Measurement and Evaluation of Carbon Absorption and Indoor Environment Regulation Capabilities of Different Green Walls in Low-Carbon Buildings

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Abstract：Utilizing green wall plants to absorb CO_2 is one of the effective means to achieve carbon sequestration in buildings. However, the carbon absorption and indoor environmental regulation capabilities of different plant types still need further understanding. Therefore, this study selected three common indoor plants as research subjects, using a closed measurement method and controlled variable approach to compare the carbon dioxide absorption capacity of three common indoor plants and their regulatory impact on the indoor thermal and humidity environment. By using the unit leaf area method to quantify the impact of plants, the study obtained the CO_2 absorption, humidity release, and temperature difference values per unit leaf area for each plant under the same environment. Through comparison, it was found that the Epipremnum aureum has an outstanding performance in CO_2 absorption, while the Chlorophytum comosum shows a higher humidity release capability. The Epipremnum aureum 's CO_2 absorption rate is 0.39g/d·m^2, 1.2 and 1.34 times higher than the Philodendron and Chlorophytum comosum. The Chlorophytum comosum 's humidity release is 94.59g/kg·d·m^2, 1.4 and 2.9 times more than the Philodendron and Epipremnum aureum. Based on this, a typical household was used as an example to design a green wall and calculate its carbon absorption potential. The study not only provides new quantitative indicators for the assessment of the carbon sequestration capacity of green walls but also offers new perspectives and references for the application of building carbon sequestration technology.

Keywords: Green Wall Plants; Carbon Absorption; Indoor Environmental Regulation; Carbon Sequestration Capacity Assessment

1. INTRODUCLTION

As global climate change intensifies, the construction sector has emerged as a significant contributor to the total carbon emissions. Buildings are not only consumers of energy but also a major source of greenhouse gas emissions (Jingxin Li.,2024). Therefore, exploring and implementing carbon sink strategies in architecture to mitigate the negative environmental impacts has become a crucial topic in the field (Xi, Chang.,2022). Architectural carbon sinks, as an innovative solution, involve planting vegetation both inside and outside buildings (Fudan Liu.,2022), utilizing their natural photosynthesis to absorb and store carbon dioxide (Deng, Linjing.,2018), offering a new approach to reducing the environmental impact of buildings. However, despite the concept of architectural carbon sinks being widely accepted (Anastasia Svirejeva-Hopkins.,2004), most research has focused on quantifying existing carbon sinks in buildings (Jianghuan Qin.,2024) and how to measure and detect carbon sinks within the entire lifecycle of urban carbon emissions (Liying Li.,2021). There is still a limited amount of systematic research on the carbon absorption efficiency and environmental regulation capabilities of different indoor plants in practical applications (Ke En Lai.,2023)

This study aims to fill this research gap by comparing the carbon dioxide absorption capacity and the regulation of indoor thermal and humidity environment of three common indoor plants—Epipremnum aureum, Philodendron, and Chlorophytum comosum—under controlled conditions (Jenny Berger.,2024), (Giancarlo Mangone., 2014). We employed sealed chamber measurement techniques and the control variable method to ensure the accuracy and comparability of the experimental results. Additionally, this study innovatively introduces the unit leaf area method to quantify the carbon absorption and humidity release capabilities of different plants, providing a new quantitative approach for assessing and comparing the carbon sink potential of various plants.

The research findings indicate that Epipremnum aureum has a distinct advantage in terms of carbon dioxide absorption per unit leaf area, while Chlorophytum comosum excels in its humidity release capability. These results not only fill the gaps in existing research but also provide a scientific basis for the selection and arrangement of indoor plants. Furthermore, the study also used a typical residence as an example to design a green wall and estimated its carbon absorption potential, offering a reference for the practical application of architectural carbon sink technology.

This study is poised to offer theoretical support and practical guidance for the continued development and application of building carbon sink technologies. It also aims to provide fresh scientific evidence for the green design of indoor environments and the strategic placement of plants, thereby fostering the sustainable development of the built environment and enhancing the well-being of its occupants.

