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Nature Based Solution for indoor air quality treatment

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Nature Based Solution for indoor air quality treatment

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Abstract. Plants have the ability to absorb and degrade VOCs (volatile organic compounds). Foliage can intercept particulate matter (PM) and thus, help to reduce its concentration in the air. Plants can be used as filters in indoor conditions adding an ecosystem service to the decorative purpose. A plant-based air filtration system that actively improves indoor air quality has been developed and installed at a students' residence at Brunel University, London. This unit replaces an existing window with a mini-greenhouse containing upwards of 30 plants and is connected to an air circuit to treat the indoor air. A monitoring plan is collecting data on the performance of the solution until at least the end of 2021. Preliminary results are presented, which indicate good effectiveness at reducing tVOCs and lower efficiency at reducing PM.

1. Introduction

In modern buildings exchange of air between inside and outside is reduced for energy efficiency purposes. In recent years increased attention is being paid to the fact that many household objects, i.e., office equipment as well as construction materials, emit pollutants into the air, a process referred to as outgasing. The presence of people and pets also has a detrimental impact on indoor air quality. As a result, it is not uncommon to find that the indoor air in buildings can be more polluted than outside air even in dense urban environments [1, 2]. At the same time, modern people spend increasingly more time indoors [3]. Therefore, the quality of the indoor air is a major concern in terms of health and well-being for people [4].

Several studies have demonstrated the capacity of plants to absorb and remove pollutants from the air [5, 6, 7]. These pollutants are commonly measured in terms of volatile organic compounds (VOCs) or as particulate matter (PM) suspended in the air. A system (herewith called Casetta) was developed to use the natural ability of plants to filter air to remove air pollutants from indoor spaces by cycling air in a controlled manner through dense plant foliage. This nature-based solution (NBS) developed by alchemia-nova GmbH is in essence a small conservatory filled with plants that can be mounted in place of a window, thus providing air filtering services while being a decorative element. Air ducts and ventilators actively cycle the indoor air through this plant-based filter.

This paper presents some of the results observed while testing the Casetta under a real-life use scenario at a students' residence at Brunel University in London. The study was conducted in the course of the project ReCO_2st (Pr. Nr. 768576) funded by the European Commission under the Horizon 2020 program.

2. Materials and test set-up

The nature-based air filtering system - Casetta - services one section of a dormitory building at Brunel university, consisting of a corridor with 5 attached sleeping rooms and a kitchen, a toilet and a showering room. The total area of the affected rooms is slightly over 90 m^2, the air volume of that building section is almost 200 m^3. The air filtering system is attached to the staircase area leading to the corridor and has air ducts extracting the air and returning the air to opposite sides of the corridor. Figure 2 shows a floor plan with the location of the Casetta unit in relationship to the rooms it services.

The Casetta unit replaces a window section of 2,5 m height by 1 m width. It has an internal volume of 1.600 litres. It contains four levels of plant containers, arranged in a way such that the air pass through several layers of foliage before exiting the system. The containers hold 7 -10 plants selected for their ability to absorb VOCs, produce good dense foliage and offer side benefits such as humidification of the air and pleasant optics. Plant foliage occupies about 1.000 litres of the volume inside the Casetta. The plants are cultivated in a hydroponic system composed of a substrate of expanded clay. Irrigation is provided by an automated watering system.

The air circulation is provided by two duct fans, one for inflow and one for outflow. These fans are set to deliver an airflow of 280 m^3/h, so an air-exchange rate of approximately 1,4 times per hour is achieved. Air exchange between the dormitories and the corridor occurs by usage of the facilities (residents open and close the doors) and slits on the doors. The Casetta air filtering system extracts and delivers the air directly only to the corridor.

By forcing the air to move from the bottom upwards, the stomata of the plants, which are located mostly on the bottom side of the leaves, are exposed directly to the prevailing air current which facilitates the uptake of VOCs. Dense foliage can also help to reduce the load of particulate matter (PM) in the air, mostly through adhesion on the waxy surface layer of the plants [5, 7]. The filtered air is then pushed out at the top part of the unit and guided back into the room.

