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Study on Oxygen Production Capacity of Green Window System based on Subsistence Building

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Abstract

In 2020, COVID-19 was in the global pandemic. China adopted extensive non drug intervention measures to cut off the spread of virus and achieved remarkable results, which led to a reflection on ecological architecture, i.e., the ability of buildings to enter a self-sustaining state under the adverse external environment (e.g., air pollution, virus transmission, toxic gas leakage, hurricanes, etc.). In this paper, the authors summarize the existing building and plant co-construction methods and introduce a maintenance-free green window system (MGWS)based on the concept of "subsistence building", and compare the indoor negative oxygen ion concentration of the MGWS with the equivalent amount of plants under closed conditions through measurements. The results show that the MGWS has a higher concentration of negative oxygen ions, which is more beneficial to human health and offers the possibility of subsistence buildings.

Keywords

Virus Transmission; Subsistence Building; Green Window System; Negative Oxygen Ions.

1. Introduction

The COVID-19 pandemic has led to a dramatic loss of life and a massive increase in health burden worldwide .Up to 18 December 2021 (17:00 GMT), more than 200 countries, areas or territories have been registering infection cases of COVID-19 illustrating the severity of the world-wide pandemic. The number of infections and deaths is still rising (over 273.66 million confirmed cases and 5.34 million confirmed deaths [1]. As the most direct and fundamental method to control the spread of the coronavirus in the pandemic, isolation is one of the most necessary way to prevent virus transmission. Indoor air conditioning and ventilation system can reduce the risk of infection when there is no virus or infected person in the room, but the virus spread by aerosol (such as SARS,COVID-19)[2], once a building has a virus or virus infection in a room, centralized air conditioning system or natural ventilation will cause aggregation infection ,which led to a rethink of buildings-How to ensure the normal life of indoor people under the bad external natural environment (such as virus transmission, air pollution, toxic gas leakage, hurricane, etc.).

2. Literature Review

2.1 Plant-architecture Co-construction

Since the American architect Paul Soleri proposed the concept of "eco-architecture" in 1960s, eco-architecture has been summarized in two directions: one is to integrate architecture into nature,

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making it a part of the ecosystem and reducing the damage to the natural environment. The second is to introduce nature into architecture, integrating plants and buildings to naturalize the artificial environment [6-7]. The main forms of integration between plants and buildings are enclosure system, internal space, site surrounding (Figure 1.). Kamal Meattle[8] found that 6-8 waist-high tiger orchids or 4 shoulder-high scattered anemones could produce enough oxygen to meet a person's daily needs. Nearly 1,200 plants were placed in a 4,645 m2 office building in Delhi. It was found that the plants not only met the daily air intake of 300 residents, but also increased the blood oxygen level of the residents by 42% and reduced eye allergy cases by 52%.