2. MATERIALS AND METHODS

In this section, we will first outline the origins and main features of the materials used in our experiment. Subsequently, we will delve into a detailed description of the research methods employed in this study, along with the experimental results obtained.

2.1. MATERIALS

In this study, we selected three common indoor plants: Philodendron, Chlorophytum comosum, and Epipremnum aureum. Prior to the commencement of the experiment, we first pruned these plants to ensure uniform growth among all specimens. Subsequently, we selected plants with similar growth conditions and propagated them hydroponically to eliminate the potential influence of roots and soil on the experimental outcomes.

To measure the area of the leaves, we employed an innovative approach. Initially, the contours of the leaves were meticulously traced onto grid paper, approximating them as polygons. Utilizing Pick's Theorem, we calculated the area of each leaf. Comprehensive details of the plants, including their names and leaf areas, are tabulated in the following Table 1:

Equation 1: Pick's Theorem

$$S_y = n + m/2 - 1$$

Where:

- S_y = Leaf area（cm^2）
- m = The number of grid points on the leaf contour boundary（item）
- n = The number of grid points within the leaf area（item）

Table 1: Plant Information

scientific name	Plant Taxonomy	Leaf area
Epipremnum aureum	Araceae family, Epipremnum genus	158.5 cm^2
Chlorophytum comosum	Asparagaceae family, Chlorophytum genus	149.6 cm^2
Philodendron	Araceae family, Philodendron genus	163.5 cm^2

2.2. Experimental Setup

Due to the limited leaf area of the plants, we utilized transparent acrylic boards to fabricate a 400mm × 400mm × 400mm cubic box, sealed the holes reserved on the lid and the box, creating a sealed space, and tested the internal carbon dioxide as well as temperature and humidity levels (Figure 1).

Figure 1: Experimental Setup and Its Schematic Diagram

A total of four experimental chambers were set up, with one serving as the blank control group, and the other three containing the three types of plants. A Pengyun S21A2 detector was placed in each chamber, with the device parameters detailed in Table 2 (Table 2).

Table 2: Measuring Instrument

Instrument Name	Measurement Parameters	Measurement Error
Pengyun S21A2 Carbon Dioxide Detector	Carbon Dioxide Concentration (ppm)	±3%of reading +50ppm
Pengyun S21A2 Light Sensor	Light Intensity (Lx)	±6%Lx
Pengyun S21A2 Thermometer	Air Temperature (℃)	±0.3%℃
Pengyun S21A2 Hygrometer	Relative Humidity(%)	±0.3RH

2.3. Experimental Design

First, we conducted a selection process to identify the most robust specimen from each of the three types of plants. Subsequently, these three plants were hydroponically cultivated for seven days to ensure they all reached an optimal state, while also eliminating the influence of soil on the experiment. We then employed Pick's Theorem to calculate the leaf area and thoroughly cleaned and disinfected the acrylic boxes to exclude the impact of microorganisms. The boxes were left empty for a day to ensure that the environmental conditions within the four boxes were roughly equivalent. At the start of the experiment, the measuring devices were activated first to ensure stable data readings. The plants were then gently placed into the experimental boxes to minimize the impact of air disturbance. Concurrently, a light sensor was used to measure the light intensity in each box, ensuring consistency across all boxes. Finally, the boxes were sealed with polyethylene film, and the three experimental groups along with the control group began testing simultaneously, with the test duration lasting for 96 hours.

2.4. Data Analysis

Additionally, to better quantify the data, the following formula (Equation 2) is used to convert the units of carbon dioxide, and the anther formula (Equation 3) is employed to calculate the absorption:

Equation 2: The conversion formula between the units of CO_2 gas concentration and mass units.

$$N = \frac{MV_i}{M_iV_x} \times 10^{-3}$$

Where:

- N = Gas Concentration of CO_2 (ppm)
- M = Gas Mass of CO_2 (g)
- V_i = Ideal Gas Volume(L/mol)
- M_i = Molar Mass of CO_2 (g/mol)
- Vx = Box Volume (m^3)

Equation 3: Carbon Dioxide Absorption per Unit Leaf Area

$$\gamma = \frac{M}{S_y}$$

Where:

