Active living wall modules - CO₂ and CH₂O purification

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Abstract: Today, our green walls help to alleviate urban heat island effects, reduce noise and improve air quality. However, this design can be found to be detrimental to airflow and it does not use air to improve air now. Therefore, we must consider the characteristics of the factory and the correct principle of fluid mechanics design. The air can flow through the green wall by inhalation to achieve the function of beautifying and purifying the air. And we will put active living wall module indoors, because many studies have shown that people spends to 80% to 90% of the time to stay indoor. Researchers believe that indoor air quality is closely related to people's health. It also meets WELL building standards. And there are also studies that indicate that plants in the classroom can increase the attention of school children. Therefore, the purpose of this study is to use fluid mechanics to design a new green wall for air purification and beautify the environment and promote air quality to create a better living environment. This study placed the active living wall module and the wooden core board together in a transparent acrylic box. After the veneer volatilizes volatile organic substances such as formaldehyde, the module is activated to cause the volatilized gas to pass through the pores below the leaves of the plant as the gas flows. It is also measured whether the concentration of the organic substance before and after passing is effectively changed after passing through the plant. At the same time, the relationship between the wind speed and the stomata of Baihejing is obtained experimentally, and the best photosynthesis efficiency can be obtained. This study found that the pumping mode removed 33% more formaldehyde than the non-exhausted mode. For this study, when 10.5 V (0.6 m/s) is given, there is an optimum photosynthesis efficiency between the wind speed and the planting pores, so the test will be tested at 0.6 m/s. We have found that active living wall module achieve increased efficiency in reducing pollutants. There is another experiment in this study to compare the active living wall modules with the commercially available air purifier. We evaluated the purification of formaldehyde and carbon dioxide, and the price and energy consumption etc. We found that this active living wall modules and commercial air purifier have the same ability of purification. However, there are still many issues in this research that have not been discussed in the future, so it will be more in-depth experiments and research, and also to develop a with the technology of low energy consumption, low pollution, low cost and good aesthetics, the active living wall module goal of reducing indoor air pollution is advanced.

1. Introduction

Today, our green wall has several advantages like to ease the urban heat island effect, some studies have pointed out that this type of cooling strategy affects the indoor and outdoor environment of the building [1] and Bart Felder and Köhler found that the cooling effect of the green wall depends on the outdoor temperature. The cooling effect of the green wall during the cold and hot days was 0.4°C and 5.8°C, respectively. [2] Another advantage is reduce noise, some studies have pointed out that the leaves and branches of the green wall plants effectively reduce noise. The muffling effect of plants is that when sound waves propagate through the trees, they are reflected and refracted by leaves and branches, consuming some of the energy, thus reducing the noise. [3] The last advantage is improve air quality. NASA was the first to study the use of plants to purify indoor air quality. In the 1970s, it began to pay attention to air pollution problems in space stations and observe whether plants can establish self-
circulating air purification systems. The results show that microorganisms in common plants and media can remove a variety of volatile organic compounds, such as formaldehyde, benzene, trichloroethylene. [4] However, it can be found that the current design of the green wall is only because it wants to meet the minimum requirements of the regulations, and is not good at taking care of the green wall, resulting in the appearance of a green wall that has died or has no effect, and the design is also not conducive to air flow. At the same time, indoor planting produces moisture, and in the state where air does not flow, it is quite bad for indoor air quality.

At present, some reports also point out that modern people have 80 to 90% of their time doing ordinary daily activities indoors [5], so it can be known that indoor air quality is closely related to people's health. And one study of the purpose is to test the relationship between child’s direct attentions with the planting vs. non-planting classroom. Controlling of different kinds of classes and different levels of children’s attention characters. Results of the qualitative analysis show the planting effect increasing child’s attention in all different kinds of classes and all levels of children’s attention character. [6] And one study report that they used pilot-scale trials to test the capacity of potted plants, a passive green wall and an active green wall (AGW) to remove particulate matter (PM) and total volatile organic compounds (TVOCs) from a room in a suburban residential house in Sydney, Australia. With further empirical validation, AGWs may be implemented to efficiently clean indoor air through functional reductions in PM and TVOC concentrations. [7] So we are considering the characteristics and conformity of planting Proper fluid mechanics design allows the air to flow actively, and we were to redesign and improve the current green wall and mainly to place indoor ventilation in the public space environment, so that the design of the new green wall can beautify and clean air function.

2. Materials and Methods

2.1 Active living wall modules design
In order to understand whether the size of the planting and green wall modules and air purification efficiency are related, this study designed the first to fourth generation green walls. The fourth generation has been used as the next experimental model. The fourth generation of each group of green wall modules has a length, width and height of 24.4 cm and 18 cm and 32 cm, respectively. But can be assembled or disassembled according to research needs. This study consists of four modules.

