CO_2 Purify Effect on Improvement of Indoor Air Quality (IAQ) through Indoor Vertical Greening

Ying-Ming Su and Chia-Hui Lin

***Abstract*—Modern people usually situate inside buildings, therefore indoor air quality (IAQ) is important to living environment. In this research, we measured the transpiration rate of 50 experimental plants first, and then we chose Bird's-Nest Fern (Asplenium nidus) as experimental subject to measure CO2 adsorption, which was one of the common indoor plants with high transpiration rate in Taiwan. We constructed an indoor 189 pots green-wall of Bird's-Nest Fern. CO2 adsorption was measured continuously before, during and after the experiment. The experiment consisted of three tests, A: Without plants (day time), B: With plants (day time), C: With plants (with light, night). Three measurements were compared between different tests from A to C. The result of the experiment indicated that the density of CO2 was reduced from 2000 to 600 ppm in 5.37 hours of test C. In average, the efficiency of CO2 adsorption was 1.38ppm/hr each plant. The indoor temperature decreased to 2.5 ℃ and relative humidity increased about 2~4%. We concluded that Bird's-Nest Fern had superior properties to CO2 adsorption, temperature and humidity conditioning to indoor air quality improvement.**

***Index Terms*—CO2, Indoor air quality (IAQ), Bird's-Nest Fern (Asplenium nidus Linn), indoor green-wall, transpiration rate**

I. Introduction

Plants are the lungs of the earth: they produce the oxygen that makes life possible, add precious moisture, and filter toxins. Houseplants can perform these essential functions in your home or office with the same efficiency as a rainforest in our biosphere. In research designed to create a breathable environment for a NASA lunar habitat, noted scientist Dr. B.C. Wolverton discovered that houseplants were the best filters of common pollutants such as ammonia, formaldehyde, and benzene. Hundreds of these poisonous chemicals could be released by furniture, carpets, and building material, and then trapped by closed ventilation systems, leading to the host of respiratory and allergic reactions now called Sick Building Syndrome.[1~3]. Besides methods such as enhancing ventilation and using equipment, the most natural ways of reducing SBS is to decorate the buildings with indoor plants.

Indoor plants become an important design method for energy saving, indoor air quality and work performance. Indoor plants can not only decorate the indoor spaces, some scientific researches also show that raising plants will contribute to the release of pressure and tiredness. The green environment will obviously increase the amplitude of the alpha wave inside human brain, and lower blood pressure, myoelectricity and skin conductivity. It will also release pressure and anxiousness and improve working attention. [4~6] Besides, indoor plants can reduce the employees' absence from work; increase their degree of satisfaction for work and feelings for life. [7~8] In a word, decorating plants inside a room will indeed benefit to our physical and psychological health.

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A. Harm of CO2 on human body

Indoor CO2 mainly comes from human breathing, smoking and open-fire heating etc. In concentrations between 0.2% and 0.3% in a closed-air-circuit area shared by crowds, CO2 will cause nausea, dizziness, and headache. With the rise of the concentration, temperature and humidity goes up, as well as dusts, bacteria and body odor, while oxygen and the numbers of ions in the air decreasing, causing uncomfortable. [9] Environment with low concentration of CO2 is not classified as toxic; however, a high concentration will do great harm to human body, leading to serious health condition such as suffocation. Nowadays, most offices have common problems that they are overused by too many people and are often not equipped with qualified ventilation systems [10~11].

B. Transpiration Rate

Transpiration is part of water cycle. It is the loss of water vapor from parts of plants and through the process water is purified and plants are cooled. To be specific, the diffusion of water vapor in the atmosphere lead to the cross-ventilation, temperature decreased which help purify the air, moisturize the air, remove biological exhaled gas and chemical toxicant, and inhibit the micro-organisms in the air so that indoor air quality can be improved[12~13]. Personal breathing zones placed high evapotranspiration rates of plant; you can increase the humidity and removal of exhaled gases and chemical substances. Also can inhibit the microorganism in the air [14~15].