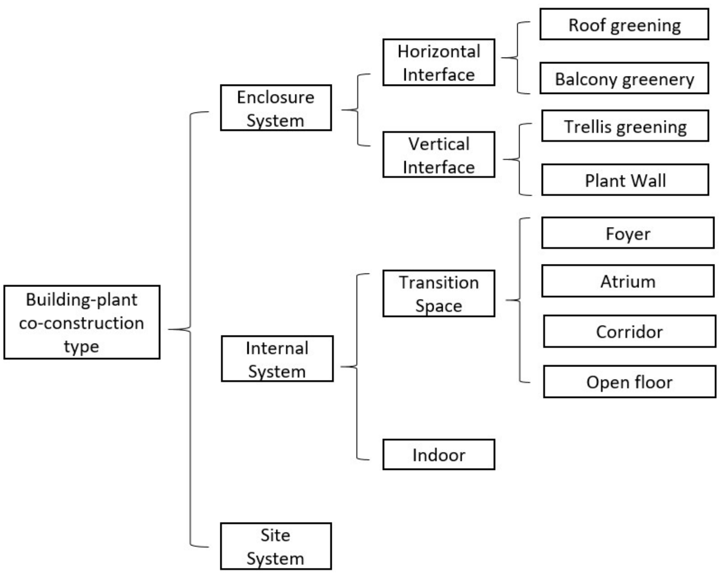

Figure 1. Building-plant Co-construction Type

2.2 Subsistence Building and Virus Transmission

The concept of self-sustaining housing was first developed by the University of Cambridge in the United Kingdom Alex Parker proposed that its original intention was to design a set of self-service system applied to buildings, to reduce the dependence of buildings on limited regional ecosystems. In 1975, Robert [9] defined it as a completely independent house. It depends on the intake of the outside world, such as sunshine, rain, etc. It is necessary to support the gas supply, water supply, power supply, sewage and other systems of the municipal pipe network.

There are three possible modes of transmission of respiratory infections: direct contact transmission, short-range droplet transmission and long-range aerosol transmission [10]. Maintaining a certain social distance and wearing a mask can cut off the first two transmission routes, but facing the uncertainty of virus transmission in the outside air, how to reduce the possibility of virus aerosol transmission is the main problem we face. Most modern buildings are equipped with natural ventilation and centralized ventilation systems to meet the human body's air demand. However, in the face of the harsh outdoor air environment (virus transmission, air pollution, toxic gas leakage, etc.), it is an important goal to build "Subsistence building" to ensure the normal survival of people indoors without exchanging air with the outside world. As an important kind of artificial environment, building is also the main activity space of people. The building has a relatively complete water supply and energy system. Cubic farms can provide food and ensure material energy. Modern technologies such as internet and 5g break the boundaries of traditional spaces and make home office and study possible. Plants provide fresh air. Buildings cover energy sources such as air, water, and food, and can be in a relatively self-sustaining state in modern society when (electricity, gas) and internet are essential to sustain people's production and living needs(Figure 2.).Plants provide material and energy as producers in natural ecosystems, but most plants play an ornamental and decorative role in buildings. We can use plant photosynthesis to consume CO_2 and release O_2, make full use of the

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ecological role of plants in the ecosystem, integrate the ecological effects of plants into the system of buildings, and form a "human-plant-building" organism to cope with changes in the bad external environment.

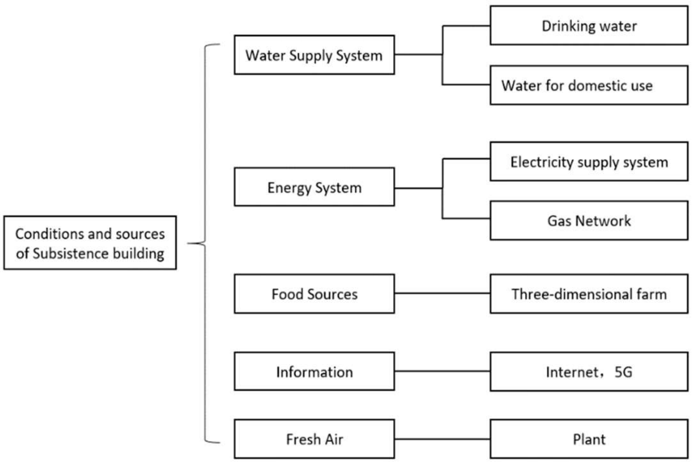

Figure 2. Building Self-sustaining Systems

3. Methodology

Based on the concept of "Subsistence building" and previous research, the authors designed and built a "maintenance-free green window system" (MGWS) in a teaching building in Changsha(Figure 3.) [11], using trace irrigation technology to ensure sufficient water for plants at all times to reduce daily maintenance. The water supply, planting units, and indoor ventilation of plants are integrated into the building windows to save indoor space and fully maximize the use of sunlight. The MGWS provides oxygen to people indoors and reduces indoor-outdoor air circulation and centralized mechanical ventilation, thus cutting off the path of virus aerosol transmission.