![Module evolution](image)

**Figure 1. Module evolution**

2.2 Principle of Active living wall modules in fluid mechanics design and Absorption of formaldehyde
The study plans to build an active air-extracting green wall unit module, including planting species with strong purification ability and setting up a fan setting system in the module to passively for the initiative, it is desirable to force dirty air through the green wall implants and root microorganisms to produce fresh and clean air. The active living wall module is placed in a closed fumigation box to test the situation
in which the plant absorbs formaldehyde after the fan is turned on.

![Fan installation position for green wall](image)

**Figure 2.** Fan installation position for green wall

### 2.3 Comparison of efficiency and cost of purifying air between green wall module and commercial air purifier

Comparing the purification capabilities of active green living modules and commercially available air cleaners to formaldehyde, CO$_2$, PM$_{10}$ and PM$_{2.5}$, testing the possibility of replacing traditional air cleaners with green living modules, and developing a low energy consumption, low pollution, low cost and aesthetically pleasing technology to reduce indoor air pollution. Two commercially available air purifiers were used in the US Honeywell 18005 (A) and Japan DAIKIN MC75LSC (B), and the first test completed the four-generation active living wall module was compared and tested. The active living wall module is 57 cm long, 22 cm wide, 67 cm high and 0.2 m$^3$ in volume. The test plants are selected from the group of Nephrolepis exaltata Schott. Pocket coconut 4 pots each, because of their ability to remove CO$_2$ and formaldehyde according to previous studies[8]. Two T5 tubes are installed on the upper and lower layers, the light intensity is maintained at 90 ± 5 μmol·m$^{-2}$·s$^{-1}$ PPF, and the wind speed is fixed 0.6 m according to the results of the previous unit module test.

The test plants were fully watered one night before the test and the ambient temperature was 25 ± 2°C. The test plants were placed in 0700 HR at a light intensity of 90 μmol·m$^{-2}$·s$^{-1}$ PPF in a growth box for domestication. On the day of the test, 0800 HR was used to separate the active living wall module from the H and D cards. The cleaners were individually placed in a fumigant tank with a length of 100 cm × a width of 70 cm × a height of 200 cm and a volume of 1.4 m$^3$, and the plants were depleted.

![Two commercially](image)

**Figure 3.** Two commercially

A small fan with a length of 12 cm × a width of 12 cm is placed at the bottom of the fume tank to evenly mix the pollutant concentration. The line incense (special grade Laoshanxiang, Chengzheng Industrial Co., Ltd., Taoyuan, Taiwan) is used as the source of formaldehyde, CO$_2$ and PM release. After the 28 cm line burns out (40 minutes), turn off the small fan at the bottom and start the air cleaner and the green wall module fan. Use the 5-in$^1$ air quality detector (Heite Horticultural Technology Co., Ltd., Taichung, Taiwan) to record the initial concentrations of formaldehyde, CO$_2$, PM$_{10}$ and PM$_{2.5}$ in the fumigant tank at 0900 HR, and each A data is recorded in 30 minutes and continuously monitored for 6 hours up to 1500 HR. The green wall module reference test uses 0.6 m/s wind speed, light intensity 90 μmol m$^{-2}$·s$^{-1}$ PPF, ambient temperature 25 ± 2°C, 5 repetitions per treatment, 1 fumigation box per repetition, and Set 3 empty boxes, and take the mean value of the to represent the decrease of pollutant concentration caused by non-plant factors such as pipe wall adsorption and photolysis.

The results of the experiment were plotted and regression analysis with the drawing software SigmaPlot10.0 (SPSS Inc, USA). Investigate the cost of using the air purifier, and the air purification effect and cost of the active living wall module.
3. Results and Discussion

3.1 Module optimum wind speed test
The results showed that 0.6 m/s wind speed treatment resulted in the fastest decline of formaldehyde, CO₂, PM₁₀ and PM₂.₅ in the gas box. The net photosynthesis rate of 0.6 m/s wind speed treatment was significantly higher than the other wind speed treatment, and Yabuki and Miyagawa (1970) pointed out that the wind speed was 0.5 m/s. The 0.6 m/s treated cucumber (Cucumis sativus L.) has the highest net photosynthetic rate, which is due to the reduction of interfacial layer resistance due to the applied wind speed, promoting CO₂ diffusion and enhancing photosynthesis efficiency [9].