- S_y = Leaf Area（cm^2）
- γ = Carbon Dioxide Absorption per Unit Leaf Area per Day（$g/d{\cdot}m^2$）

In terms of humidity calculation, since the measured value is relative humidity, which is not convenient for quantitative data processing, the following formula is used to convert the units of relative humidity:

Equation 4: The transformation of specific humidity from relative humidity

$$d = 622 * \frac{\varphi \cdot P_{sb}}{(P - \varphi \cdot P_{sb})}$$

Where:

- d = specific humidity (g/kg）
- φ = relative humidity (%)
- P_{sb} = Saturated Vapor Pressure (kpa）（Taking 2.5 kPa at 21°C）
- P = Atmospheric Pressure（kpa）Taking：101kpa

Equation 5: Calculating the Moisture Release per Unit Area

$$\delta = \frac{d}{S_y}$$

Where:

- δ = Moisture Release per Unit Leaf Area per Day（$g/kg{\cdot}d{\cdot}m^2$）
- S_y = Leaf Area（cm^2）

Based on the aforementioned formulas, we first used the precisely measured leaf area as the baseline data. Further integrating the detailed data collected from the experiment, we calculated the daily carbon dioxide absorption per unit leaf area and the daily transpiration per unit leaf area for each plant species. Through an in-depth analysis of this data, we plotted the absorption curves for various plants, thereby conducting a detailed comparative analysis.

3. DATA ANALYSIS

In this section, we will conduct a detailed analysis of carbon dioxide, as well as temperature and humidity.

3.1. Analysis of the Impact of Carbon Dioxide Concentration

To delve deeper into the impact of plants on indoor carbon dioxide levels, we conducted a 96-hour experimental observation for each type of plant, with the results presented in Figure 2. It is evident from the figure that, compared to the control group, the carbon dioxide concentration in all plant groups showed varying degrees of decline, indicating that the continuous presence of plants plays a positive role in reducing indoor carbon dioxide levels.

Additionally, in accordance with the physiological patterns of plants, the entire experimental process exhibited distinct cyclical variations. Upon close examination of each cycle, it was observed that after 18:00 every evening, due to the respiration of plants beginning to surpass photosynthesis, there was a slight increase in indoor carbon dioxide levels. However, once 7:00 AM arrived, with the enhancement of light, photosynthesis became more active, and plants started to absorb more carbon dioxide, leading to a significant decrease in indoor carbon dioxide concentration. Throughout the entire cycle, the amount of carbon dioxide absorbed by plants exceeded the amount released, thereby causing an overall downward trend in carbon dioxide concentration.

