

# The Development of a Live Air Cleaner as Indoor Garden for an Unventilated Air Conditioned Room

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## Abstract

Urban temperatures continue to increase due to urban heat island and global warming. Air temperatures in warm, humid tropical cities have exceeded 32°C. To achieve thermal comfort in buildings, people adopted air conditioners (ACs) that can consume more than 40% of the building's electrical energy. Air conditioning is often not accompanied by a supply of fresh outdoor air to minimize heat gain from the warm outdoor air. In that unventilated room, the CO<sub>2</sub> concentration easily exceeds 1,000 ppm and causes discomfort. Plants such as *Dracaena sanderiana* require CO<sub>2</sub> for photosynthesis. At the same time, they produce O<sub>2</sub>. *Dracaena sanderiana* has the potential to keep CO<sub>2</sub> concentrations in the room for not exceeding the comfort limit. That plant can be integrated into architectural elements, both interior and exterior (combined with windows or facades), in the form of a "living air purifier" or Live Air Cleaner (LAC). This research developed a LAC in the form of an interior garden that can be used as an interior architectural element. The application of LAC helps to save the electrical energy of unventilated air-conditioned rooms while preventing the room CO<sub>2</sub> concentration from reaching the maximum limit of indoor CO<sub>2</sub> level acceptable to humans. The research adopted experimental methods using three experiment chambers to measure the *Dracaena sanderiana*'s CO<sub>2</sub> absorption efficiency. The experiments found that *Dracaena sanderiana* had a unique performance, which should be considered when it is used as a live air cleaner. Though this plant absorbs CO<sub>2</sub>, its efficiency is low. Sufficient volume of *Dracaena sanderiana* is needed if it is to reduce indoor CO<sub>2</sub> concentration.

**Keywords:** *Live Air Cleaner, Air conditioning, Indoor garden, CO<sub>2</sub> absorption*

## Introduction

Urban indoor air quality (IAQ) is a global problem as a metropolitan population spends 90% of its life indoor (Tarran et al., 2007). Modern countries prioritize IAQ because it can affect human health and productivity (Suhaimi et al., 2017). Air conditioning in urban buildings has two main objectives, namely temperature control and air refreshment. For the second purpose, the level of refreshment with outdoor

air is usually in the range of 11-15% per hour and tends to produce higher levels of air pollution in the room than outside (Burchett, 2009). Indoor CO<sub>2</sub> levels are, in general, higher than outdoor because of the occupants (Burchett et al., 2008). Air composed of 21% O<sub>2</sub> and 0.033% CO<sub>2</sub> taken in by people from the healthy air becomes 16-17% O<sub>2</sub> and 4% CO<sub>2</sub> content during discharge from the lungs. This change leads to a rapid rise in CO<sub>2</sub> content in the environment (Bulgurcu et al., 2006). Increased levels of CO<sub>2</sub> cause loss of concentration and drowsiness faster than the depletion of O<sub>2</sub> (Burchett, 2009). According to ASHRAE, the recommended level of indoor CO<sub>2</sub> is 1,000 ppm as the maximum indoor air concentration acceptable to humans (Stanke

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et al., 2010). Some organizations (such as UTS) choose CO<sub>2</sub> levels of 800 ppm as the maximum trigger for extra ventilation (Burchett, 2009). Various efforts have been made to ensure that IAQ sustainability is guaranteed. Temperatures in humid tropical cities have exceeded 32°C. To achieve thermal comfort in buildings, people use air conditioners (AC) that can consume more than 40% of the building's electrical energy. Air conditioning is often not accompanied by a supply of fresh outdoor air to minimize heat gain.

Researchers found that indoor plants can reduce indoor air pollution. Generally, plants, carbon dioxide (CO<sub>2</sub>), light, and temperature are involved in photosynthesis (Suhaimi, et al, 2017). Indoor plants consume carbon dioxide and produce oxygen through photosynthesis (Cetin, 2015). Indoor plants have been shown to eliminate most types of airborne pollutants that arise from both outside and indoor sources (Tarran et al., 2007). Plants can absorb air pollution, and offer coolness and shade. Besides, spending half an hour in the park can lower blood pressure, reduce anxiety and anger, and provide a feeling of calm and pleasure (Burchett et al., 2008; Wood et al., 2010). Indoor plants are one of the botanicals that can act as bio-filtration. Bio-filtration is the filtration and metabolic breakdown of contaminant compounds, usually in soil or water, but also indoor air (Llewellyn and Dixon, 2011). Bio-filters are bioreactors in which contaminated air or water flows pass through areas with a high biological activity where contaminants are neutralized by biological processes (Soreanu et al., 2013).

