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A Sustainable Indoor Air Quality Monitoring Approach Through Potable Living Wall for Closed Confined Spaces: a Way Forward to Fight Covid-19

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Abstract. The COVID-19 pandemic has greatly influenced various aspects of life, part of which has consequently paved the way toward improvements in building design criteria, especially for closed confined spaces. The closed confined spaces are directly proportional to the quantity and quality of the volatile organic compounds (VOCs) present in the atmosphere, from which human beings breathe. In managing the impact produced by VOCs, a practical, sustainable, economical and environmentally friendly concept of indoor living walls has become a prominent feature for improving the indoor air quality (IAQ) of closed confined spaces to efficiently reduce sick building syndrome (SBS) factors. In modification of common practice of ventilation systems, living wall technology leverages the natural ability of plants to purify indoor air quality by reducing air pollutants and allows the recycling of indoor air and the creation of a productive and inspiring environment. In this paper, the concept of a portable living wall through the use of a native plant species locally available in Sindh, Pakistan is introduced. Herein, the portable living concept was assessed by means of the design, construction, and data collection (testing and monitoring) of various environmental parameters carried out before and after the installation of the living wall. The study was monitored for 90 days, and analyses for various types of air pollutants were carried out in the environmental laboratory. During the monitoring period, the parameters humidity, VOCs, hazardous chemicals of concern (HCOC), CO_2 and CO showed reductions in their values, with changes observed ranging from 61.5 to 58%, 0.66 to 0.01 ppm, 0.2 to 0.01 ppm, 1070 to 528 ppm and 0.2 to 0.01 ppm, respectively. The outcomes showed noticeable changes in air pollutants coupled with reductions in heating, ventilation, and air conditioning (HVAC) energy consumption by up to 25%, mainly due to limited air requirements for ventilation.

Keyword:

Potable living wall, Indoor air quality, Closed confined space, COVID-19, SDG 3

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1. Introduction

It has been reported that due to lockdown during COVID-19, the air quality of many metropolitan cities has improved. Pertaining to VOCs, ground-based measurements have shown a drastic drop in the first phase of lockdown compared to the prelockdown period [1]. Higher ozone mixing ratios have also been reported in several states, i.e., by 14% in Rome, 36% in Wuhan, and approximately 25% in both Nice and Turin [2]. COVID-19 spread has been reported mainly due to exhaled breath. Screening of exhaled breath has been used to study several diseases, such as lung cancer and asthma. However, VOC biomarkers have shown potential results in analyzing respiratory infections, especially COVID-19 [3].

Closed spaces that are airtight and have limited fresh outdoor air exposure experience low levels of IAQ and are addressed as a serious issue. Well-being risks are not the only problem; contaminated indoor air is also found to be negatively affected. A living wall has the potential to improve indoor air quality while reducing the quantity of air needed for ventilation, creating the potential for energy savings [4].

Indoor living walls are considered biological air purification systems for improving the IAQ of a particular close space, as they are composed of a variety of plant types and microbes that live in their roots. These microbes have the capability to improve indoor air quality and the well-being of particular closed-space occupants. Plants are typically grown on a vertical surface that allows airflow through the wall and over the root system. Through microbial activity, airborne contaminants such as CO2, VOCs, and other contaminants are degraded into end products that are nontoxic to well beings and their surroundings [5].

The living walls include a coordinated water conveyance framework through a self-supporting nursery channel that can be planned on the walls of a structure [6]. This gives extraordinary potential in lessening energy consumption in structures depending on the thickness of the plants used in the living wall. Accordingly, the concealed structure will encounter low temperatures. Furthermore, the developed system assures air quality by sifting airborne particles into its leaves and branches while retaining vaporous contaminations through photosynthesis, which is proven to have decreased tiredness levels as well [7]. Among the three fundamental strategies proposed by the Environmental Protection Association (EPA), namely, controlling the source and developing ventilation and air purification to ensure indoor air quality, living walls could be one of the solutions. A living wall is an indoor vertical aquaculture green divider in which the air is effectively drawn through the mass of plants and the root framework to sanitize the air inside any structure. Such walls are acquiring acknowledgment in Asia, Europe, and North America for their efficiency [8].

