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Improving Indoor Air Quality: Utilizing Tropical Ornamental Plants for Carbon Dioxide Reduction

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Abstract

This study investigates types of ornamental plants for improve indoor air quality by specifically reducing CO_2 levels. The fourteen plant types examined are *Epipremnum aureum*, *Spathiphyllum* sp., *Nephrolepis Exaltata*, *Chlorophytum Comosum*, *Codiaeum Variegatum Blume*, *Epipremnum Aureum* (Linden & André) *G. S. Bunting*, Crinum asiaticum, *Dracaena trifasciata*, *Diffenbachia picta Schott*, *Portulacaria afra f. variegata*, *Peperomia obtusifolia (L.) F.Dietr*, *Aglaonema cochinchinense*, *Pilea Cadierei*, and *Cordyline fruticose (L.) A.Chev*. The ability of each ornamental plant to reduce CO_2 levels was recorded over a 24-hour period. It was observed that *Epipremnum aureum* exhibited superior CO_2 absorption capabilities compared to other ornamental plants in this study. It had an average CO_2 absorption and release of -36 and 2 ppm, respectively, in the closed chamber, both during the daytime and nighttime. It is suggested to incorporate these plants in various living areas such as the living room, kitchen, bedroom, or office spaces.

Keywords : Indoor Air Quality; Reducing Carbon Dioxide; Ornamental Plants

Introduction

The quality of indoor air in urban environments is a growing concern, with potential health implications for those who spend significant time indoors. One key pollutant of concern is carbon dioxide (CO_2). Elevated levels of CO_2 can lead to discomfort, reduced cognitive function, and even health problems. Fortunately, nature offers a solution: the use of ornamental plants for indoor air purification. In enclosed environments with a large number of inhabitants, CO_2 buildup can occur. Humans produce and exhale higher concentrations of CO_2 in occupied indoor spaces than they do outdoors [1]. CO_2 concentration in living areas increases as people live indoors for extended periods without sufficient ventilation. Typically, living areas are equipped with air conditioning units but lack proper ventilation systems. Prolonged exposure to high CO_2 concentrations can cause occupants to experience headaches, nausea, fatigue, and listlessness. Therefore, the removal of CO_2 from enclosed environments is essential [2-3]. However, the installation of ventilating fans can bring hot air into the room, resulting in increased electricity consumption. The issue of indoor air quality is exacerbated by the fact that people are spending more time indoors, combined with reduced building ventilation aimed at conserving energy [4]. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers standard (ASHRAE Standard 62.1) recommends that the maximum acceptable CO_2 concentration for comfort should not exceed 700 ppm [5]. The CO_2 setpoint of a ventilation fan system can significantly impact energy consumption. In a typical 30 m^2 office with 1–3 occupants, it appears that growing plants vertically can reduce carbon dioxide concentrations within buildings could reduce indoor CO_2 concentrations by

