficiently in the morning from 7am to noon or during daylight periods. In the afternoon from noon to 7 pm, they all emit CO_2. However, epipremnum aureum emits the least CO_2 at 0.06 ppm/cm^2. Therefore, these reasons contribute to epipremnum aureum being the most effective plants among those tested in this research. Our study also found that epipremnum aureum should be placed within a 1.50 meter distance from windows for the most desirable results in helping to enhance indoor

FIGURE 12. CO_2 prediction model obtained by linear regression.



air quality. Daylight from windows encourages CO_2 absorption in plants. Sunlight in the afternoon serves to encourage the plants in our sample to emit CO_2. Twenty pots of epipremnum aureum were able to help improve air quality by decreasing CO_2 from 281 to 347 depending on particular light density conditions. With sufficient amounts of epipremnum aureum, in this research 150 pots, air quality in classrooms can be improved by 430 ppm in an 80-minute class fill with 20 students. By installing 150 pots of epipremnum aureum in classrooms, 24.67% of CO_2 can be removed. This figure is less than that recorded by Husti et al. (2016) which found a 58.33% reduction. Although air quality in classroom in this research cannot be totally cleaned by epipremnum aureum, it can help enhance indoor air quality slightly. If plants emit certain levels of CO_2 during experiments, using large amounts is not as cost effective as using smaller amounts as we found in this study. However, large amounts of plants are still needed to bring the CO_2 down as quickly as possible if the prevailing quality of indoor air is a concerning factor in any decision. Suitable indoor plants are not only for decoration but also for making the indoor spaces healthier (Su and Lin 2013). This is a preliminary study within our research, Epipremnum aureum should be compared with other plants in other situations, such as in ventilated rooms and rooms with volatile organic compounds (VOC). Further studies related to oxygen levels, VOC, and particle matters during experiments impacted by plants should also be investigated.

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REFERENCES

1. Andrade A., Dominski F.H., 2018, Indoor air quality of environments used for physical exercise and sports practice: Systematic review, Journal of environmental management, vol. 206, pp. 577–586.
2. Atarodi Z., Karimyan K., Gupta V.K., Abbasi M., Moradi M., 2018, Evaluation of indoor air quality and its symptoms in office buildings—A case study of Mashhad, Iran, Data in Brief, vol. 20, pp. 74–79.
3. Brilli F., Fares S., Ghirardo A., Visser de P., Calatayud V., Muñoz A., Annesi-Maesano I., Sebastiani F., Alivernini A., Varriale V., Menghini F., 2018, Plants for Sustainable Improvement of Indoor Air Quality, Trends in plant science, vol. 23, no. 6, pp. 507–512.
4. Clements-Croome D.J, Awbi H.B., Bako´ Biro Zs, Kochhar N., Williams M., 2008, Ventilation rates in schools, Building and Environment, vol. 43, pp. 362–367.
5. Gao J., Wargocki P., Wang Y., 2014, Ventilation system type, classroom environmental quality and pupils' perceptions and symptoms, Building and Environment, Vol. 75, pp. 46–57.
6. Husti A., Cantor M., Stefan R., Miclean M., Roman M., Neacsu I., Contiu I., Magyari K., Baia M., 2016, Assessing the indoor pollutants effect on ornamental plants leaves by FT-IR spectroscopy, Acta Physica Polonica A, vol. 129, no. 1, pp. 142–149.
7. Irga P.J., Torpy F.R., 2016, Indoor air pollutants in occupational buildings in a sub-tropical climate: Comparison among ventilation types, Building and Environment, vol. 98, pp. 190–199.
8. Irga P.J., Abdo P., Zavattaro M. Torpy F.R. 2017, An assessment of the potential fungal bioaerosol production from an active living wall, Building and Environment, vol. 111, pp. 140–146.
9. Jamaludin N.M., Mahyuddin N., Akashah F.W., 2016, Assessment of Indoor Environmental Quality (IEQ): Students Well-Being in University Classroom with the Application of Landscaping, MATEC Web of Conferences.
10. Lohr V., Pearson-Mims C., 1996, Particulate matter accumulation on horizontal surfaces in interiors: Influence of foliage plants, Atmospheric Environment, vol. 30, no. 14, pp. 2565–2568.

11. Pettit T., Irga P.J., Abdo P., Torpy, F.R., 2017, Do the plants in functional green walls contribute to their ability to filter particulate matter?, Building and Environment, vol. 125, pp. 299–307.
12. Pettit T., Irga P.J., Torpy F.R., 2018, Towards practical indoor air phytoremediation: A review, Chemosphere, vol. 208, pp. 960–974.
13. Su Y., Lin C., 2013, CO_2 purify effect on improvement of indoor air quality (IAQ) through indoor vertical greening, Proceedings of the world congress on engineering 2013, vol. 3, London, 3–5 July, 2013.
14. Su Y., Lin C., 2015, Removal of indoor carbon dioxide and formaldehyde using green walls by bird nest fern, Horticulture Journal, vol. 84, no. 1, pp. 69–76.
15. Torpy F., Zavattaro M., Irga P., 2017, Green wall technology for the phytoremediation of indoor air: a system for the reduction of high CO2 concentrations, Air Quality, Atmosphere and Health, vol. 10, no. 5, pp. 575–585.
16. Torpy F., Irga P., Burchett M., 2014, Profiling indoor plants for the amelioration of high CO2 concentrations, Air Quality, Urban Forestry and Urban Greening, vol. 13, pp. 227–233.
17. Tudiwer D., Korjenic, A., 2017, The effect of an indoor living wall system on humidity, mould spores and CO_2-concentration, Energy and Buildings, vol. 146, pp. 73–86.
18. Wang C., Er, S.-., Abdul-Rahman, H., 2016, Indoor vertical greenery system in urban tropics, Indoor and Built Environment, vol. 25, no. 2, pp. 340–356.
19. Yarn K., Yu K., Huang J., Luo W., Wu P., 2013, Utilizing a vertical garden to reduce indoor carbon dioxide in an indoor environment, Wulfenia, vol. 20, no. 10, pp. 180–194.
20. Zuo L., Wu D., Yuan Y., Li H., Yu L., 2020, Effect of arrangement and quantity of epipremnum aureum on work efficiency and subjective perceptions, Environmental Science and Pollution Research, vol. 27, no. 15, pp. 17804–17814.