II. Experimental Environment

This study was focused on IAQ effect of indoor plants and composed of three stages: (1) Optimum Setting (2) Numerical Simulation (3) Evaluation and Control. The experiment procedure proceeds were shown in Fig. 1.

We used Leaf Porometer as laboratory equipment to record the transpiration rate data. We chose the 50 experimental object plants in their proper sizes recommended by The Environmental Protection Administration Executive Yuan, R.O.C. (Taiwan) which is selected according to the recent Taipei sales conditions for flower market. This study divided 50 plants into 4 categories according to their characteristics: herbaceous foliage plant, herbaceous flowering plant, trailing plant and woody plant. This study had experimented 50 plants once every 12 hours, 10 leaves at a time. The experiment lasted for 144 hours continually.

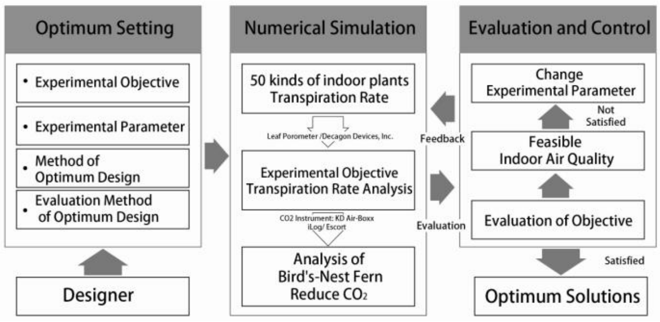

Fig. 1. Experiment procedure

We set up the laboratory which is 4.8×3.4×3.1 m^3 shown in Fig. 2. The experimental conditions used were summarized in Table 1. The average temperature of daytime was 28.15℃ and that of nighttime was 27.56℃. The average moisture of daytime was 76.93% and that of nighttime was 67.71%. Results of the average transpiration rate and the standard deviation of the four categories measurements were analyzed through SPSS analysis.

We had adopted the following instruments for CO2 absorption experiment: 1.CO2 monitor: KD Air-Box,

Fig. 2. The image of experimental lab

TABLE I
EXPERIMENTAL CONDITIONS

Instrument	:	Operating Environments: 5-40° C; 0-90% relative humidity (non-condensing)
		Accuracy: 10%
		Sample Chamber Aperture: 6.35mm (0.25 in)
		Measurement Range: 0 to 1000 mmol/㎡s
Air inlet	:	Velocity U_{in} = 1.2 m/s, ventilation rate = 6 1/h
		k_{in} = 3/2(U_{in} × 0.05)2, εin = 0.09 × k_{in}3/2/0.4
Temperature	:	28.15℃(daytime average) 27.56℃(nighttime average)
Moisture	:	76.93%(daytime average) 67.71%(nighttime average)

2.temperature and humidity monitor: iLog / Escort. All data values in the study were monitored in the seven-day-experiment.

The experiment was conducted in a L360×W360×H300cm laboratory (Fig. 3). A one-centimeter thick Styrofoam on the windows and the surrounding walls and ceiling were covered with tinfoil. A galvanized steel sheet covered the ground and special cautions were taken to stuff the gaps around the door. Monitoring equipment was placed in the center of the room and a monitoring spot was left outside the laboratory for another monitor. The laboratory was equipped with fluorescent of T5 lamps.