3.2 Plant purification ability test
The formaldehyde concentration in the fumigant tank treated at 0.6 m/s wind speed decreased by 0.974 ppm after 3 hours of test; 0.762 ppm decreased without additional wind speed treatment. (Figure 4)

![Figure 4](image)

Figure 4. Change in formaldehyde concentration in a closed aeration tank

3.3 Comparison of air purification efficiency between green wall module and commercial air purifier
Comparison of air purification efficiency between H brand air purifier and active living wall module
The H brand air purifier and the active living wall module are reduced to 55.2% and 65.3% of formaldehyde in the gas box, and the formaldehyde concentration of the active green wall module was significantly lower than the H brand (P < 0.001). The PM₁₀ of the H brand removal capacity in the sealed fume box is 100%; the active living wall module removal PM₁₀ capacity in the sealed fume box was 91.5%. The PM₂.₅ of the H brand removal capacity in the sealed fume box is 100%; PM₂.₅ of the active living wall module removal capacity in the closed fume box was 74.5%. The CO₂ of the H brand rises to 1.5%; the CO₂ of the active green wall module decreased by 11.1%, and the CO₂ concentration of the active living wall module was significantly lower than the H brand (P < 0.001). (Figure 5)

3.3.1 Comparison of air purification efficiency between D brand air purifier and active living wall module.
The D brand air purifier and the active living wall module decreased to 40.4% and 60.4% formaldehyde in the closed fume box, and the formaldehyde concentration of the active living wall module was significantly lower than the D brand (P < 0.001). The PM₁₀ of the D brand removal capacity in the sealed fume box is 100%; the active living wall module the PM₁₀ removal capacity in the sealed fume box was 88.2%. The PM₂.₅ of D brand removal capacity in the sealed fume box is 100%; The PM₂.₅ in the sealed fume box is 100%; the active living wall module the PM₁₀ removal capacity in the sealed fume box was 88.2%. The PM₂.₅ of D brand removal capacity in the sealed fume box is 100%; The PM₂.₅
of active living wall module removal capacity in the closed fume box was 62.2%. They reduced the CO₂ in the closed fume box by 3.6% and 13.9%, respectively. The CO₂ concentration of active living wall module was significantly lower than that of the D brand (P < 0.001). (Figure 6)

Fig. 6 ALW and (HAVC-D) were tested in a fumigant tank for 6 hours of formaldehyde (A), CO₂ (B), PM₁₀ (C) and PM₂.₅ (D) concentrations

3.4 Comparison of Active Living Wall Module and Commercial Air Purifier Cost

The main body of the active green wall module and the pot is planted with 8 pots and 3 cm in diameter. It is expected to replace the plant in 3 months to maintain the purification effect. The annual cost is NT.6,624. The cost of buying two air purifiers on the market and replacing consumables in one year is estimated to be NT.7,079 for the H brand air purifier and NT.15,120 for the D brand air purifier. The active living wall module tested has a total power consumption of 78.4 W after the fan and light source are turned on, the H brand air cleaner consumes 63 W, and the D brand air cleaner consumes 82.5 W.

4. Conclusion
In this study, we learned that the modified active living wall uses the principle of fluid mechanics to increase the cleaning ability of the green wall by inhalation. This study found the best air purification rate, avoiding the loss of plant water caused by excessive wind speed, in order to reduce the ability to purify the air. It has also been studied that the cleaning ability of the active city green wall can achieve the same effect as the commercial air purifier. For this research, the active green wall will be improved to reduce energy consumption, and the green wall will continue to beautify. Most people spend 90% of their time stay indoors, so I think the green wall of this research innovation will help improve our quality of life. The wall allows the ventilation to be carried out unconsciously, so that the active green wall can be placed indoors to beautify the environment and purify the air, making our living circle more comfortable and healthy.

Reference
[1] Taleghani, M. (2018). "Outdoor thermal comfort by different heat mitigation strategies- A review." Renewable & Sustainable Energy Reviews 81: 2011-2018.
[2] Bartfelder, F, M. Köhler, Experimentelle untersuchungen zur function von fassadenbegrünungen; 1987: Dissertation TU Berlin 612S.
[3] Veisten, K., et al. (2012). "Valuation of Green Walls and Green Roofs as Soundscape Measures: Including Monetised Amenity Values Together with Noise-attenuation Values in a Cost-benefit Analysis of a Green Wall Affecting Courtyards." International Journal of Environmental Research and Public Health 9(11): 3770-3788.
[4] Wolverton, B.C., A. Johnson, and K. Bounds. 1989. Interior landscape plants for indoor air pollution abatement. Report. National Aeronautics and Space Administration, Stennis Space Center, Mississippi.
[5] Human requirements in future air-conditioned environments
[6] Syu, 2010 ; He, 2012
[7] The in situ pilot-scale phytoremediation of airborne VOCs and particulate matter with an active green wall. T. Pettit1 & P. J. Irga2 & F. R. Torpy1
[8] The effect of plants on preschool children's attention in the classroom Mao-Feng Hung Thongbai et al., 2010