25.7%–34.3%, resulting in approximately a 12.7%–58.4% reduction in building ventilating energy consumption [6-7]. An alternative method to reduce high concentrations of CO_2 without relying on ventilation fans is the use of ornamental plants. Green walls not only provide aesthetic benefits but also possess the ability to remove indoor CO_2. Therefore, using ornamental plants to reduce CO_2 levels in urban indoor air is a viable solution. Numerous studies have indicated that vertical plant walls have the potential to remove indoor air pollution. They not only enhance aesthetics but also possess the ability to remove indoor CO_2. Su and Lin [8] found that Bird's nest fern has the ability to remove CO_2 at a rate of 1.984 ppm/hr. One alternative to reduce high CO_2 concentrations without the use of ventilation fans is to employ ornamental plants. Plants offer a sustainable but underexploited solution for enhancing indoor air quality [9]. Yarn et al. [10] demonstrated that *Spathiphyllum kochii* can absorb CO_2 from human respiration. Husti et al. [11] investigated the removal of indoor air pollutants by ornamental plants in a workplace and found that they can reduce CO_2 concentrations by 58.33%. Jamaludin et al. [12] reported significant reductions in relative humidity, total volatile organic compounds (TVOC), and CO_2 levels in a university classroom after introducing a landscape. Torpy et al. [13] studied the reduction of high CO_2 concentrations using two plants in a green wall application. They found that *Chlorophytum comosum* and *Epipremnum aureum* are effective for CO_2 removal at specific light densities. Torpy et al. [14] discovered that *HL-acclimatized D. lutescens* is the most efficient species per unit leaf area in removing high CO_2 concentrations, even in low light conditions. *Epipremnum aureum* and *Spathiphyllum sp*. plants are the most effective species in reducing CO_2 [15]. Furthermore, plants also absorb other indoor air pollutants, such as volatile organic compounds (VOCs), making them versatile air purifiers [16]. The highest toluene removal was found in *Sansevieria trifasciata* while the ethylbenzene removal from air was with *Chlorophytum comosum* [17]. Integrating ornamental plants for CO_2 reduction in urban settings presents unique challenges, including limited space and potential outdoor pollutants. Nevertheless, creative solutions like vertical gardens and rooftop gardens have shown promise in urban areas [18]. Green building initiatives are increasingly concerned with indoor air quality. Living in green buildings not only promises good health and lower electricity bills but also provides a better indoor environment while reducing energy demands. The effect of CO_2 absorption is influenced by various factors, including intense light and relative humidity (RH). In these real environments, the intensity of natural light exceeded that of controlled artificial lighting, consistent with most previous studies using light intensities ranging from 100 to 2,000 Lux [15, 19, 20-22]. However, few of these studies focused on the plant's ability to reduce CO_2 emission under natural light, a condition that can cause stress to plants. Light stress negatively impacts photosynthetic efficiency, leading to stress conditions when the plant cannot move, affecting various metabolic processes and causing decreased growth. For instance, high light stress occurs when light intensity exceeds the plant's capacity for photosynthesis and other metabolic processes, potentially damaging cell components like membranes, proteins, and DNA due to the accumulation of reactive oxygen species (ROS). Photoinhibition may also occur, reducing photosynthetic efficiency by inactivating photosystem II (PSII) in chloroplasts. On the other hand, low light stress happens when light intensity falls below the level needed for optimal photosynthesis and growth. In such conditions, limited energy is available for plant metabolism, resulting in reduced photosynthesis rates and growth. Additionally, low light stress may lead to a decrease in photosynthetic pigments like chlorophyll, further hampering the plant's ability to absorb and utilize light energy [19, 23-25]. Additionally, Thailand offers a wide variety of ornamental plants; however, determining which plants are most effective at reducing indoor CO_2 levels is not well-established. Therefore, the objective of this study is to investigate ornamental plant species for indoor CO_2 reduction in both light and dark conditions in a real environment. The study's findings can be applied to enhance indoor air quality using ornamental plants, contributing to green building practices.

Methodology

The experiment involved screening fourteen ornamental plant species to reduce CO_2 levels. Subsequently, a real room experiment was conducted to investigate the performance of the plants that showed the best results in reducing CO_2 levels in the previous experiment.

1. Plant Preparation

The screening of plants for CO_2 removal involved an experiment with fourteen ornamental plant species: *Crinum asiaticum*, *Epipremnum aureum*, *Nephrolepis exaltata*, *Dracaena trifasciata*, *Chlorophytum comosum*, *Diffenbachid picta Schott*, *Spathiphyllum* sp., *Portulacaria afra*, *Peperomia obtusifolia*, *Aglaonema cochinchinense*, *Epipremnum aureum (Linden & André) G. S. Bunting)*, *Codiaeum Variegatum Blume*, *Pilea* Cadierei, and *Cordyline fruticosa (L.) A.Chev*. When selecting plants, consideration was given to choosing sizes that could fit well in the closed chamber. These plants were cultivated in plastic pots measuring 4 inches, each containing a mixture of 200 g of soil and coco coir in a 1:1 ratio as the growth medium. Additionally, the pots were covered with aluminum foil to eliminate any potential interference from factors such as soil and pot absorption [17]. In this experiment, the leaf area of all ornamental plants was quantified using a data processing image method with the Petiole program (Figure. 1) following the methodology outlined by Hrytsak et al. [11].