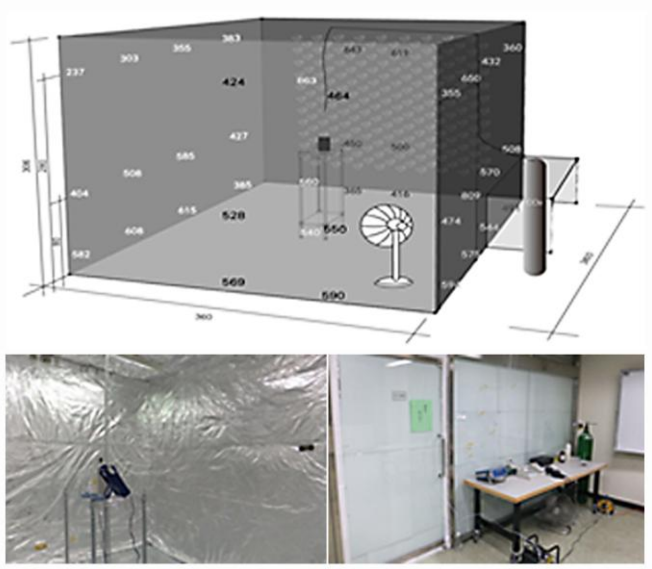

Fig. 3.Lab and Monitor outside the lab

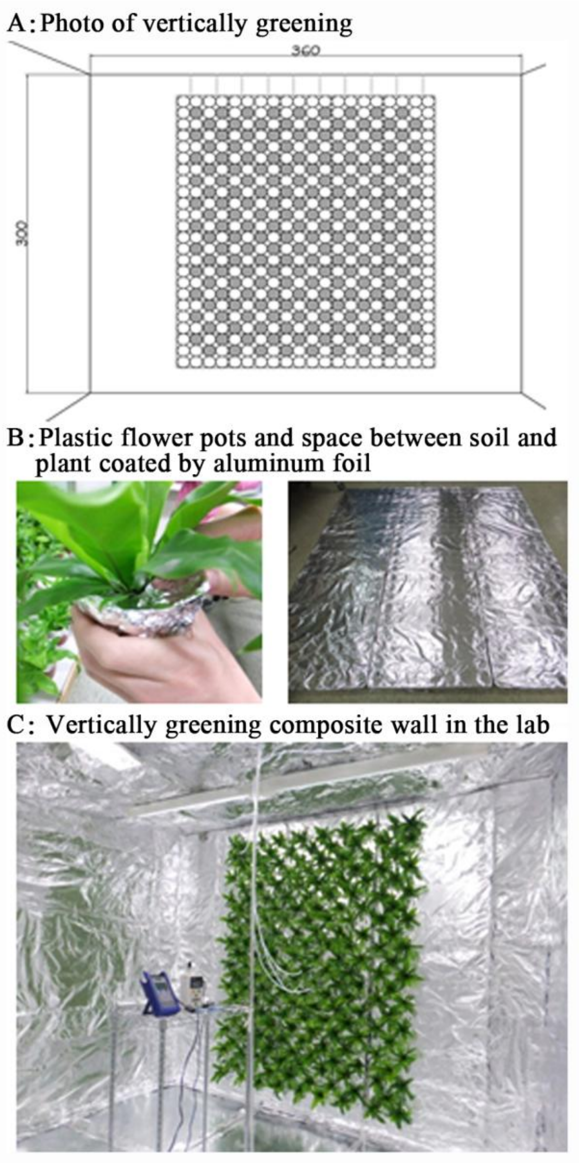

Fig. 4. photos of experimental environment

In accordance with the National Standards of Republic of China (CNS standard), the illumination range should be between 750~300lux. After the installation of lighting, the

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measurements of laboratory's illumination were taken at the height of 80cm and 280cm, every 75cm in width. The laboratory's average illumination of 13 sets altogether 39 data was 512.5lux.

One of the laboratory's walls (L300×W260cm) was covered with a composite vertical greening by Bird's-Nest Fern in 3-inch pots, altogether 189 pots (Fig. 4). Each pot approximately included 8 large leaves (18 × 4cm), six medium-sized leaves (15×3cm) and eight small leaves (8× 2cm) ，altogether occupying an area of 15㎡. Plastic flower pots and space between soil and plant as well as the composite wall were coated by aluminum foil to reduce other media's effect on the experimental data. A fan was placed to evenly spread the formaldehyde gas in the confined space.

Format and save your graphic images using a suitable graphics processing program that will allow you to create the images as PostScript (PS), Encapsulated PostScript (EPS), or Tagged Image File Format (TIFF), sizes them, and adjusts the resolution settings. If you created your source files in one of the following you will be able to submit the graphics without converting to a PS, EPS, or TIFF file: Microsoft Word, Microsoft PowerPoint, Microsoft Excel, or Portable Document Format (PDF).