Among all effective approaches, mechanical ventilation, energy recovery ventilation, infiltration, etc., are commonly used to introduce fresh air in closed spaces, whereas a plant-based living wall is an innovative complement to these traditional approaches. Herein, a similar approach has been introduced while focusing on the native plant species locally available. The living wall structure was designed on the approach of a portable system that would be sustainable in different aspects, namely, its own air circulation system, irrigation system, low weight, low cost, energy saver, easy to handle, etc.

2. Methodology

The living wall was tested and monitored at the Environmental Engineering Lab, Sir Syed University of Engineering and Technology, Karachi, Pakistan, where a number of air-borne pollutants, toxic chemicals, and other contaminants were found to affect the overall environment of lab activities. The lab was chosen mainly because the students spend the majority of their time indoors in the lab, where levels of pollutants may run more occasionally compared to the outdoor levels. Many of these pollutants can cause adverse health reactions in students, which somehow contribute to SBS. Traditional methods of indoor pollutant control in closed spaces involve the use of outdoor ventilation. Outdoor ventilation requires the intake of outdoor air, which must be heated or cooled to meet indoor temperature and humidity requirements. Therefore, a sustainable IAQ monitoring approach through potable living walls was chosen, focusing mainly on the humidity, VOCs, HCOC, CO_2, and CO values.

3. Living Wall Design

Design characteristics

The living wall consists of a specific type of aluminum bar having a particular area (1” × 4” and 1” × 2.75”) dimensions used to build a lightweight aluminum frame that bears the overall load of the structure. The Aluca bond strongly compressed the aluminum sheets to cover the overall bar structure, which was fixed on the wall. A plastic water reservoir (3.5’× 2’×1’) at the base of the living wall provided water to the plants, which fulfilled the aesthetic perspective of the living wall as well. Pot frames were screwed on an aluca bond sheet, and the non-biodegradable pots were affixed to it to make the wall eco-friendly. Plants were placed in the pots so that the filtration process could also occur. Two types of fans were used while fabricating the living wall. The first one aims to suck the air from behind the plants and guarantee ventilation. On the other hand, the second one was placed at the top of the wall to transfer fresh air to the room. The fans used behind the plants were 4” dia. with a capacity of 12 volts DC, whereas the second one at the top was 8” diameter holding a capacity of 220 volts. A power supply was used to connect the fans to the electric supply. For the flow of water through the indoor plants, the principal sub-primary funneling framework was laid, which was going through each column of a pruned plant. The primary lines of plastic material and sub-fundamental elastic material have been utilized with the parts to make the model economical. Pipes were associated utilizing a tee connecter to the furthest limit of each column. Moreover, the funneling framework was furnished with an opening precisely over each pot to shower water into the plant. Since the volume of the aquarium was large, two different aquarium filters were used. This was done to keep the fish alive, maintaining the oxygen level of water and keeping the water used for a long time. Native plants were picked to endure indoor lighting conditions and their capacity to further develop IAQ. Significant variables were considered while picking the plants for a venture, which included direction, environment, and light and wind openness. Although there are several plant species that can be used for living walls, the ones selected were strongly capable of reducing the VOCs and amount of air pollutants that cause illness and several health hazards with a dominant biofiltration process. Some of the common indoor plants that were used include snake plants, spider plants, dragon plants, arrowhead plants, and ti plants. The fabrication details and model description are shown in Figure 1 and Figure 2, respectively.