The Nature based solution of the Casetta type was installed in the later part of the year 2019 and was commissioned in January 2020. Sensors at the inflow and outflow points of the air ducting inside of the room provide data to evaluate the performance of the unit. Measurements for PM1, PM2.5, PM10, tVOCs, CO2 relative and absolute humidity and temperature in several instances relating to the NBS technologies were taken with sensor sets from Cloud Garden (https://cloudgarden.nl/en/product/climate-sensor/). That data was validated with custom sensors made by alchemia-nova based on Amphenol SM-UART-

Figure 1: View from the exterior of the Cassetta type NBS air filtering unit at Clifton Hall, Brunel University, London

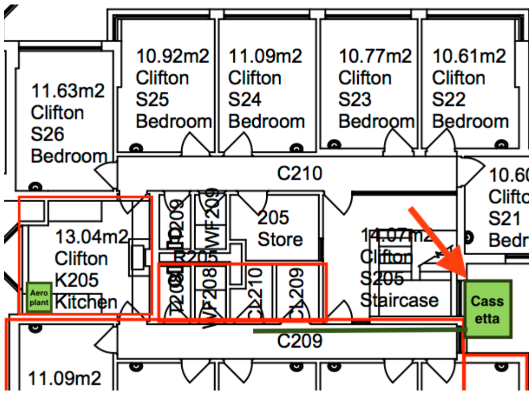

Figure 2: Floor plan of the 3rd. floor of the building. The NBS cassetta takes up the space of a window frame on the right.

04L (for PM) and Amphenol MICS-VZ-89TE (tVOC) sensors. The parameters PM (1; 2,5 and 10 μm), total VOCs, temperature and relative humidity are measured and logged every 10 minutes by the sensor suit integrated into the NBS unit. These values will be validated by independent sensors (Airthinx IAQ from Airthinx Inc.) provided by the Brunel test site which also includes CO_2 measurements.

Due to the Covid pandemic the normal activities at Brunel University and the campus dormitories were severely disrupted. For almost all of 2020 until now the test site was not inhabited. As a result the permanent data collection is not reflective of the intended use scenario. However, this circumstance was used to perform a controlled experiment described here: pollution loads (spikes) were introduced artificially in a concentrated manner in brief time intervals. The pollution load with the NBS unit turned on and then with the unit turned off were measured and analysed. Normal sized incense sticks were burned for the duration of 10 minutes in the corridor, which were handheld by one person and slowly carried up and down the corridor to achieve a homogenic distribution of the air pollutants in the whole volume. After 10 minutes the pollution sources where removed from the area and the rooms were left empty. Data was collected for several hours afterwards to obtain pollution declination curves. This procedure was repeated 4 times, two times with the Casetta turned on, two times with the Casetta turned off. The sample rate of the sensors was set to an interval of only one minute, to get a denser monitoring during these few days.

3. Results

The data plots obtained during the artificial pollution spike experiments show the typical quick increase and slow decline in pollutants as expected. Figure 3 shows the behavior of the particulate matter (PM) parameters when the Casetta was turned on, while Figure 4 shows the PM decline curve when the Casetta was turned off. There is only a slight difference in the time needed for the PM levels to reach approximately the same background levels as could be found before the pollution spikes were introduced. It is notable that the maximum peaks for PMs were lower when the Cassetta was turned on. Figures 5 and 6 show the pollution curves for tVOCs when the Casetta was on and when off. Here the speed in the decline of the tVOCs is significantly faster when the Casetta was turned on (some 45 minutes until background levels are reached), than when the Casetta was turned off (75 minutes). The maximum pollution peak is also much lower when the Casetta is turned on.