III. Results and Discussion

Plants could turn CO2 and H_2O into carbohydrates C (H_2O) and release oxygen through photosynthesis [16]. The rate of plant's CO2 absorption could reach 10~30mg per decimeter square per hour, and thus could be used an indicator of surface photosynthesis [17].The indoor lamp lighting took the place of sunlight in the process. A fan was used instead of natural ventilation to evenly spread the formaldehyde in the space area. To ensure the accuracy of statistics, the laboratory was confined when statistics is monitored.

First, chose two fully expanded leaves and fix them twice a day respectively at 11:30 and 17:30. Then we recorded eight sets of data every day so that altogether 48 sets of data were recorded after six days (Fig. 5). A higher value represented a higher rate of transpiration and indicated that the plant could effectively adjust the humidity as well as release more anion to clean air. The plants ranking on the top of the list for experiment were Begonia masoniana, Fittonia verschaffeltii var. Argyroneura, Begonia res, Peperomia caperata and Bird's-Nest Fern (Asplenium nidus). Therefore, this study had chosen Bird's-Nest Fern (Asplenium nidus), a local plant of high transpiration rate, low requirement of optical activity, drought-and-shade-tolerant, and often of an appropriate size for indoor planting, as the detection objects. The recorded

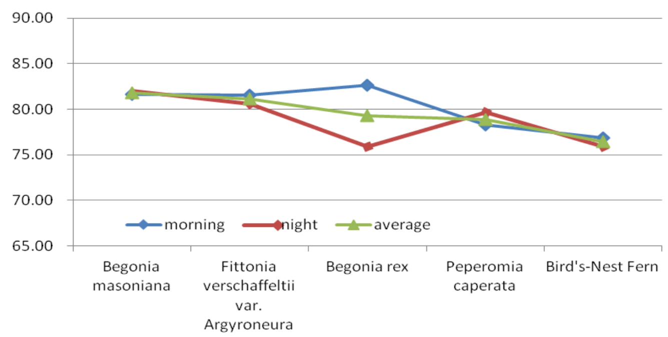

Fig.5. the Standard deviation and transpiration rate of Top 5

data showed that Bird's-Nest Fern's transpiration rate was among the highest, of 78 mmol/ (m2*s).

According to the results, the interior designers could select suitable indoor plants not only to decorate house but also make it more efficiency and healthy. Choosing the indoor plants with high transpiration rate to decorate houses could have more possibility to improve the heat radiation, thus it would cool down the air.

A. Transpiration Rate of Bird's-Nest Fern

Three measurements were compared between different tests from A: Without plants (day time), B: With plants (day time) to C: With plants (with light, night) in average. The indoor temperature decreases to 2.5 ˚ C and relative humidity increases about 2~4%. The 48 average transpiration rate of 78 mmol/ (m^2*s). (Fig. 6, TABLE II)

B. Reaction rate with release of CO2

Results showed when CO2, concentration of 2000ppm, was released, A: With plants (day time), it took 8 hours

TABLE II
EXPERIMENTAL DATA OF BIRD'S-NEST FERN

Day	time	First leaf bottom	First leaf top	2nd leaf bottom	2nd leaf top
Day1	morning	78.8	72	74.1	69.7
	afternoon	73	70.3	73.6	71.8
Day2	morning	77.7	71	76.7	73.2
	afternoon	80.5	77.6	79.3	72.7
Day3	morning	82.7	75.6	81.6	75.5
	afternoon	86.8	82.3	88.2	82.5
Day4	morning	88.9	86.2	87.4	83.7
	afternoon	81.8	75	77.5	72.9
Day5	morning	83.5	79.3	81.8	75.5
	afternoon	81.6	73	83.7	77.3
Day6	morning	82	75.9	78.2	72.7
	afternoon	80.8	75.6	73	70.1