## Method

This research used experimental methods that followed a set of scenarios (Table I, II, and III). Three experiment chambers, namely EC1, EC2, and EC3 with their dimensions of 0.3x0.3x0.7 m<sup>3</sup>, 1.0x1.0x1.0 m<sup>3</sup>, and 2.4x2.4x2.4 m<sup>3</sup>, were used. A split type air conditioner, a TCL 0.5 HP, was used to maintain the EC's air temperature at 24°C. The concentration of CO<sub>2</sub> and O<sub>2</sub> inside ECs were measured and recorded by, consecutively, Combo IAQ Meter 77597 and Lutron DO-5510. Hobo data logger was also used to record the outdoor and indoor environment, which included air temperature and air humidity.

Two plant lamps, LED 25W E27 AC85-265V, were used to generate photosynthesis when sunlight was absent. CO<sub>2</sub> was added to EC by burning 20 ml of spirits (methylated spirits) at the beginning of each scenario. Each scenario was last for 12-48 hours, during which the changes in the concentration of CO<sub>2</sub> were recorded. Each scenario was repeated three times to get the averaged results. The scenario of the experiments was made mainly to find the optimum performance of the *Dracaena sanderiana* (Lucky Bamboo) in absorbing CO<sub>2</sub>.

Table 1. Scenario For EC1

Plant	CO <sub>2</sub> Source	Time	Light	Scenario (E)
<i>Dracaena sanderiana</i> (Lucky Bamboo)	Ambient air	24 hours	Sun (Fig. 1) without LED plant lamp (Fig. 2)	1
	Ambient air	12 hours (night time)	LED plant lamp (Fig. 3)	2
	Ambient air	24 hours	Sun (Fig. 1) LED plant lamp (Fig. 3)	3

Figure 1. *Dracaena sanderiana* in EC1 with sunlight



Figure 2. *Dracaena sanderiana* in EC1 at night without an LED plant lamp

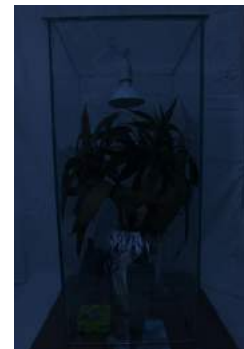


Figure 3. *Dracaena sanderiana* in EC1 at night with an LED plant lamp



Table 2. Scenario for EC2

Plant	CO <sub>2</sub> Source	Time	Light	Scenario (E)
<u>Dracaena sanderiana</u> (Lucky Bamboo)	Ambient air	24 hours (1 pot)	Sun (Fig. 4) LED plant lamp (Fig. 5)	4
	Ambient air	24 hours (6 pots)	Sun (Fig. 6) LED plant lamp	5
	Ambient air	48 hours (6 pots)	Sun (Fig. 6) Without the LED plant lamp (Fig. 7)	6
	Ambient air	48 hours (6 pots)	Sun (Fig. 6) LED plant lamp (1 <sup>st</sup> night) (Fig. 8) Without the LED plant lamp (2 <sup>nd</sup> night) (Fig. 7)	7

Figure 4. Dracaena sanderiana (1 pot) in EC2 with sunlight



Figure 5. Dracaena sanderiana (1 pot) in EC2 in the night with LED plant lamp



Figure 6. Dracaena sanderiana (6 pots) in EC2 with sunlight



Figure 7. Dracaena sanderiana (6 pots) in EC2 in the night without LED plant lamp

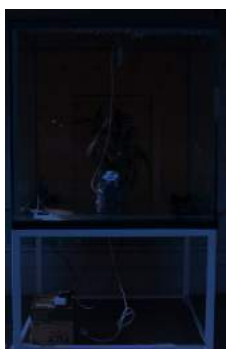


Figure 8. Dracaena sanderiana (6 pots) in EC2 in the night with LED plant lamp



Table 3. Scenario EC3

Plant	CO <sub>2</sub> Source	Light	Plant Position	Scenario (E)
<u>Dracaena sanderiana</u> (Lucky Bamboo)	Spirits (20 ml)	sun	west window	8
	Spirits (20 ml)	sun	north window	9
	2 Humans	sun	west window	10
	2 Humans	sun	north window	11