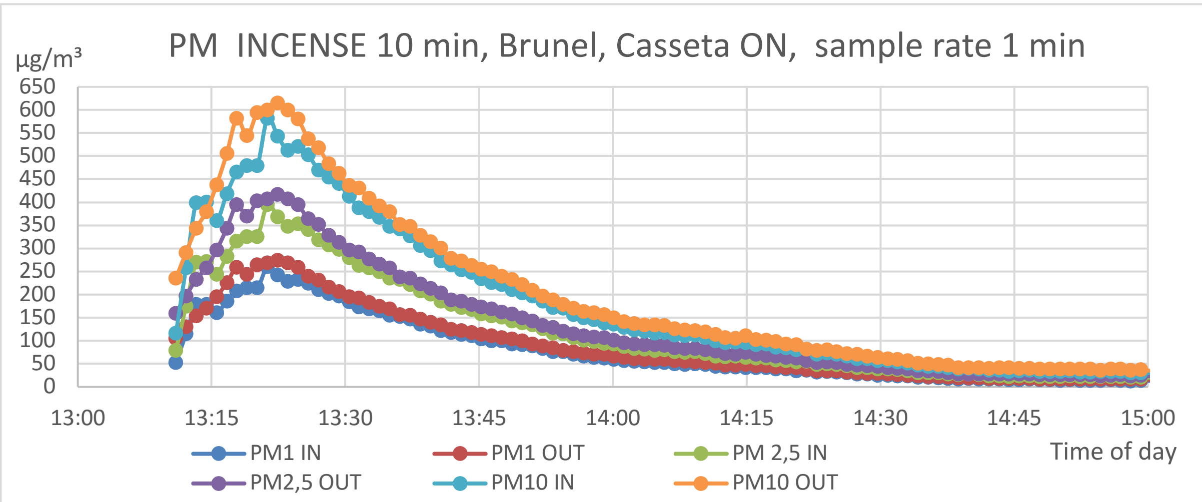

Figure 3: PM loads in the room air during the artificial spike tests plotted against the time of day for the variant with the Casetta turned on. "In" refers to air flow into the room, "out" refers to the air outbound from the room into the Casetta measured 5 cm in front of the inflow and outflow exhaust grills.

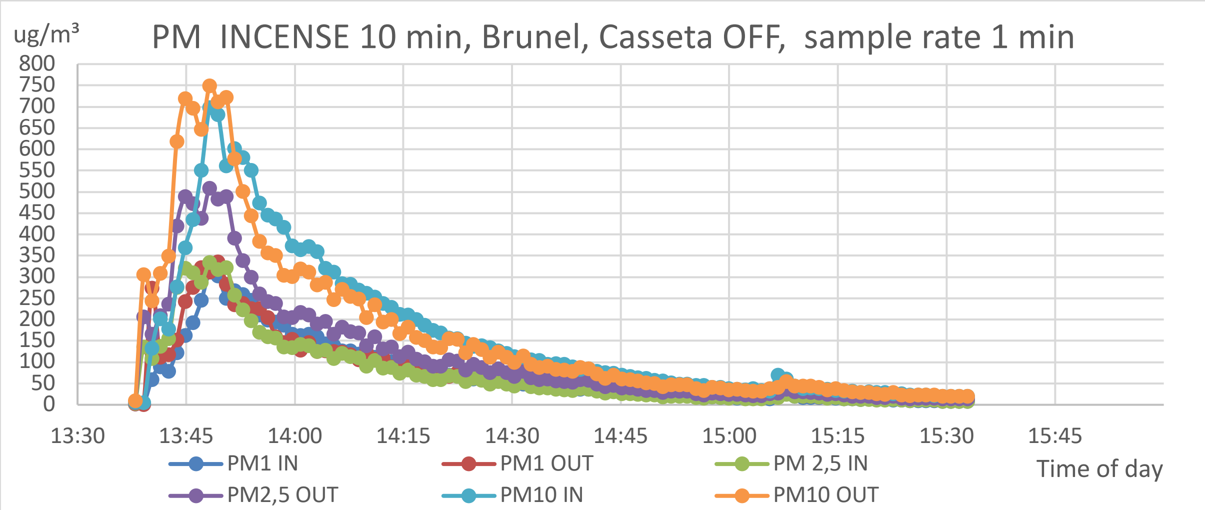

Figure 4: PM loads in the room air during the artificial spike tests plotted against the time of day for the variant with the Casetta turned off. "In" refers to measurements at the air inflow point without air flow, "out" refers to measurements at the point where air would usually flow out of the room into the NBS.