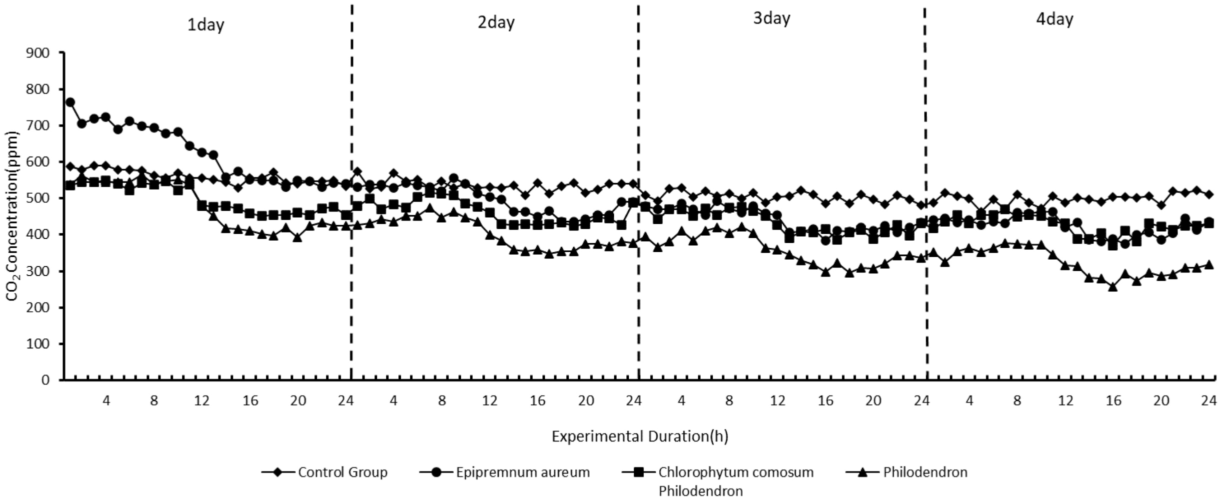

Figure 2: CO_2 Concentration Change Curves for Various Plant Species

Based on the calculations, detailed data on the carbon dioxide absorption of each plant species were obtained, as shown in Table 3. These data further confirm that under the same experimental conditions, Epipremnum aureum exhibits the most significant capacity for CO_2 absorption, while Chlorophytum comosum has relatively weaker absorption capabilities. Therefore, from the perspective of CO_2 absorption, Epipremnum aureum has higher efficiency and intensity.

Table 3: Carbon Dioxide Absorption of Various Plants

Plants name	*Reduction in CO2 (ppm)*	*Periodic Decrease in CO2 (ppm)*	*Periodic Decrease in CO2 Mass (mg)*	*Carbon Dioxide Absorption per Unit Leaf Area per Day (g/d·m^2)*
Epipremnum aureum	*265ppm*	*52ppm*	*6.13mg*	*0.39g/d·m2*
Chlorophytum comosum	*219ppm*	*43ppm*	*5.4mg*	*0.33g/d·m2*
Philodendron	*118ppm*	*35ppm*	*4.4mg*	*0.29g/d·m2*

3.2. Temperature Impact Analysis

In the 96-hour experiment conducted on each type of plant, where they were observed in smaller clusters, the results are presented in Figure 3. According to the chart data, it can be observed that around 2:00 PM each day, the indoor temperature reaches its peak, and this peak temperature fluctuates with the hourly changes in the outdoor weather temperature of the day. However, it is noteworthy that when the indoor temperature reaches its peak, the experimental groups equipped with green plants show a more or less significant decrease in temperature, indicating that green plants have the ability to regulate indoor temperature and reduce peak temperatures.

Additionally, during non-peak temperature intervals, we observed a reduction in the temperature decrease in the plant groups, and the overall temperature throughout the period was slightly higher than that of the blank control group. This phenomenon indicates that the presence of green plants helps to dampen fluctuations in indoor temperature, thereby enhancing the thermal comfort of the indoor environment. In short, green plants not only provide temperature regulation during high-temperature periods but also help maintain a stable indoor temperature during non-high-temperature periods, creating a more comfortable indoor environment for occupants.