Figure 9. Dracaena sanderiana (6 pots) in EC3 with sunlight west window



Figure 10. Dracaena sanderiana (6 pots) in EC3 with sunlight north window



## Result and Discussion

Five to eight hours of experiments by Sue found a decrease in CO<sub>2</sub> concentration by various plants (Suhaimi, et al, 2017). Reductions of CO<sub>2</sub> from 1000 ± 10 ppm were 71.67 ppm (Prayer Plant), 66.67 ppm (Syngonium), 64.60 ppm (Fern Kadaka), 60.67 ppm (Golden Pothos), 55.4 ppm (Dumb Cane), and 23.67 ppm (Anthurium). Other studies have shown that 189 Bird's-Nest Fern pots can reduce CO<sub>2</sub> concentrations from 2000 ppm to 1000 ppm in 2 hours 6 minutes and to 600 ppm in 5 hours 37 minutes (Su, 2014). In the same period, we experimented in EC3 using Dracaena sanderiana for 4 hours. Plants were placed on the edge of the window exposed to direct sunlight. In the first 2 hours, the plants were placed in the northern window, and the next 2 hours were placed in the western window. The source of CO<sub>2</sub> was 20 ml of spirits. A fan

facing directly to the plant was used. An AC maintained the air temperature at 24°C.

Figure 11. CO<sub>2</sub> concentration on EC3, facing north

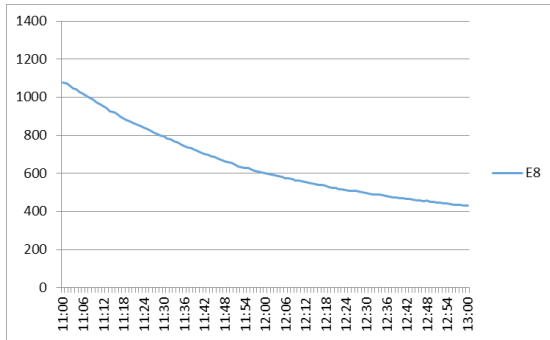
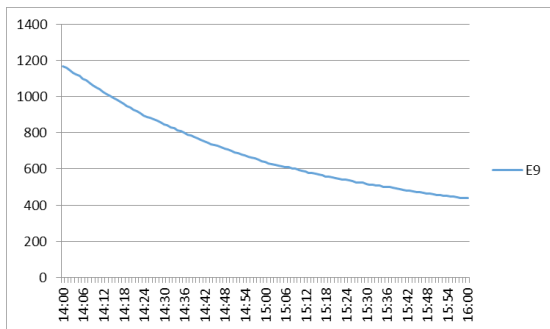


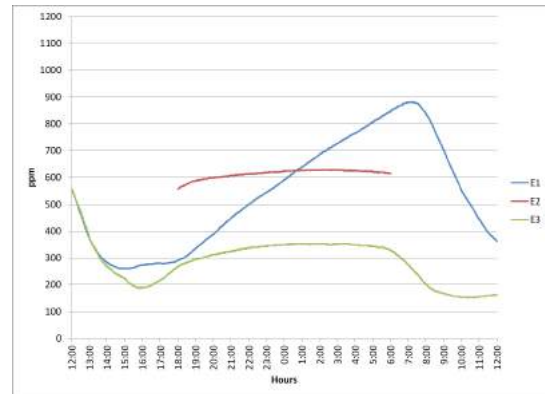
Figure 12. CO<sub>2</sub> level on EC3, facing west



Figures 11 and 12 show that *Dracaena sanderiana* reduced CO<sub>2</sub> concentration by 600-700 ppm within two hours. It is because plants carry out photosynthetic processes actively when directly exposed to the sun. However, the amount of CO<sub>2</sub> reduction changed when the experiment was carried out for 24 hours and 48 hours.

The experiment without CO<sub>2</sub> from ambient air was carried out in EC1 in three stages and used outdoor air. The first experiment (E1) lasted for 24 hours and used sunlight during the day but without any plant lamp at night. The second experiment (E2) lasted for 12 hours and used plant lamps at night. The third experiment (E3) lasted for 24 hours and used sunlight during the day, plant lamps at night (Fig. 13).