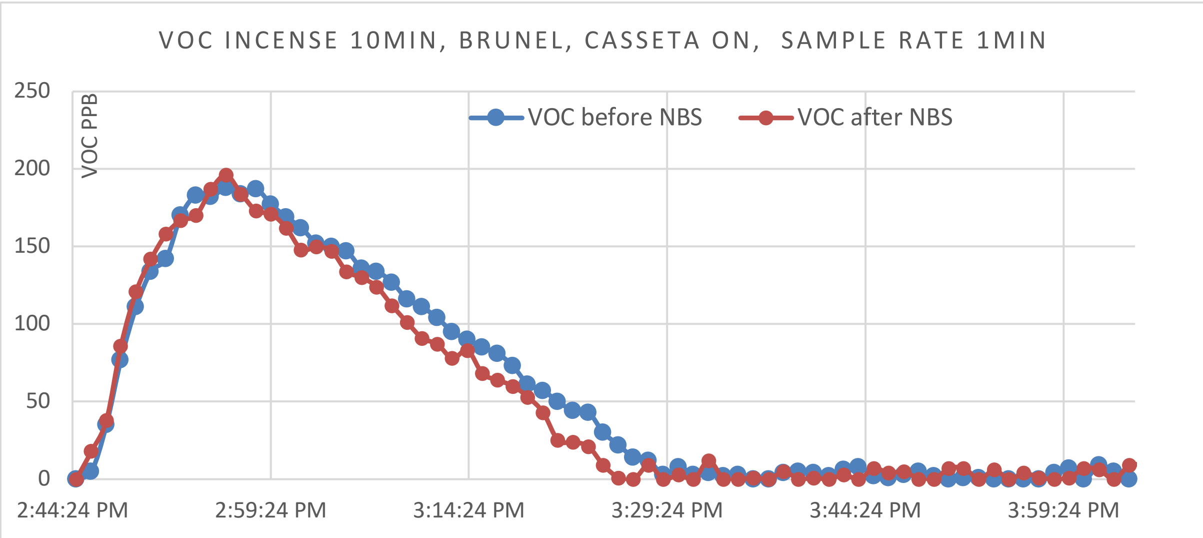

Figure 5: tVOC loads in the room air during the artificial spike tests plotted against the time of day for the variant with the Casetta turned on.

The results are also summarized in table 1 in terms of reduction of pollution loads per minute. In this table also the summary values for CO_2 are shown, indicating that CO_2 reduction is very notable. Further, the Casetta adds between 2 to 6 kg of water per day to the air that passes through the unit, depending on the temperatures and incidence of solar radiation. The water is replenished via an automated watering system.