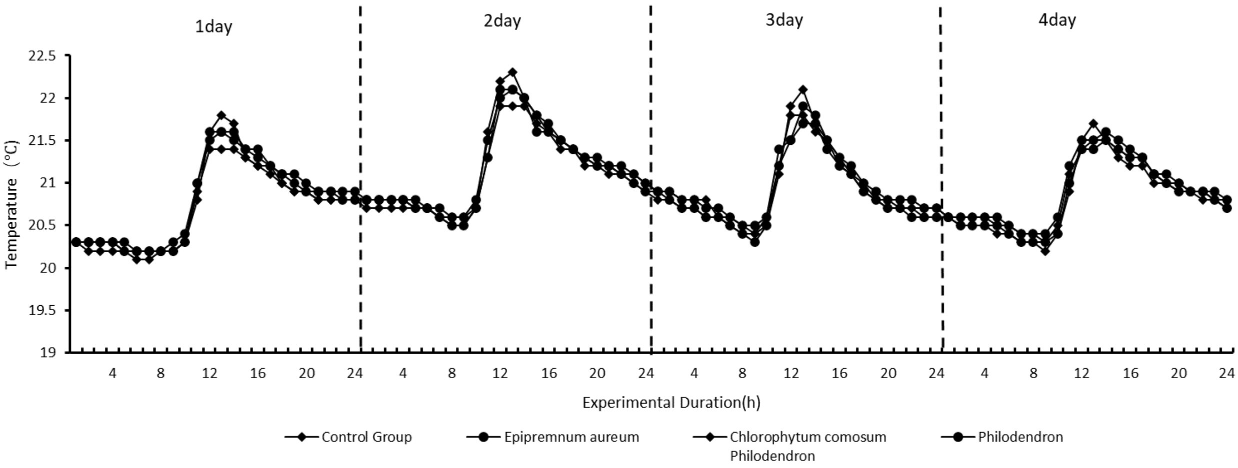

Figure 3: Temperature Variation Curves Among Different Plants

In the 96-hour experiment where each plant was divided into smaller sections, the results are depicted in Figure 4. As shown in Figure 4, compared to the control group, there is a noticeable increase in relative humidity in the experimental groups, accompanied by periodic fluctuations. In conjunction with the analysis from Figure 2, it can be observed that as CO_2 levels decrease significantly, the relative humidity also continuously increases, indicating a common periodic variation between the two. After 9:00 AM, relative humidity experiences a rapid increase, which is sustained until 2:00 PM when it reaches the peak value for the day, and then it begins to slowly decline, reaching another rise by 9:00 AM the next day. Overall, the presence of plants greatly assists in regulating indoor humidity levels.

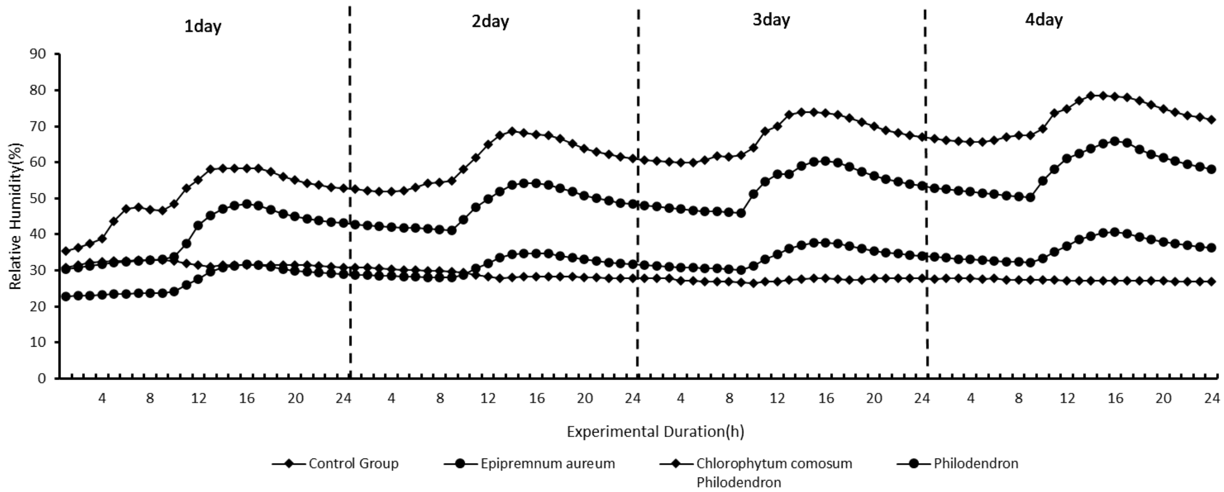

Figure 4: Humidity Variation Curves Among Different Plants

After conducting a detailed analysis of the experimental data for each group, we found significant differences in the moisture release by different plants into the indoor environment. Based on the comparison of leaf areas and data analysis, we compiled Table 4. Table 4 shows that under the same environmental conditions, the Chlorophytum comosum exhibits the most pronounced effect on moisture release, followed closely by the Philodendron, while the Epipremnum aureum has a relatively weaker effect on moisture release.

Table 4: Humidity Release by Various Plants

Plants name	*Humidity Release (g/kg)*	*Cyclic Humidity Release (g/kg)*	*Moisture Release per Unit Leaf Area per Day (g/kg·d·m^2)*
Epipremnum aureum	*5.66g/kg*	*1.415g/kg*	*94.59 g/kg·d·m^2*
Chlorophytum comosum	*4.31 g/kg*	*1.078g/kg*	*65.93 g/kg·d·m^2*
Philodendron	*2.07 g/kg*	*0.518g/kg*	*g/kg·d·m^2*

3.3. Architectural Simulation

Based on the aforementioned plant test results, to more intuitively demonstrate the carbon sequestration capacity and humidity release that plants exhibit in practical applications, we have constructed a plant wall as shown in Figure 5, to simulate its use in a real environment.