Figure 1. Fabrication phase (1) Bottom structure fame (2) Top cover of aluca bond sheet (3) Back view of fans placement at the top and center (4) Pots and plants (5) Irrigation pipe and (6) Aquarium and pump

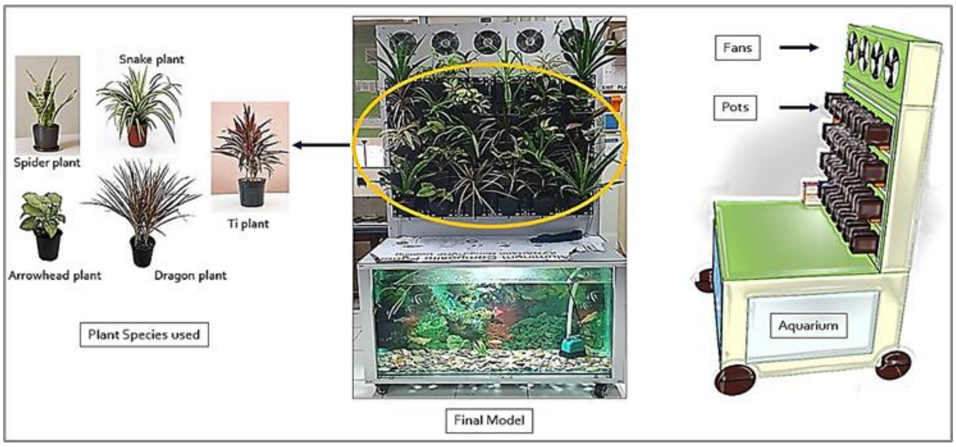


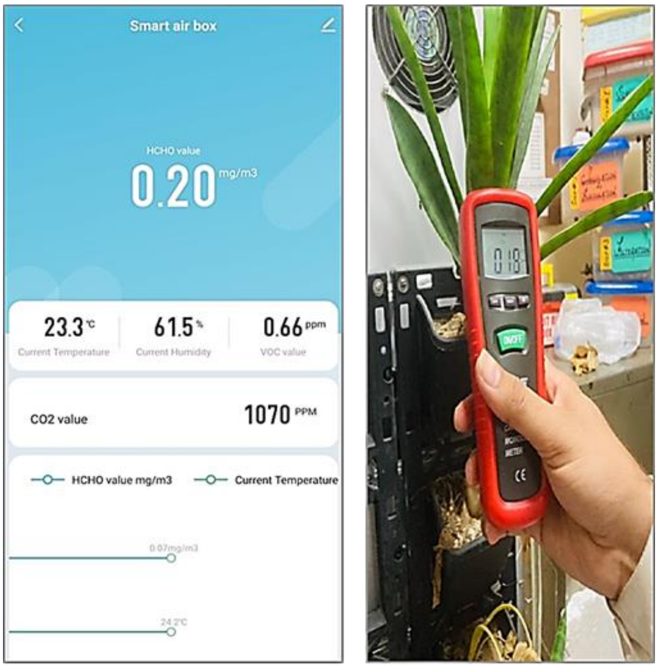
Figure 2. Model description

Measuring instruments

The testing, monitoring, and analyses were performed for ninety days (during winter) at intervals of 10 days. Readings were taken before and after the placement of the living wall in the laboratory. The portable living wall in this research was tested in an environmental engineering laboratory to assess its removal capacity pertaining to air contamination. Since wastewater testing was performed by other students in the lab during the study period, most processes involved toxic gas interactions, which caused contamination of the overall surroundings of the laboratory, in which VOCs were dominant. The air quality measurement instruments used involve a Smart Air Box, which monitors HCOC, VOC, CO_2, temperature, and humidity. It accurately measures the indoor air quality levels and clearly shows the changes in air quality. A CO Meter Device was used to detect the presence of CO and measure the concentration levels between 1-1000 parts per million (ppm). Similarly, a humidity meter was used to check humidity and temperature for regular intervals of time.

4. Results and Discussion

The readings taken at different time intervals through the Smart Air Box and CO meter device in the environmental engineering lab after the placement of the living wall can be seen in Figure 3.