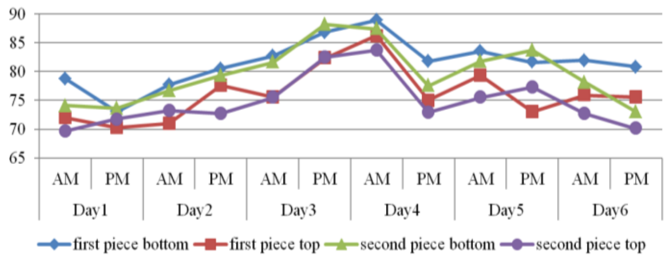

Fig.6.the data of Bird's-Nest Fern transpiration rate& indicating velocity change of transpiration rate

without any plants to decrease the concentration to 600ppm. B: With plants (day time), it took 6 hours and 18minutes at day. C: With plants (with light, night), it took 5 hours and 37 minutes at night to decrease to the same concentration.(Fig. 7) Time cost was least in the third experiment with plant at night, which was 2 hours and 25 minutes less than the experiment without plants. This indicated that the longer acclimation time was, the better effect plants achieved. Also, though at night, the photosynthesis of plants continued as long as there was light.

C. Change of temperature and humidity of experiment

In the experiment, the change of temperature and humidity was recorded both under the condition with and without plants. Result showed that the temperature of the laboratory with

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plants was about 2° C lower than that without plants which was 22.5~23.5° C. With plants, the temperature of the laboratory was 21.8~22.1° C at daytime and 21.9~22.2° C at night. (Fig. 8) The laboratory with plants in it could keep to a certain temperature. The humidity in the laboratory without plants was relatively low while it rises 10%RH when there were plants (Fig. 9). This indicated that plants could cool the temperature, kept the room to a certain temperature and meanwhile increased the humidity by 10%RH.

IV. Conclusion

The quality of the indoor environment significantly affected our health. The research indicated that 189 pots of Bird's-Nest Fern could reduce the concentration of CO2 from 2000ppm to 1000ppm in 2hr 6min from 600ppm to in 5hr 37min of test C: With plants (with light, night). Bird's-Nest Fern could keep the room to a certain temperature and increase the humidity by 10%RH. In average, the efficiency of CO2 adsorption was 1.38ppm/hr each plant. The indoor temperature decreased to 2.5 ℃ and relative humidity increased about 2~4%. The 48 average transpiration rate of Bird's-Nest Fern was 78 mmol/ (m^{2}*s). This indicated that the longer acclimation time was, the better effect plants achieved. Also, though at night, the photosynthesis of plants continued as long as there was light.

Conversion of the total absorption by 189 pots of Bird's-Nest Fern:
Absorption of CO2:
2000ppm-600ppm=1400ppm
1400/5.37= 260.7ppm/hr
260.7/189=1.3794≒1.38ppm/hr

Indoor plants could not only decorate the indoor spaces, release of pressure and tiredness, they could improve the quality of indoor air condition and reduce the pollutants in the air. This study showed that indoor plants can also contribute to lowering the temperature through better transpiration rate potentially.