Figure 13. EC1 result

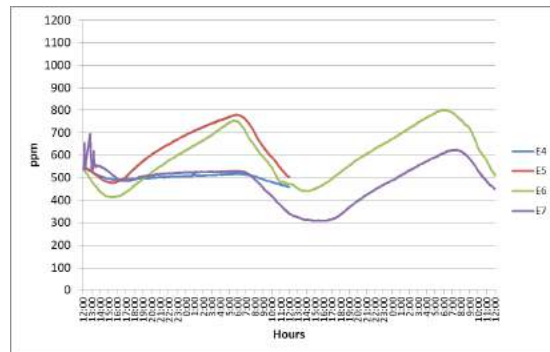


Note:

- E1: 24 hours, without plant lamps.
- E2: 12 hours, with a plant lamp (at night).
- E3: 24 hours, without plant lamps.

The next experiment was carried out in EC2 using ambient air in four stages. The first stage (E4) used one pot for 24 hours with one plant lamp. The second stage (E5) used six pots for 24 hours with one plant lamp. The third stage (E6) used six pots for 48 hours without any plant lamp. The fourth stage (E7) used six pots for 48 hours with a plant lamp on the first day and did not use a plant lamp on the second day (Fig. 14).

Figure 14. EC2 result



- E4: One pot, 24 hours, with a plant lamp.
- E5: Six pots, 24 hours, with a plant lamp.
- E6: Six pots, 48 hours, without any plant lamp.
- E7: Six pots, 48 hours, with a plant lamp on the first day.



Table 4. Experiment Result

Experiment	Time	CO <sub>2</sub> reduction (ppm)	CO <sub>2</sub> increase (ppm)
E1	12.00-17.30	300	-
	17.30-07.00	-	600
	07.00-12.00	520	-
E2	12.00-17.30	-	-
	17.30-07.00	-	58
	07.00-12.00	-	-
E3	12.00-17.30	359	-
	17.30-07.00	-	57
	07.00-12.00	105	-
E4	12.00-17.30	55	-
	17.30-07.00	-	22
	07.00-12.00	54	-
E5	12.00-17.30	70	-
	17.30-07.00	-	278
	07.00-12.00	252	-
E6	12.00-17.30	134	-
	17.30-07.00	-	288
	07.00-17.30	242	-
	17.30-07.00	-	331
E7	07.00-12.00	281	-
	12.00-17.30	61	-
	17.30-07.00	-	36
	07.00-17.30	199	-
E7	17.30-07.00	-	299
	07.00-12.00	172	-

Based on the results of the experiment for 24 hours and 48 hours, *Dracaena sanderiana* had a pattern in absorbing and releasing CO<sub>2</sub>. From morning to evening (07.00-17.30), it consumed 55 ppm to 520 ppm of CO<sub>2</sub>. At night (17.30-07.00), it released 22 ppm to 600 ppm of CO<sub>2</sub>. The use of plant lamps (a combination of the red and blue light) affected plants, CO<sub>2</sub> released was less than without using plant lamps (E2, E4, E5, and E7 in Table 4). It shows there is a mechanism of CO<sub>2</sub> absorption as an ingredient in the process of photosynthesis. Plants use light as an energy source for photosynthesis. Red color emits a narrow spectrum of light (660 nm) that is close to the maximum absorbance for both chlorophyll and phytochromes. The photosynthetic-mediated proteins in sub-compartments of chloroplasts, including stomatal opening and closing and photosynthetic activity, responded most to the blue of high light intensity (Muneer et al., 2014).

However, the absorption rate of CO<sub>2</sub> in the morning was lower than when it was without a plant lamp (E2, E4, E5, and E7 in Table 4).

One of the factors that influence indoor CO<sub>2</sub> concentrations is the number of indoor plants (Cetin, 2015). Based on the number of plants, in E5 that using six plants can decrease CO<sub>2</sub> levels more than E4 that using one plant. The number of the plant can influence the chlorophyll index. The chlorophyll index is used to calculate the total chlorophyll content of the leaves. Chlorophyll is an essential part of the Calvin–Benson cycle, and it is responsible for harvesting light during photosynthesis, which results in the excitation of electrons that can continue to the photosynthesis process further to process the CO<sub>2</sub> that has been absorbed (Ahlman, 2019).

