Monitoring of air quality and indoor environment in rooms occupied by houseplants

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ABSTRACT

The present paper describes an experimental test to identify the possible influences that the presence of plant species may have on the environmental quality of indoor spaces. For this purpose, a selection of houseplants with high air purification capacities was made based on existing literature (Sansevieria, Poto, Spathiphyllum, Ficus Benjamina, Kentia and Areca). Two adjacent rooms within an experimental building were used as test cells. The two rooms have similar characteristics. One room was occupied with the plants and the other was left empty. The test was conducted without human presence, except for maintenance tasks. Indoor environmental quality variables (T, RH and CO_2) were recorded every 10 minutes during the whole period of the experiment. In addition, spot measurements of formaldehyde and volatile organic compounds were also included. From the analysis of the results recorded by the sensors it is concluded that the presence of houseplants can reduce the concentration of VOCs. The conclusions are less clear for the CO_2 measurements, due to the uncertainties identified. Nevertheless, it was detected that factors such as plant density, irrigation, ventilation, sun exposure and the type of substrate and specimen, influenced the test. The results such as the increase in CO_2 when placing a high number of plants with organic substrate or the good performance of most species to reduce this pollutant, allow the design of a new detailed experiment with specific conditions on the number and type of plants, the type of substrate and the possibility of introducing pollutants in a controlled way.

KEYWORDS

Nature Based Solutions, Indoor Environmental Quality, Indoor Air Quality, Houseplants, Pollutant reduction

1 INTRODUCTION

In the current scenario of energy emergency caused in part by excessive consumption of buildings (European Parliament and UE Council, 2018), retrofitting operations aimed at improving their efficiency are being promoted across Europe (European Commission, 2020). These operations are proving beneficial in terms of reduced consumption and improved comfort, but negative impacts on indoor air quality correlated with lower building air exchange rates after retrofitting have been identified (Broderick et al., 2017; Dovjak et al., 2020).
The accumulation of some contaminants indoors can pose a health risk. Some wood construction materials, disinfectants, combustion gases and tobacco release components such as formaldehyde. This compound can remain for months in hot spaces with high relative humidity (Armijos Moya et al., 2021). It has been proven that certain potted plants can retain, metabolize, evaporate, or implement some action to reduce contaminants, this type of decontamination is known as phytoremediation. In Delgadillo-López paper is specified which plant species can reduce certain pollutants and by which specific mechanism (Delgadillo-López et al., 2011). There are several studies in this regard, in (Wolverton et al., 1989) the capacity of different domestic plants to reduce formaldehyde, benzene and trichlorethylene is quantified. In (Armijos Moya et al., 2021) the results indicate that the substrates have a greater capacity to reduce formaldehyde while the plants have a greater capacity to reduce CO_2.

A preliminary study to monitor the influence of plant species on indoor air quality is presented here as a supplement to be considered for incorporation into ventilation strategies. The results provide guidelines for the design of a future, more in-depth experiment to quantify the potential for pollutant reduction in the indoor environment using plants.

2 METHODOLOGY

Indoor Environmental Quality (IEQ) of two adjacent rooms was monitored by recording comfort conditions (humidity and temperature) and air quality (concentration of CO_2, formaldehyde and Volatile Organic Compounds). The study covers three recording periods, the first one allows to know the initial conditions of both rooms, the second one determines the effect in terms of CO_2 and temperature when adding a group of plants to the interior of one of the rooms. During the third period, the individual performance of the included plant species has been studied, analyzing their impact on the presence of CO_2, formaldehyde and VOCs (Table 1).

Table 1: Monitoring Periods

Stage	Period	Plants	Irrigation	Ventilation
1.- Equality determination	29/06(19:00) - 06/07(17:00) / 2020	No	No	No
2.- Plants presence	23/07(00:00) - 05/08 (19:00) / 2020	In PR-01	1	Both rooms
3.- Species analysis	18/11(12:00) -23/12 (13:00) / 2020	In PR-01	4	Both rooms

The two rooms (PR-01 and NR-02) selected as case studies are located in an experimental house within the facilities of the Eduardo Torroja Institute for Construction Science (IETcc) in the city of Madrid. The city has a Continental Mediterranean Climate. The rooms have been kept without human presence during monitoring, except for maintenance periods that last from 5 to 42 min and may include watering, data downloading and window opening. These periods can be inferred from Table 1.