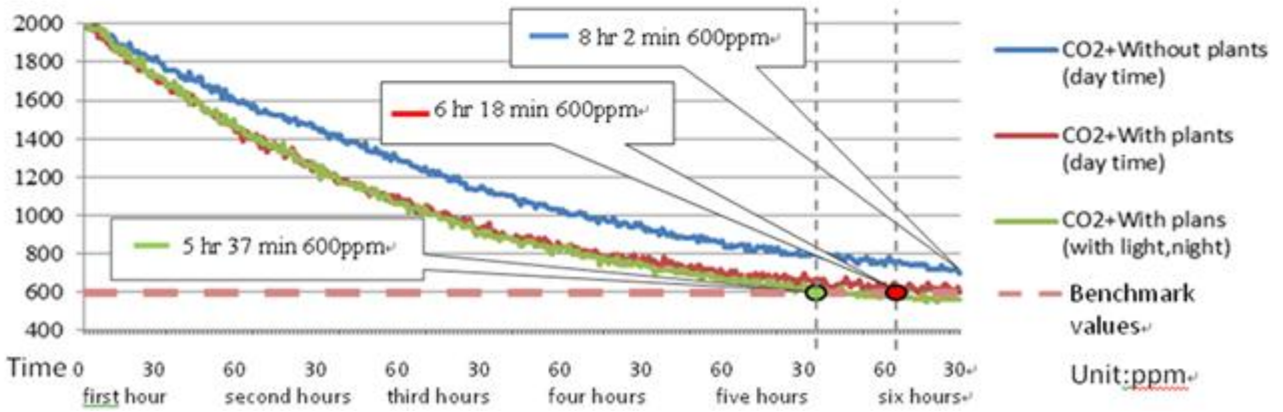

Fig. 7.CO2 reaction time of experiments

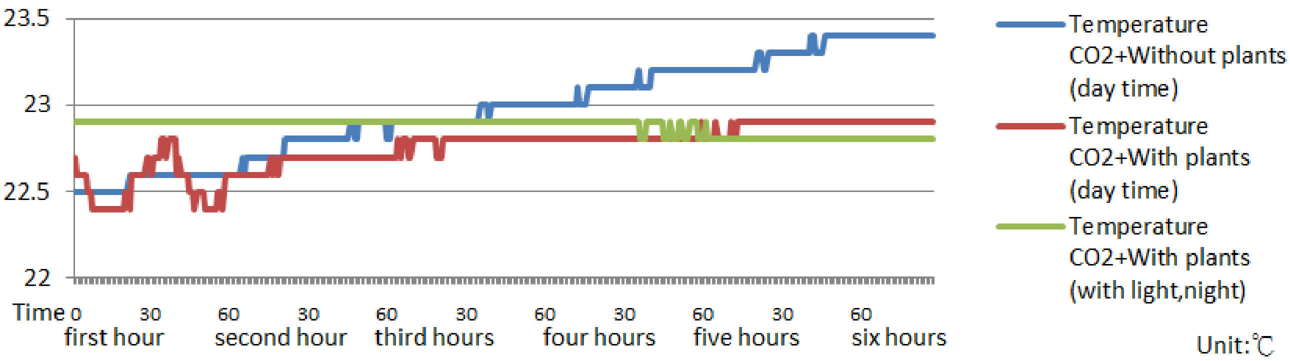

Fig. 8. Data overlapped results of temperature of experiment

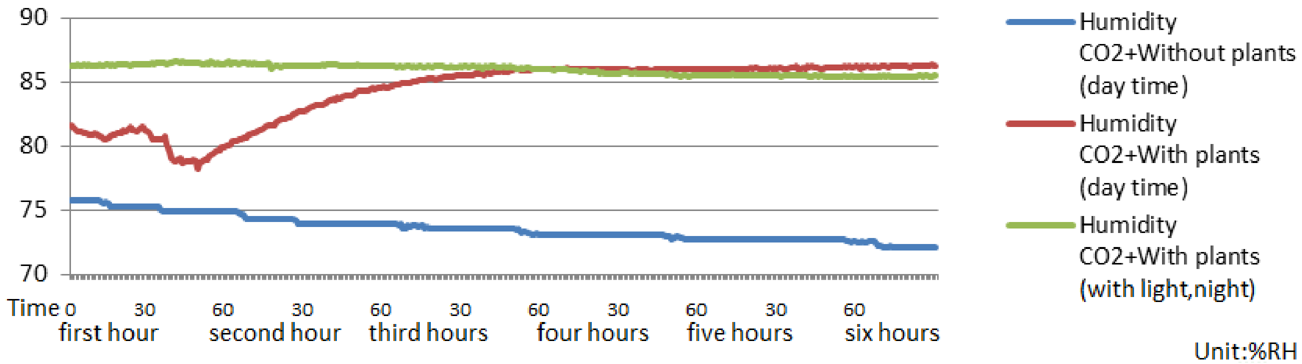

Fig. 9. Data overlapped results of humidity of experiments

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