2. Experimental setup

The experiment involved screening ornamental plant species to reduce CO_2 levels and assessing their CO_2 absorption and emission abilities. Fourteen plant species were placed inside an acrylic closed chamber measuring 0.30 m in diameter, 0.50 m in height, with a total volume of 3.5 m^2. A fan was installed inside the chamber, as shown in Figure 2. There were two conditions: one with an unplanted chamber as a control, and the other with plants inside the chamber. Each plant species was studied in an uninhabited room using natural light to ensure the applicability of the results to real environments. The experiment lasted for 24 hours, during which the plants were exposed to natural daytime from 06.00 to 18.00, and nighttime from 18.00 to 06.00. Light intensity was measured using an Extech Lux meter. The plants inside the closed chamber were positioned approximately 10 cm away from a window, with a window size of 2.5 m by 1.5 m and a height of 20 m on the northeast side, as shown in Figure 3. CO_2 concentration was released into the chamber, and CO_2 concentration (ppm), relative humidity; RH (%), and temperature (°C) were recorded for analysis.

The experiment assessed the ability of ornamental plants to absorb CO_2, based on the results from previous experiments. It was conducted in a classroom with dimensions of 190 m^2 and a height of 2.91 m. In this experiment, there were zero plots of ornamental plants in the control group (C) and 100 plots throughout the room (P), with CO_2 meters installed in designated areas. The CO_2 meters were positioned between 60 cm and 120 cm above the floor level.

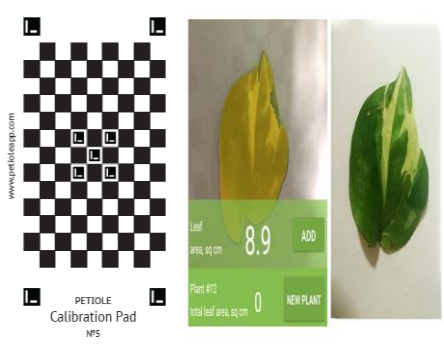


Figure 1 Petiole program

Figure 2 Experimental closed chamber

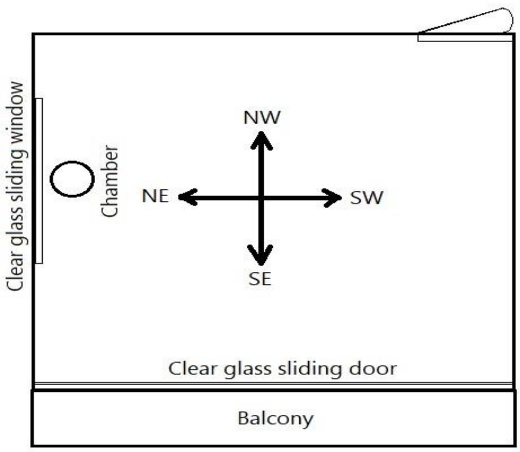


Figure 3 the positioning of the plants and the closed chamber

3. Carbon dioxide Assessment

Measure CO_2 concentration (ppm), RH (%), and temperature (°C) continuously using a Lutron air quality meter (AQ-9901SD) inside the chamber to collect data over 24 hours. Record readings with a monitoring device equipped with a data logger, as depicted in Figure 2. To maintain comfort, the CO_2 concentration should not exceed 700 ppm, following the guidelines of ASHRAE Standard 62.1 [5]. Evaluate the plants' ability to absorb or emit CO_2 over this 24-hour period by comparing CO_2 levels at different times with the CO_2 levels in the ambient air at 0 minutes. A negative value indicates CO_2 absorption, while a positive value suggests CO_2 emission.

4. Statistical analysis

Microsoft Excel to calculate the average CO_2 concentrations, and T-test was employed, with a significance level set at 95%, to assess the significance of CO_2 concentrations for each plant, using SPSS version 22.0.