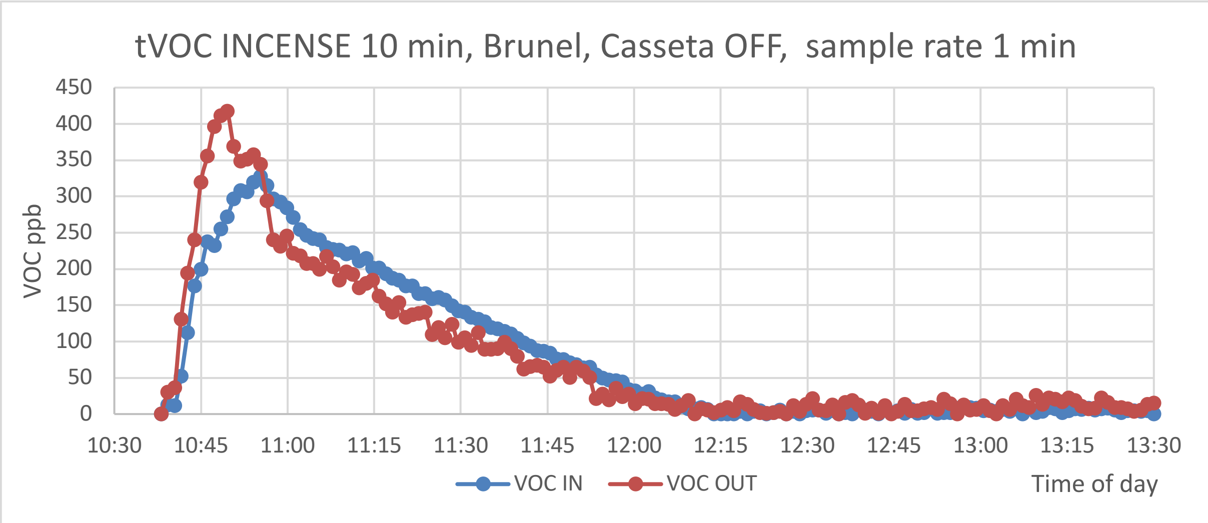

Figure 6: tVOC loads in the room air during the artificial spike tests plotted against the time of day for the variant with the Casetta turned off. "VOC IN" refers to measurements at the usual air inflow point into the room, while VOC OUT refers to measurements at the point where normally the air is sucked out of the room.

4. Discussion

The results of the tests show that the NBS air filtering system is quite effective at reducing tVOCs from the air, while reduction of PM under the test conditions was less pronounced. The reason why PM removal was lower may be due to the timing of the experiments when the plants where slightly wilted due to insufficient maintenance of the plants due to Covid restrictions. In addition, the air flow may have been set at a level that was too high. The tests yielded several leads to find optimization potential in the design and operation of the unit. A new test series may be performed in the summer of 2021 to evaluate optimizations.

Table 1: Summary calculation of the air filtering performance of the NBS Casetta unit

	CASSETA OFF	CASSETA ON	Improvement in %
Average $PM_{2.5}$ decrease rate (ug/m³/sec)	4,14	4,38	5,8%
Average VOC decrease rate (ppb/sec)	3,90	5,46	40%
Average CO_2 decrease rate (ppm/sec)	12,84	22,98	79%

The Covid pandemic has prevented the study of the NBS air filtering technology under normal activity levels in the premises. In the uninhabited test rooms the background PM levels were below the recommended levels by the WHO for the best air quality (less than 25 $\mu g/m^3$ of air), the background tVOC pollution was also below recommended limits of 0,3 mg/m^3 [1, 8]. However, it remains to be seen if under normal usage conditions the air quality will be different than in this preliminary test. Spikes of tVOC and PM under normal usage of the premises are expected.

The reduction of CO_2 levels probably cannot be attributed to the effect of the plants alone, some fresh air infiltration through windows or doors due to the dynamic air flow caused by the air duct fans may have occurred.

The air humidity via evapotranspiration is significant and it must be considered in room ambient calculation. This increase in air humidity might be welcome during the heating season in rooms that tend to be too dry when heated. But it may be a concern in buildings where water condensation in walls may be an issue.

The Casetta can occupy the space of a window and thus functioning as a heat bridge. Care must be taken to ensure the integrity of the temperature isolation function of the system. At the same time, this little greenhouse with plants can be used to influence the room temperature in a clever way. The evapotranspiration activity of the plants has a cooling effect on the air, while direct sunshine entering the conservatory will produce some heat. In Europe it may be best to place the Casetta conservatory facing southwards in countries with long and cold winters and mild summers, while in southern countries with longer summers and plenty of sunshine it may be best to place the Casetta facing north, to make use of its cooling effect. East or West orientation may be viable options depending on site specific characteristics.

The operational weight of the unit at about 600 kg has to be considered for the building planning and installation. The multiple effects of the solution in terms of air filtering performance, aesthetics, design options, air humidification and thermal impacts should be planned to carefully extract highest benefits of the solution.

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