Smart Air Box CO meter

Figure 3. Readings taken through Smart Air Box and CO meter

Temperature and humidity variations

Winter in Karachi ends in January; therefore, a minor variation in the temperature can be noticed after January. However, the overall indoor temperature remained constant after the placement of the living wall, as shown in Figure 4. On the other hand, the humidity of the lab did not vary with time. The humidity values remained in the range of 62-65% throughout, as shown in Figure 5.

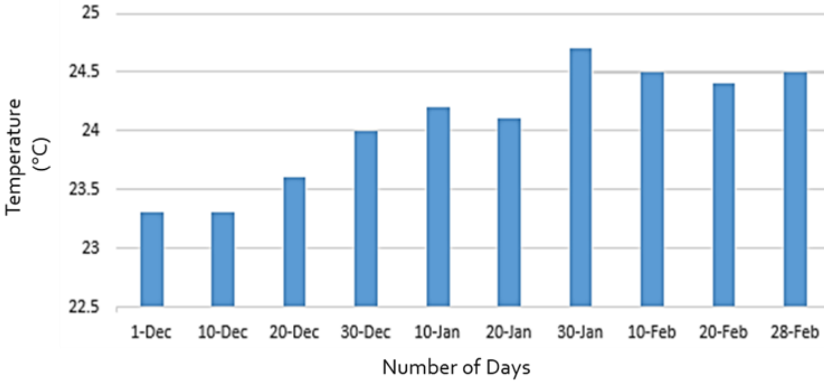


Figure 4. Temperature readings before (1st Dec) and after the placement of the living wall

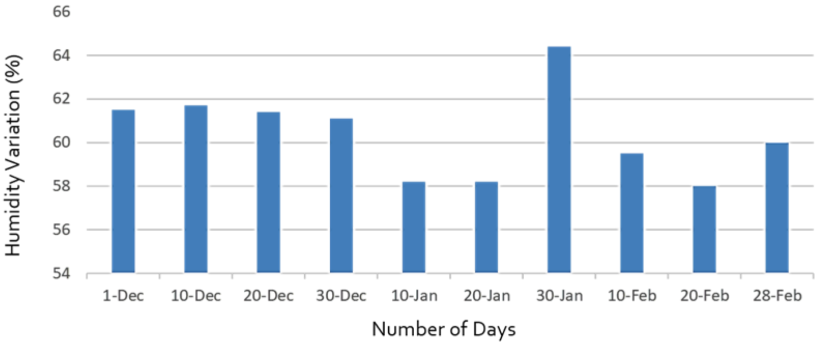


Figure 5. Humidity readings before and after the placement of the living wall

Volatile organic compounds (VOCs)

The living wall showed prominent outcomes in reducing air contaminants and VOCs. Prior to installing the living wall, the VOC value for the lab was found to be 0.66 ppm on 1st December, which was drastically reduced to 0.01 ppm by February 28, as shown in Figure 6. This ensures that the placement of living walls could help reduce VOCs. Since VOCs have been found to be associated with COVID-19, the study outcomes ensure that placing the proposed living wall at a particular affected place, such as hospitals and COVID-19 wards, could mitigate its risk of spread. However, more profound studies with such setups are required specifically focusing on the compounds that lead to COVID-19.