Results and Discussion

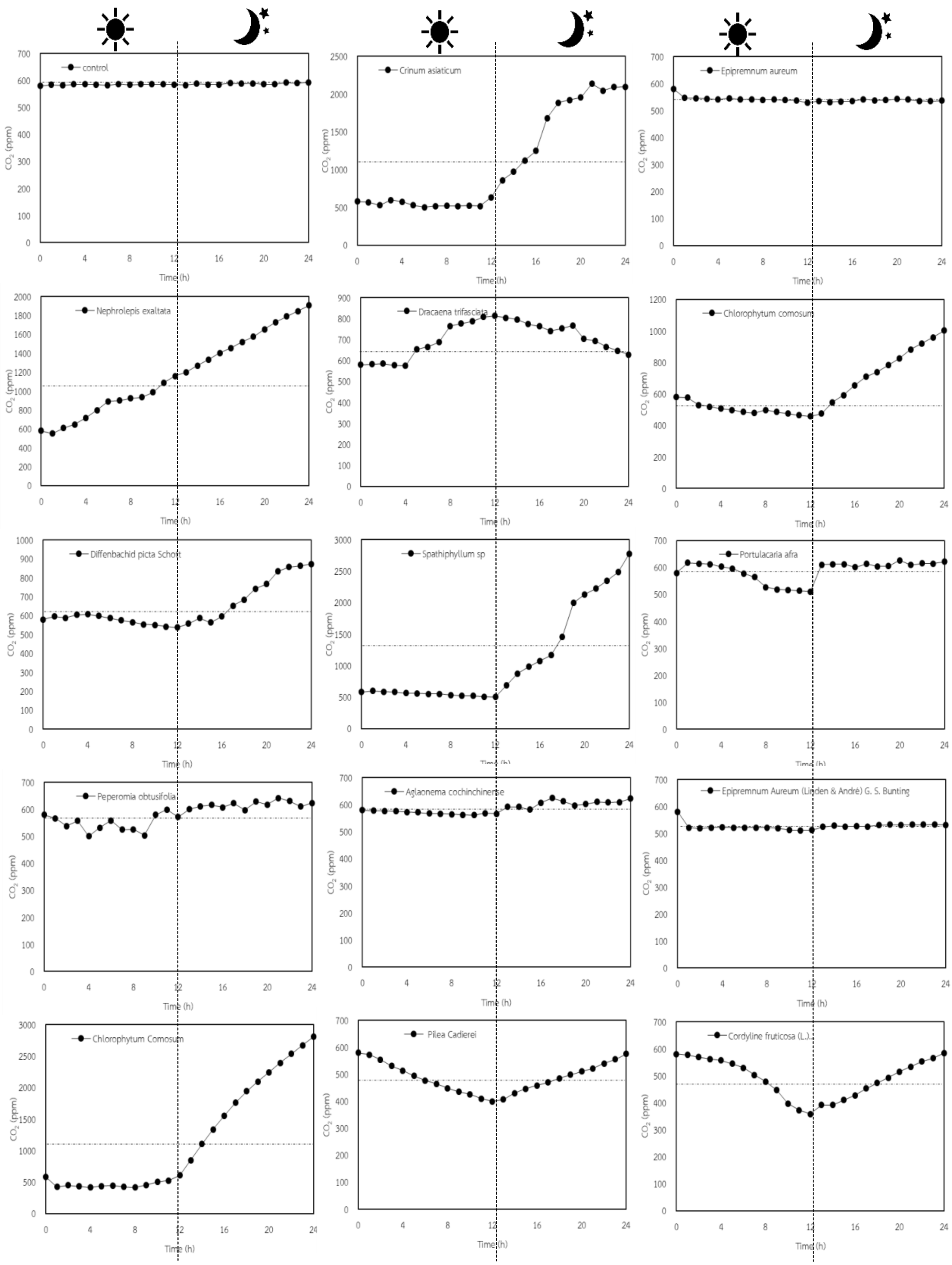
Room Environment

During the experiment in a real environment, daytime light intensity ranged from 407 to 4,454 Lux, with an average of 2,670 Lux, which was higher than the 1,643 Lux observed in natural light [15]. This variance may be attributed to the plant's positioning and the environmental conditions within the room. At night, there was no light. The average RH and temperature room environment were 62±4%, and 32.1±17°C, respectively. Inside the chamber, the average RH and temperature were 59.7±2.3%, and 30.2±0.6°C. A suitable lighting environment is essential for plant growth, as plants use photosynthesis to provide energy for their growth. Therefore, it can be inferred that the lighting conditions in this experiment did not have a negative impact on the visible growth of indoor plants over a short period of time [21, 26].

Screening ornamental plants for CO_2 emission reduction

The natural light duration was 12 hours (06.00-18.00) in the natural lighting environment. The initial CO_2 concentration in the controlled chamber was approximately 586 ppm as shown in Figure 4.