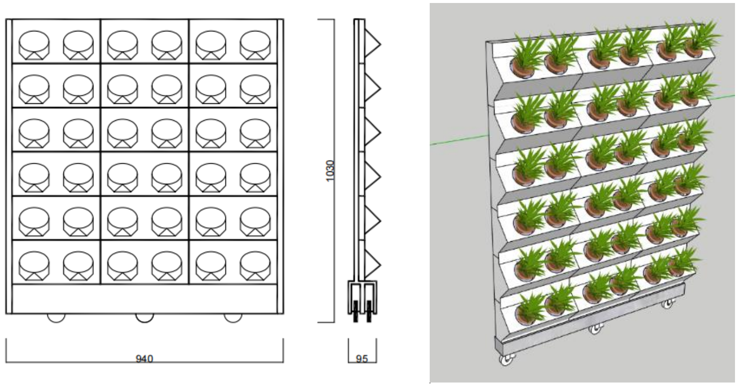

Figure 5: Physical Model of a Plant Wall

For carbon dioxide, the Epipremnum aureum has a CO_2 absorption rate of 0.39 g/d·m² per unit leaf area per day, which translates to approximately 0.81 mg/min of CO_2 absorbed by a single pot of Epipremnum aureum. Consequently, a plant wall could absorb up to 29.25 mg/min of CO_2. Over the course of a year, such a plant wall would have a carbon sequestration capacity of 15.37 kg/a. This contributes significantly to the carbon sink for the entire lifecycle of a building, reducing its overall carbon emissions.

In terms of humidity, currently available small humidifiers have a humidification capacity of approximately 65-70g/h, with a power consumption of 2.5 watts. This equates to an energy consumption of 9000 joules for every 65-70 grams of moisture released, amounting to 2.16×10^5 joules of energy per day. In contrast, one square meter of plant leaves can add 7.8 g of moisture to the indoor environment without the need for external energy input over the course of a day. A pot of green plants with a leaf area of 2-3 square meters can achieve an energy-saving rate of 1.5%. For a plant wall, the energy-saving rate can be as high as 40-60%, significantly reducing the energy consumption required for indoor humidification.

4. CONCLUSION

Through the aforementioned experiments, we can determine the impact indicators of plants on the indoor environment. Regarding carbon dioxide, under the same unit of leaf area, the Epipremnum aureum has the best absorption capacity for indoor CO_2, reaching 0.39 g/d·m², followed by the Philodendron 'Princess' and the Chlorophytum comosum at 0.33 g/d·m² and 0.29 g/d·m², respectively. The former is 1.2 times and 1.34 times that of the latter two.

For temperature, both the Chlorophytum comosum and Philodendron 'Princess' have a better mitigation effect than the Epipremnum aureum, but the reduction effect is not significant. This may be due to the greenhouse effect caused by the transparent acrylic box, which affects the experimental results.

Finally, in terms of humidity, the Chlorophytum comosum has the largest humidity release per unit area, reaching 94.59 g/kg·d·m², far exceeding the Philodendron 'Princess' at 65.93 g/kg·d·m² and the Epipremnum aureum at 32.68 g/kg·d·m². Its humidity release capacity is 1.4 times and 2.9 times that of the latter two. In the future, indoor plants can be used to calculate the indoor humidity increase, cooling effect, and air purification capacity with specific data.

It can be seen that by quantifying the impact of plants on the indoor environment, we can more accurately assess specific situations under different indoor conditions. In the field of architecture, the potential application of plant walls is beyond our imagination. When placed indoors, they not only serve as a part of the furniture, playing a dual role in purifying the air and beautifying the space; when placed outdoors, they become a part of the building's outer structure, not only playing a carbon sink function but also enhancing the structure's thermal performance, effectively reducing the building's energy consumption. Plant walls have far-reaching practical significance and application value in promoting carbon sinks, energy saving, and emission reduction.

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