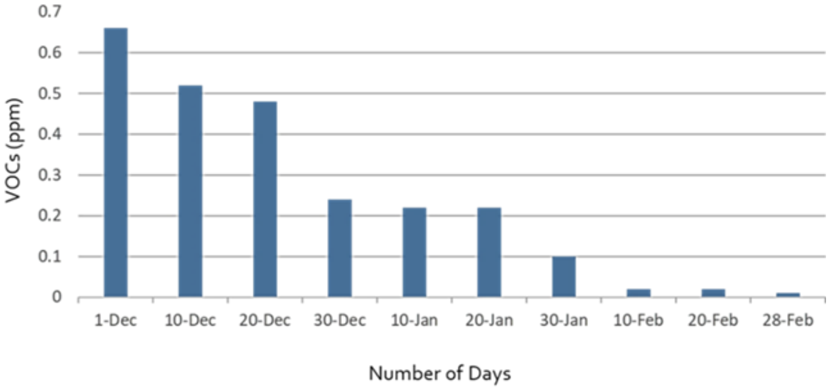


Figure 6. Variation in VOCs before and after the placement of the living wall

Hazardous chemicals of concern (HCOC), CO_2 and CO

The living wall has shown prominent results not only for maintaining the temperature, humidity, and VOCs of a confined space but also has proven to be very efficient in reducing the HCOC, CO_2, and CO values. Formaldehyde is released into the atmosphere mainly due to biomass combustion. In the current study, the concentration of HCOC was slightly noticed as the study area was the environment lab where combustion usually occurs while performing the experiments. However, after the placement of the living wall, the concentration levels of HCOC decreased from 0.20 to 0.01 ppm, as shown in Figure 7. Similarly, the CO_2 concentration noticed before the placement of the living wall was found to be 1070 ppm. Such levels of CO_2 are reported to have caused complaints of drowsiness and poor air quality. However, the study outcome assured a drastic drop in CO_2 concentration to 528 ppm, as shown in Figure 8. Finally, CO does not poison plants since it is rapidly oxidized to form carbon dioxide, which is used for photosynthesis. Although the CO values were found to be in the permissible range before the placement of the living wall, a drop in its concentration was also witnessed after the installation of the living wall. The concentration of CO was found to be 0.20 ppm before and 0.01 ppm at the end of the study, as shown in Figure 9.