The effect of screening fourteen plant species on CO_2 concentration emission within the closed chamber is shown in Figure 4. Significance was observed for each plant ($p<0.05$). Over 24 hours, *Nephrolepis exaltata* exhibited rapidly changing net CO_2 emission rates, with an average of 1,178 ppm. In contrast, *Epipremnum aureum* exhibited a decrease of 8%, with an average CO_2 concentration of 541 ppm. This finding aligns with the results of Plitsiri and Taemthong (2022), who observed that in experiments conducted under natural daylight conditions, *Epipremnum aureum* displayed the highest CO_2 removal capability [15]. While *Dracaena trifasciata* had an average net CO_2 emission of 703 ppm. CO_2 emissions gradually increased during the day but decreased quickly during the night. This variation could be due to the Crassulacean Acid Metabolism (CAM) photosynthetic pathway of the Snake plant [19], CAM is a photosynthetic pathway that temporally separates nocturnal CO_2 uptake via phosphoenolpyruvate carboxylase (PEPC, C4 carboxylation) from diurnal refixation by Rubisco (C3 carboxylation) thus CAM plants showed the phenomenon that carbon dioxide decreases during the dark period and increases during the bright period [27], whereas the other plants have C3 pathway, which is a plant that lacks photosynthetic adaptations to reduce photorespiration is called a C3 plant. In the Calvin cycle, the initial step involves the fixation



Remark: ……. represents the average CO_2 level throughout the day

Figure 4 CO_2 concentration for fourteen plants at 24 hours of carbon dioxide by rubisco. Plants that exclusively employ this 'standard' mechanism of carbon fixation are termed C3 plants, named after the three-carbon compound (3-PGA) produced in the reaction or C4 pathway. In C4 plants, the light-dependent reactions and the Calvin cycle are physically separated. The light-dependent reactions occur in the mesophyll cells (spongy tissue in the middle of the leaf), while the Calvin cycle takes place in specialized cells around the leaf veins known as bundle-sheath cells. C4 photosynthesis in action. Initially, atmospheric CO_2 is fixed in the mesophyll cells, forming a simple 4-carbon organic acid (oxaloacetate). This crucial step is carried out by a non-rubisco enzyme called PEP carboxylase, which lacks the tendency to bind oxygen (O_2). Subsequently, oxaloacetate is converted into a similar molecule, malate, which can be transported into the bundle-sheath cells. Within the bundle-sheath cells, malate undergoes breakdown, releasing a molecule of CO_2. This released CO_2 is then fixed by rubisco and transformed into sugars through the Calvin cycle, mirroring the process of C3 photosynthesis, CO_2 levels increase during the dark period and decrease noticeably during the light period [19, 27]. The remaining plants showed a trend of decreasing CO_2 emissions during the day and increasing during the night. This result suggests that among the 14 species, *Epipremnum aureum*, *Epipremnum Aureum (Linden & André) G. S. Bunting*, and *Pilea Cadierei* exhibited a reduction in CO_2 levels during the day ranging from 1% to 8%.

The CO_2 concentration emission of ornamental plants

Table 1 shows the ability of ornamental plants to absorb CO_2 per leaf area. The average CO_2 levels for each plant over 24 hours were determined *Epipremnum aureum*, *Epipremnum aureum (Linden & André) G. S. Bunting*, *Pilea Cadierei*, and *Cordyline fruticosa (L.) A. Chev.* exhibited equal abilities to absorb CO_2, with rates of 0.03 ppm/cm^2, 0.005 ppm/cm^2, and 0.28 ppm/cm^2, respectively. *Epipremnum aureum*, when placed as a green wall, is considered suitable for minimizing energy usage in buildings [15]. Other plants in the study emitted CO_2.

The CO_2 absorption and emission abilities of ornamental plants

The plants were ranked based on their CO_2 emissions and absorptions during both daytime and nighttime, as illustrated in Figure 5. During the daytime, *Nephrolepis exaltata* and *Dracaena trifasciata* were found to emit CO_2 at rates of 249 ppm and 101 ppm, respectively, while other plants exhibited CO_2 absorption

Table 1 CO_2 concentration emission of each plant over 24 hours

Type of plants	Leaf area (cm^2)	CO_2 (ppm)	ppm/cm^2
Crinum asiaticum	1,720	504	0.29
Epipremnum aureum	1,318	-39	-0.03
Nephrolepis Exaltata	697	598	0.86
Dracaena trifasciata	2,069	123	0.06
Chlorophytum Comosum	1,366	46	0.03
Diffenbachid picta Schott	2,537	63	0.03
Spathiphyllum sp.	1,796	513	0.28
Portulacaria afra f. variegata	114	8	0.07
Peperomia obtusifolia (L.) F. Dietr	378	2	0.005
Aglaonema cochinchinense	356	7	0.02
Epipremnum aureum (Linden & André) *G. S. Bunting*	1,183	-6	-0.005
Cordyline fruticosa (L.) A. Chev.	2,653	596	0.22
Pilea Cadierei	224	-90	-0.41
Cordyline fruticosa (L.) A. Chev.	238	-66	-0.28