Negative oxygen ions in the air can improve cortical function, eliminate fatigue, improve sleep, and have a variety of beneficial health effects on the nervous system, cardiovascular system, respiratory system, and blood [12]. Negative oxygen ions are oxygen carrying one electron, so the concentration of negative oxygen ions not only reflects the indoor air quality but also represents the oxygen content in the air, therefore, this experiment uses the negative oxygen ion content as an indicator to compare the oxygen production capacity of indoor greenery and MGWS.

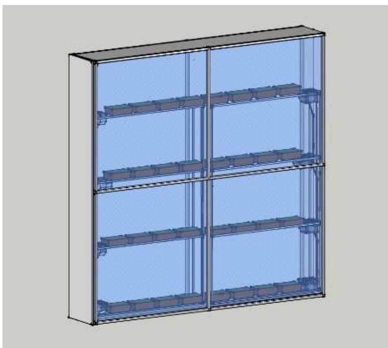

Figure 3. Maintenance-free Green Window System Model

3.1 Design of the Labs

Two adjacent rooms of equal size in the teaching building of a university in Changsha were selected to ensure that the temperature, humidity and lighting conditions of the compared rooms were the same, Eipremnum aureum was selected as the experimental plant. The size of the two experimental rooms is 6.95m long, 3.5m wide and 3.3m high. The window size of the two rooms is 1.79m wide, 2.35m high and 0.46m depth. Room 1 is an ordinary room with plants equal to the green window system, and room 2 is a modified room with MGWS.

3.1.1 Layout of Measuring Points

Considering the uneven distribution of indoor gas concentration, three measuring points in the upper (A / D), middle (B / E) and lower (C / F) are selected at the same position in each room. The average values of the three measuring points are taken as real-time data to draw the negative oxygen ion concentration change diagram.

Table 1. Conditions of two rooms

Room Number	Detection points	Number of Plants	Plant location	Fan power	Fan position
Room 1	A, B, C	120 plants	On the ground	15W	On the ground
Room 2	D, E, F	120 plants	Placed in the MGWS	15W	In the MGWS

3.1.2 Evaluation Index:

The air quality levels reflected in the data measured in this experiment were evaluated using the most commonly used Abe air quality evaluation coefficient CI, which also refers to the monopole coefficient q. The monopole coefficient is the ratio of positive to negative ions in the air and is calculated using the formula:

$$q=n+/n- \tag{1}$$

Where, n+ is the number of positive air ions; n- is the number of negative air ions. Most scholars believe that q should be equal to or less than 1 in order to give people a sense of comfort.

Air ion evaluation coefficient refers to the degree that the ion concentration in the air is close to the ionization level of natural air. The calculation formula is:

$$CI= (n- /1000)\times(1/q) \tag{2}$$

Where: CI is the air quality evaluation index; q is the monopole coefficient. The index takes air ions as an evaluation index, and also considers the composition ratio of positive and negative ions to evaluate the negative oxygen ion concentration comprehensively. The Japanese scholar Abe classified air quality into five classes according to the range of air quality evaluation index (Table 2).

Table 2. Abe Evaluation Coefficient of Air Quality

Rank	Air condition	Evaluation index
A	The cleanest	>1
B	Cleaner	1.0-0.7
C	Clean	0.7-0.5
D	Acceptable	0.49-0.30
E	Critical	0.29

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3.2 Experimental Process

First of all, the doors and windows of the two rooms were closed, and the air tightness of the room was tested. Use negative ion concentration detector every 6h to detect the concentration of negative oxygen ions in the room, when three consecutive sampling of negative ion concentration change rate <1%, depending on the concentration of negative ions in the indoor air is basically stable, to meet the experimental requirements.

The initial concentration of anions in room 1 was 1523.33/cm³, with a q value of 2.48 and a CI value of 0.615, while the initial concentration of anions in room 2 was 1730/cm³, with a q value of 2.89 and a CI value of 0.599. The initial indices were similar and met the experimental conditions. The negative oxygen ion concentration of the three testing points in the two rooms was tested and recorded every 12h, and the average value was taken as the data for calculating CI values. The difference between the last testing data and the initial data was regarded as the negative oxygen ion produced by the plants and the MGWS.