Based on the experiment, a system to minimize stress on plants was derived. When the plant was forced to photosynthesize at night, it would decrease its CO<sub>2</sub> absorption during the day. Therefore, to maximize CO<sub>2</sub> absorption during the day, plants should be placed in areas that were connected or exposed to an outdoor environment. During the day, the plants were related to the interior of the building (Fig. 15), and at night the plants were in contact with the outdoor (Fig. 16). By doing so, the plants still obtained O<sub>2</sub> at night and had the respiration process well. Therefore, during the day, the plants could absorb CO<sub>2</sub> more optimal.

Figure 15. An example of the installation of *Dracaena sanderiana* in the room as a live air cleaner In the afternoon.

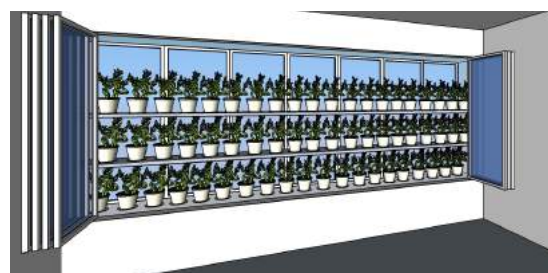


Figure 16. An example of the installation of *Dracaena sanderiana* in the room as a live air cleaner at night.

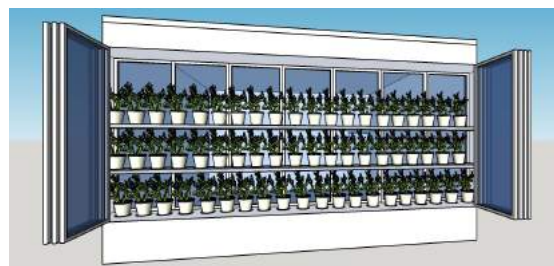


Figure 17. CO<sub>2</sub> absorption during the day in EC3

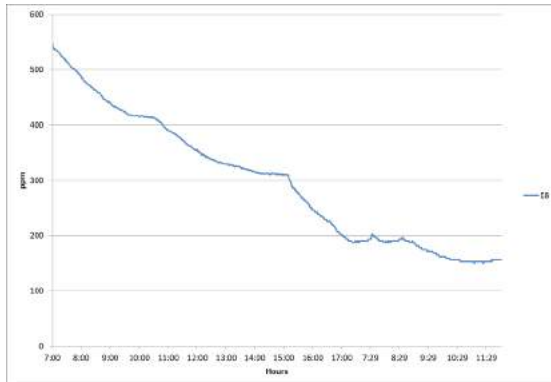


Figure 17 was a simulation when CO<sub>2</sub> was given to the room (by spirits burning), and the plants did not release CO<sub>2</sub> at night. However, when humans used the room, there was a difference, because humans produce CO<sub>2</sub> continuously. So the use of *Dracaena sanderiana* was not to eliminate CO<sub>2</sub> in the room (Fig. 18 and 19) but to prolong the time of human stay in the room based on the maximum limit of CO<sub>2</sub> levels in the room which is 600-1000 ppm.

Figure 18. CO<sub>2</sub> concentration on EC3 with Human breath, facing north

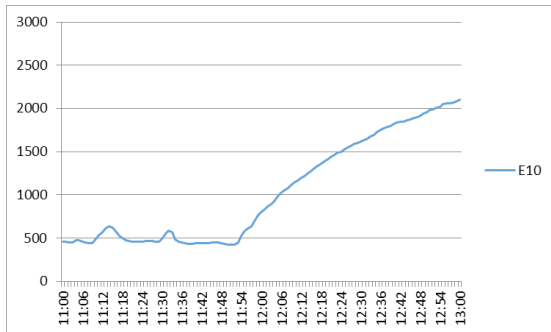
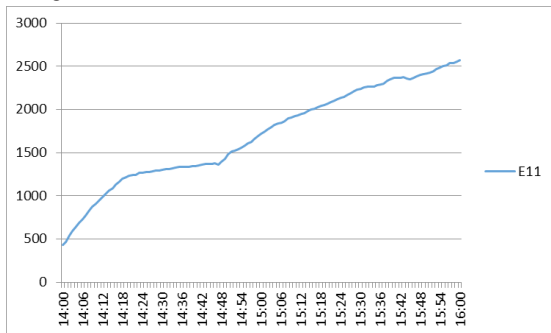