Remark: - to indicate an adsorption of CO_2

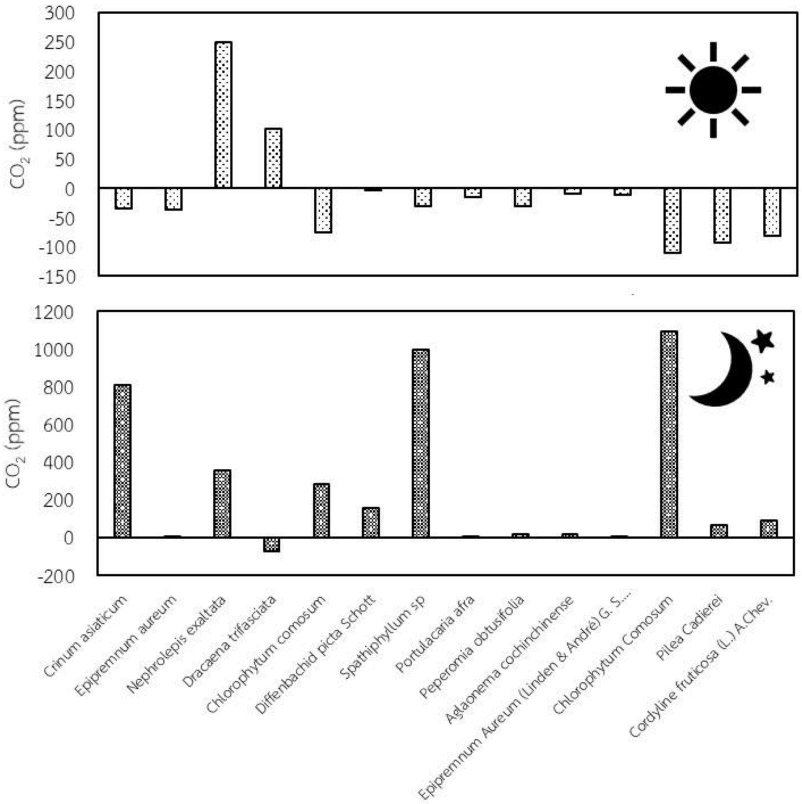


Figure 5 CO_2 concentration in day and night time

capabilities. The top four performers in CO_2 absorption during the daytime were *Chlorophytum Comosum* (110 ppm), *Pilea Cadierei* (94 ppm), *Cordyline fruticosa (L.) A.Chev.* (82 ppm), and *Epipremnum aureum* (36 ppm). Conversely, during nighttime, most plants emitted CO_2. However, *Epipremnum aureum* and *Portulacaria afra* emitted the least amount of CO_2 (2 ppm) Additionally, *Dracaena trifasciata* showed CO_2 absorption due to the Crassulacean Acid Metabolism (CAM) photosynthetic pathway, which decreases CO_2 during nighttime. When comparing CO_2 absorption under both conditions, *Epipremnum aureum* emerged as the most effective among the fourteen plants, exhibiting the lowest CO_2 accumulation in the closed chamber over 24 hours.

The Experiment for Classroom Application

From the experiment, Figure 6, it was observed *Epipremnum aureum* in classroom that the presence of 100 spotted betel plants, with a total leaf area of 108,943 cm^2, in a classroom setting led to a reduction in CO_2 levels. In a room without plants, the CO_2 concentration averaged 542 ppm over the 24-hour period. The CO_2 concentration was found to remain relatively constant 24 hours a day. However, humidity gradually increases during the night, and the temperature drops slightly. Comparison with plant, over 24-hour period, decreased at 407 ppm. It indicates that the potential of *Epipremnum aureum* can help improve the carbon dioxide levels in the air inside the classroom (Figure 7). Humidity, temperature, and carbon dioxide exhibited a relationship during daylight hours. In the morning, there is a higher absorption of carbon dioxide, correlating with increased humidity. This relationship is less pronounced in the afternoon when temperatures are higher. Stomata partially close to prevent water loss, hindering the tree's ability to fully exchange gases [28]. The rate of carbon dioxide absorption varies depending on factors such as the plant's type, age, structural characteristics, leaf arrangement, stomata distribution, and environmental conditions. External factors, including light, temperature, and humidity, also play a significant role [29-30].