4. Results

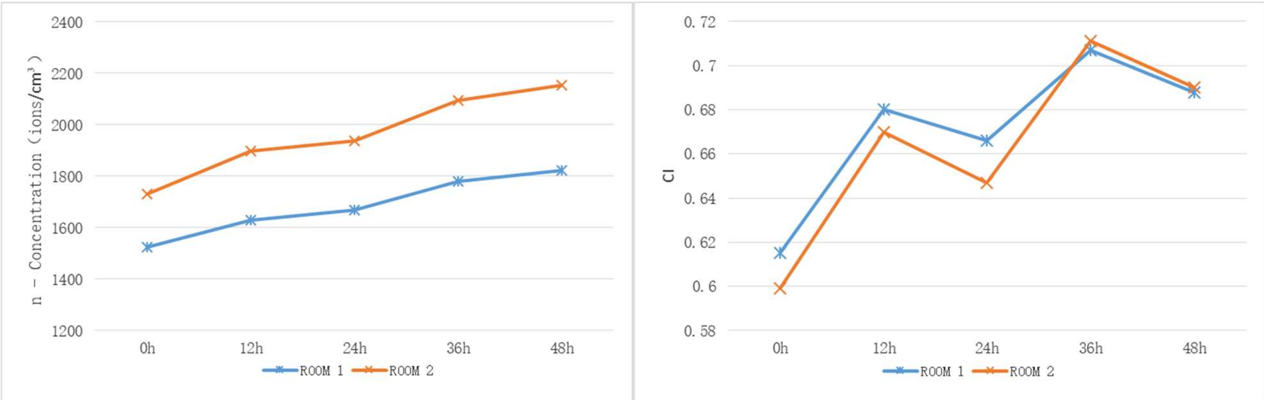

Figure 4. Average negative oxygen ion concentration

By comparing the concentration changes in the two rooms within 48 hours, it can be seen that at the beginning of the experiment, the negative oxygen ion concentration in room 2 is higher than that in room 1, which is caused by the generation of Eipremnum aureum during the installation of MGWS. After 12 hours of photosynthesis, the concentration of negative oxygen ions in both rooms increased, by 106.67/cm³ and 166.67/cm³, respectively. After 24 hours, the negative oxygen ion concentration in both rooms did not change much because the plants were mainly respiring at night. 48 hours later, the negative oxygen ion concentration in room 1 increased by 300 /cm³ and in room 2 by 423.33 /cm³ compared to the initial concentration. The CI values in room 1 and 2 increased by 0.073 and 0.091, respectively, indicating that the MGWS is more effective than traditional indoor plants to improve indoor negative oxygen ion concentration and optimize indoor air quality.

According to existing studies, negative oxygen ions are formed by water molecules or other small molecular groups in the air combined with free electrons in the air[13]. Through the above comparative experiments, it is found that the water supply device in the MGWS can ensure that the soil in the planting unit is always in a water saturated state, which is different from ordinary indoor plants. The plants in the MGWS are always well hydrated. The ventilation device in the closed MGWS accelerates the evaporation of water from the water tank, which increases the number of water molecules in the indoor environment, thus promoting the formation of negative oxygen ions. The plants in the MGWS receive better sunlight than ordinary indoor plants, and the transpiration of plants is more obvious and photosynthesis is more efficient, which helps plants produce more oxygen.

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Table 3. Comparison between the MGWS and indoor plants

Influence Factor	MGWS	Indoor plants
Sunshine	Plants are distributed in multiple layers near the window, and each layer of plants can get long-term and sufficient sunshine, which is conducive to plant photosynthesis and transpiration	Short daylight hours for plants farther from windows due to changes in solar altitude angle.
Water supply	Trace irrigation method makes the soil in the planting pot in a water-saturated state for a long time, the plant root system is well hydrated, and the plant transpiration effect is better. The automatic control water valve device keeps the water volume in the tank unchanged, which is conducive to indoor humidification.	Intermittent watering, with plant transpiration, the water in the plant soil is not often in a water-saturated state, resulting in poor transpiration
Ventilation system	The centralized ventilation duct accelerates the water evaporation in the sink, soil and plants, and the indoor humidification effect is more obvious	The air flow is dispersed and has different evaporation effects on plant soil and leaves