Figure 19. CO<sub>2</sub> concentration on EC3 with Human breath, facing west



The length of time a human stays in the room can be calculated as follows:  
Human breath composition (Marieb and Hoehn, 2013)

- Exhale : 4% CO<sub>2</sub>
- Inhale : 0.04% CO<sub>2</sub>  
(1/100 exhale – ignore)

Breathing process

- 1 breath cycle : 0.5 liter  
: 0.5 x 4% = 0.02 liter
- 1 minute : 6 – 18 times breathing (average 17 x)  
: 0.02 liter x 17 = 0.34 liter/minute

• Conversion to ppm

0.02 l/breath.minute in 1 m<sup>3</sup>

0.02 l/breath.minute in 1000 l

• (20ml/breath.minute)/1000.000ml= 20 ppm/  
breath.minute

• 20 ppm/breath.minute x 17 breath = 340 ppm/  
minute

• Initial level = CO<sub>2</sub> of normal outdoor air is  
400 ppm

• Danger limit = 1,000 ppm

• Maximum = (1000 – 400) ppm = 600 ppm  
(in 1m<sup>3</sup>)

= 600ppm x 36 m<sup>3</sup> = 21.600 ppm  
(1 room with 36 m<sup>3</sup>)

• Absorption capability of one group of plants in  
0.063 m<sup>3</sup> (612 cm<sup>2</sup> leaf surface area) = 92.25 ppm/  
hours, in 1 m<sup>3</sup> = 6 ppm/hours and 0.17 ppm/hours  
in 36 m<sup>3</sup>

• Human CO<sub>2</sub> production = 340 ppm.m<sup>3</sup>/minute  
= 20.400 ppm.m<sup>3</sup>/hours

Level of CO<sub>2</sub> indoor (for a room with volume 36 m<sup>3</sup>):

• Human production of CO<sub>2</sub> = 9.44 ppm /minutes  
= 566.4 ppm/hours

• Length of breathing to CO<sub>2</sub> limit  
= 21.600 ppm/ 566.4 ppm/hours

= 38.1 hours (limit 1000 ppm in the room)

• With 50 units of plants = 21.600 ppm / (566.4-  
8.5) ppm/hrs

= 21.600 ppm / 557.9

ppm/hrs

= 38.7 hrs

• Length of stay in the room = (38.7-38.1) hrs  
= 36 minutes

(thus *Dracaena sanderiana* adds the length of stay  
36 minutes)

The above calculation shows that before using *Dracaena sanderiana*, humans can stay 38.1 hours nonstop, but after using *Dracaena sanderiana*, they can stay 38.7 nonstop. *Dracaena sanderiana* can prolong the human stay in 36 m<sup>3</sup> of space for 36 minutes.

## Conclusion

*Dracaena sanderiana* can absorb CO<sub>2</sub>, but its efficiency is low. It has the potential of a live air cleaner. However, considerable quantities of *Dracaena sanderiana* are needed if significant CO<sub>2</sub> removal from a room is wanted. It means a large proportion of floor area should be dedicated to those plants, which is not space-

efficient. Vertical racks can be provided to stack the pots to save space. With its much lower CO<sub>2</sub> absorption than human CO<sub>2</sub> production, *Dracaena sanderiana* is intended to reduce, not remove, CO<sub>2</sub>. In other words, it is used to delay the CO<sub>2</sub> concentration limit of 1,000 ppm and thus prolong the stay time of humans in a healthier room. *Dracaena sanderiana* performs photosynthesis at night and releases large amounts of CO<sub>2</sub>. Thus, during the day, the plants can be connected to the interior of the building to absorb CO<sub>2</sub>, and at night they can be connected to the outdoor to release their CO<sub>2</sub>. It will neither interfere with the process of photosynthesis nor the process of respiration.

### Recommendation

*Dracaena sanderiana* has, like other plants, a unique nature, which should be well understood through further studies. This research was deliberately experimenting with *Dracaena sanderiana* in its natural condition. There was no biological engineering applied to *Dracaena sanderiana* to improve its CO<sub>2</sub> absorption efficiency, such as giving special nutrition. Therefore, there are topics for further studies on *Dracaena sanderiana* as well as other potential plants.

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