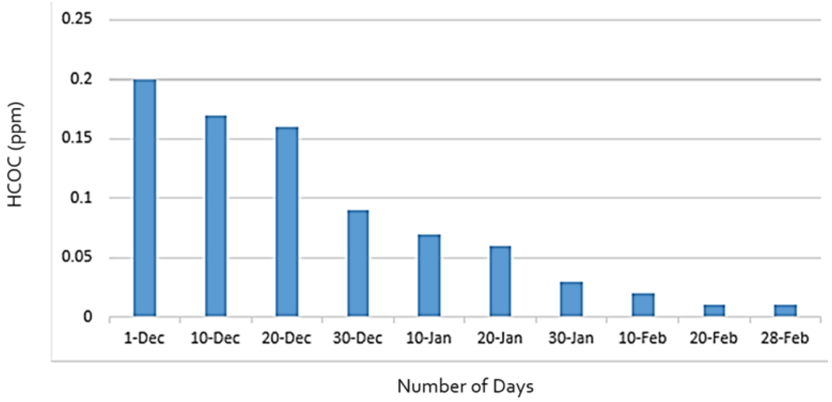


Figure 7. Variation in HCOC before and after the placement of the living wall

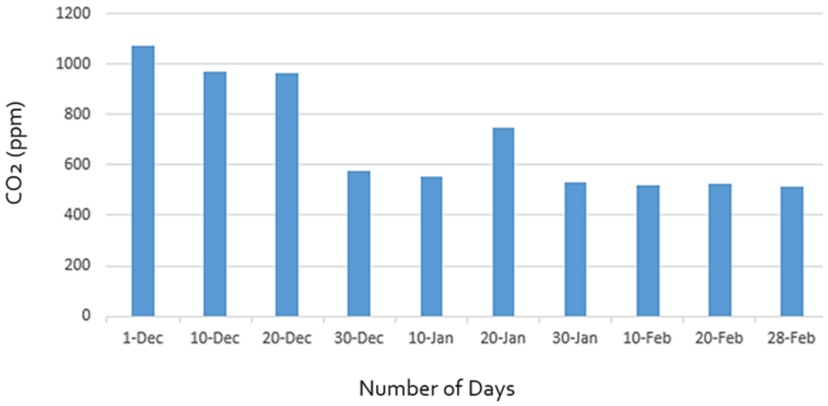


Figure 8. Variation in CO_2 before and after the placement of the living wall

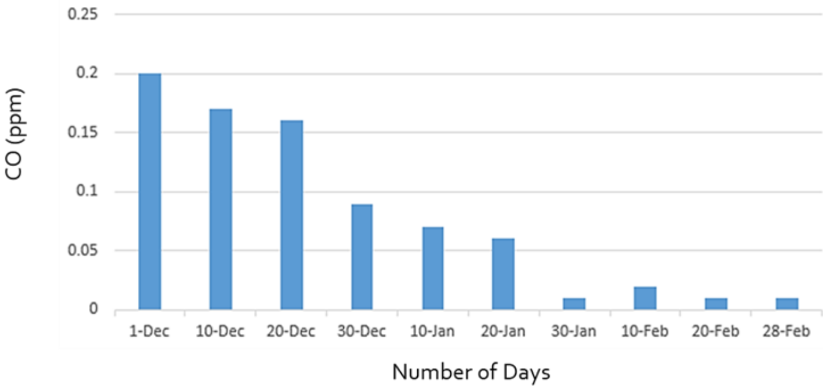


Figure 9. Variation in CO before and after the placement of the living wall

Karachi's winter season ends in January, hence there is a little variation in temperature following that month. On the other hand, Figure 4 shows that the inside temperature remained consistent when the living wall was built but there was no change in the lab's humidity over time. Readings for humidity were constant throughout the day between 62% and 65%. Air pollutants and VOCs were significantly reduced by the living wall. The lab's VOC value was found to be 0.66 ppm on 1st December before the living wall was erected, but it was significantly decreased to 0.01 ppm by 28th February as shown in Figure 6. As a result, it is recommended that installing living walls might help with VOC abatement. Here VOCs have been associated with COVID-19, the study's findings ensure that putting the suggested living wall in a particular location where the disease is an issue, like hospitals and COVID-19 wards, this living wall could help retain the disease from spreading. However, more in-depth studies with such conditions are required, focusing in particular, on the constituents that cause COVID-19.

5. Conclusions and Recommendations

Plants, as living walls, have been proven to reduce the air pollutants present in a closed confined space. The results showed a reduction in the VOC, CO_2, CO, and HCOC levels, which are viewed as exceptionally destructive to human well-being and efficiency as it contains unsafe compounds. Additionally, COVID-19 spread has been reported mainly due to exhaled breath, which somehow relates to volatile organic compounds (VOCs); thus, such a drastic drop in VOCs ensures that such living walls could help reduce the spread of COVID-19 to some extent. Furthermore, it has been noticed that such walls are extremely compelling in temperature, dampness, moisture, and noise control of a space, which is likewise one of the variables found. A living wall is a coordinated innovation, as it involves every part required for the growth and development of plants. It empowers work efficiency by reducing stress levels. Ideally, it can be regarded as a lightweight sustainable structure for indoor situations based on its simple cum portable design fulfilling the volume of the room and the number of inhabitants available there to work. Since the study was conducted in winter, the results proved to have reduced dryness.

This research can be further extended by taking into view the following considerations, i.e., (i) CO_2 levels: The CO_2 levels should be kept minimum because it increases the risk of viral airborne transmission in enclosed places, herein CO_2 levels were not checked, however, it is suggested to keep the track of CO_2 for similar research works (ii) lighter structure: The alucabond sheet used to develop the bio wall's structure makes it fairly heavy in terms of portability, however, this material can be replaced by a lighter material to make the structure more sustainable, for instance, "wood". It will also be a good solution for low-income groups with varying settlement environments, construction capacities, and building quality, lastly (iii) IoT (Internet of Things): In the current study, the biowall was manually monitored which can be updated to a smarter option by networking it to an IoT based system.

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