Figure 6 *Epipremnum aureum* in classroom

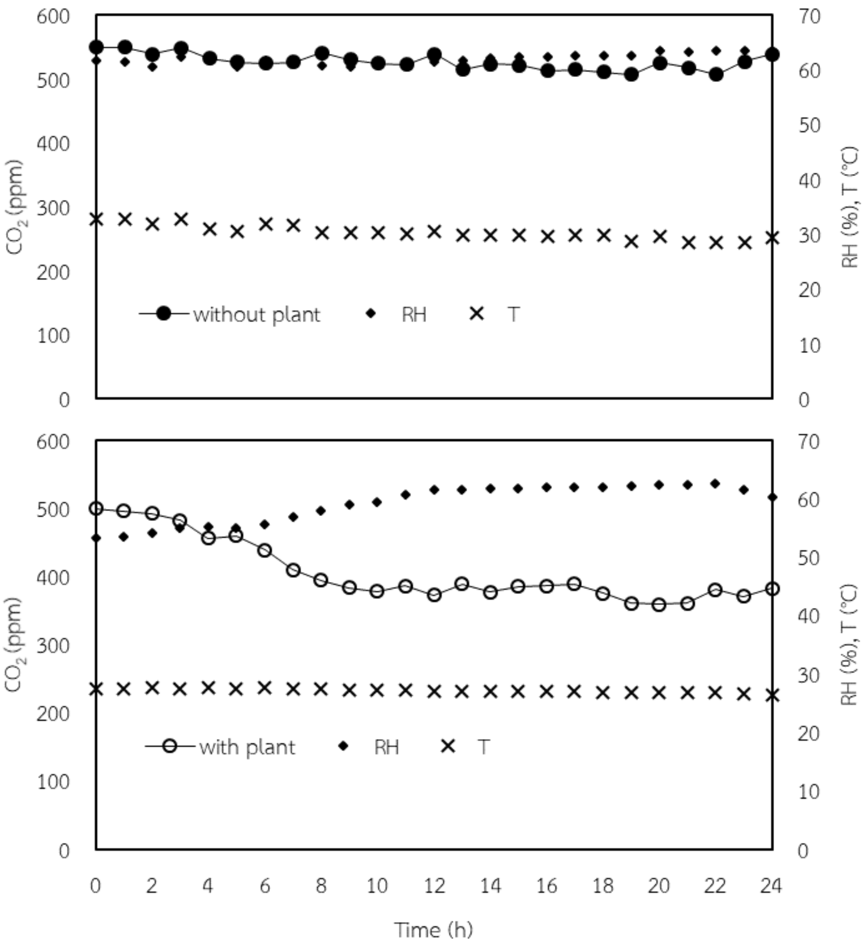


Figure 7 Average CO_2 concentration in the classroom over a 24-hour period

Conclusion

This study effectively demonstrated the potential of plant-based air purification in reducing CO_2 indoor air. As urbanization continues, it becomes increasingly important for individuals, businesses, and governments to consider incorporating ornamental plants as a practical and aesthetically pleasing strategy for improving indoor air quality.

Epipremnum aureum and Epipremnum aureum (Linden & André) G. S. Bunting are suitable for decorating living areas such as the living room or bedroom, as they effectively reduce accumulated CO_2 in these spaces. *Cordyline fruticosa (L.) A.Chev*., *Pilea Cadierei*, *Diffenbachid picta Schott*, and *Peperomia obtusifolia (L.) F. Dietr* are also well-suited for daytime living areas like offices or classrooms due to their exceptional CO_2 absorption capabilities. However, *Crinum asiaticum*, *Nephrolepis Exaltata*, *Dracaena trifasciata*, *Spathiphyllum* sp., *Portulacaria afra f. variegate*, and *Codiaeum Variegatum Blume* are not recommended for indoor use.

In conclusion, this research recommends planting *Epipremnum aureum* or *Epipremnum aureum (Linden & André) G. S. Bunting* to decorate living rooms, bedrooms, and office areas, promoting healthier and happier indoor environments. This advice aims to encourage people to choose specific types of ornamental plants for planting to reduce carbon dioxide, a greenhouse gas that is currently an environmental problem and may pose challenges in the future.

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