5. Discussion

The outbreak of this new coronavirus has triggered new thoughts on Ecological Architecture - establishing subsistence buildings with air safety. Although air-safety subsistence buildings is not the norm, it can be a new means and way to deal with extreme emergencies such as outdoor air pollution, virus transmission and toxic gas leakage. Based on the concept of "Subsistence buildings", the MGWS uses plants as the source of oxygen, strengthening the ecological role of plants as producers in the building, so that people can breathe safe and healthy air in a relatively independent space. The MGWS not only forms a self-protection mechanism externally under conditions that threaten human health such as haze and virus transmission, but also prevents the spread and diffusion of internal pollutants between rooms in the building through the ventilation system and central air conditioning system. The MGWS can be applied to the renovation of existing buildings and has the characteristics of low construction cost and easy implementation. However, the proportional relationship between human oxygen demand and the amount of oxygen produced by MGWS need to be further studied.

Acknowledgments

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References

[1] Information on https://coronavirus.jhu.edu/map.html.2020-07-31. https://coronavirus.jhu.edu/.

[2] Li, Y; Huang, X; Yu, ITS; Wong, TW; Qian, H. Role of Air Distribution in SARS Transmission during the Largest Nosocomial Outbreak in Hong Kong. Indoor Air. Vol. a(2005) No.15:p.83-95.

[3] Li Y, Duan S,Yu I T S,Wong T W. Multi-zone Modelling of Probable Sars Virus Transmission by Air Flow between Flats in Block E, Amoy Gardens, Indoor Air, Vol. b(2005) No.15:p.96-111.

[4] Li Y, Qian H,Yu I T S,Wong T W:Probable roles of Bio-aerosol Dispersion in the Amoy Gardens SARS Outbreak-further Environmental Studies. Invited prepared for the International Workshop on Population Dynamics and Infectious Disease in Asia(Singapore,2004) Vol.a,p.27-29.

[5] Xu, CW, Luo, XL, Yu, CW, Cao, SJ. The 2019-nCoV Epidemic Control Strategies and Future Challenges of Building Healthy Smart Cities, Indoor Built Environ, Vol. (2020)No.29, p.639–644.

[6] Dai Lu: From "co-construction" to "habitat creation"-a study on the integration of plant system and green building design(MS. Chongqing University, China 2010), p.29-47.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202204_8(4).0011

[7] Li Xumin. Research on the Development History and Trend of Green Building (MS. Hunan University, China 2014), p.20-33.

[8] Information on https://www.ted.com/speakers/kamal_meattle.

[9] Robert Vale: The New Autonomous House: Design and Planning for Sustainability, (Thames & Hudson Ltd, New Zealand 2002.09).

[10] Heshu Sulaiman Rahman, Masrur Sleman Aziz, Ridha Hassan Hussein, Hemn Hassan Othman, Shirwan Hama Salih Omer, Eman Star Khalid, Nusayba Abdulrazaq Abdulrahman, Kawa Amin, Rasedee Abdullah, The Transmission Modes and Sources of COVID-19: a Systematic Review, International Journal of Surgery Open, Vol.26(2020),p.125-136.

[11] Zhao M. Q, BAO S. L, Hu Y, Lin X, Han J. Y. Experimental Study on Routine Maintenance-free Green Window System,Journal of Railway Science and Engineering, Vol.15(2018) No.4,p.1002-1007.

[12] Wu Zhongbiao, Zhao Weirong:Indoor Air Pollution and Purification Technology (Beijing Chemical Industry Press. China,2005),p.606-609.

[13] Pan J.B, Tian Y, Chen Z.J, Ding Q, Zou Y, Su Y: Study on the Spatial Differentiation Characteristics of the Negative Oxygen ion Environment of Building Outdoor Green Space, Urban Architecture, Vol.33 (2018), p.40-43.