In terms of geometry, PR-01has a surface area of 6.46m² and an air volume of 16.15m³. The surface area of NR-02 is 7.68m^2 with an air volume of 19.20m³. PR-01 has facades to the south and east and NR-02 has facades to the north and east. The east facades of both rooms contain a 0.90 x 1.20m window. The north façade of the second room has a 0.60 x 1.66m window which has been kept closed and covered by a blind to reduce its thermal transmittance. Both spaces are connected to a living room located to the west (Fig.1).

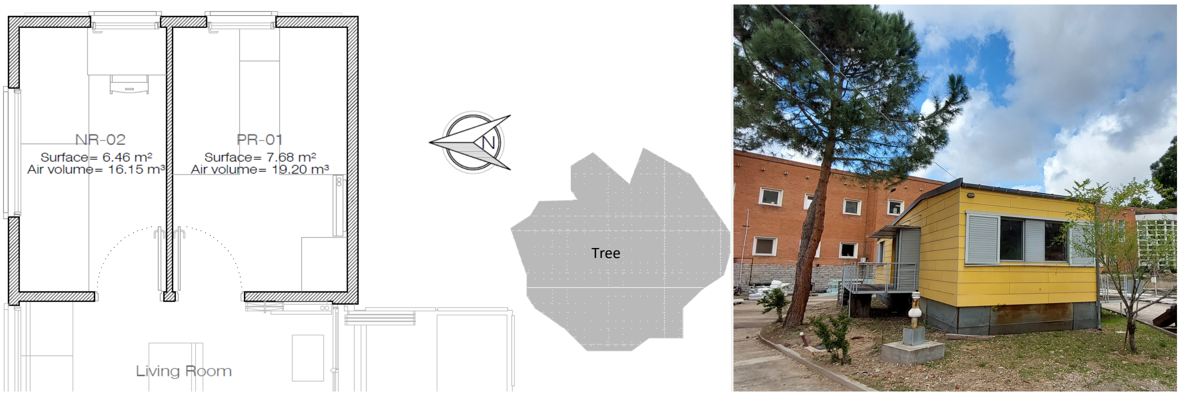

Fig. 1. Architectural plan and photograph of the east façade of the selected rooms

The instrumentation used for IEQ monitoring consists of two Wöhler CDL 210 sensors measuring CO_2, temperature and relative humidity with an accuracy of ±50ppm (range 0-2.000ppm), ±0.6ºC (range -10 a +60ºC) and ±3.0%(5-95%), respectively (Wöhler, 2020). in In the second phase of the study monitoring of pollutants was also carried out by using passive tubes for the measurement of total VOCs (passive activated carbon tubes), and specifically formaldehydes (silica gel tubes impregnated with 2,4-dinitrophénylhydrazine). In the last phase of the study, two MICA Desk sensors have been used to measure the presence of VOCs with an accuracy of ±15 % and formaldehyde with an accuracy < 200 µg/m3 :±30µg/m3 ; > 200 µg/m3 :±20% of the measurement (Inbiot, n.d.).

An initial week of monitoring has been established to check whether the indoor conditions of the proposed rooms were similar in terms of comfort and CO_2 concentrations. During this period, no vegetation was included in any of the rooms. The existing equality in the preliminary conditions allows to create a starting point for estimating the influence of the incorporation of houseplants during the second stage.

In the second stage of this study, plants were placed inside room PR-01 and the CO_2, temperature and humidity of the indoor environment of both spaces were monitored. Thus, the role of vegetation on air quality and thermal environment was estimated (Fig.2). Additionally, monitoring of pollutants (VOCs and formaldehydes) was carried our using passive tubes.

Fig. 2. Placement of plants in PR-01 during stage 2.

The plants were selected for their capacity to absorb pollutants, according to the study held by (Wolverton et al., 1989). The *Real Jardín Botánico* from Madrid provided 30 houseplants through the LIFE2017 project *My Building is Green* (Consejo Superior de Investigaciones Científicas et al., 2018). The species selected were 6 Sansevieria, 6 Poto, 6 Spathiphyllum, 6 Ficus Benjamina, 3 Kentia and 3 Areca plants, 70-90 cm high (Fig.3). All pots contain an organic vegetable substrate (volume around 0.0026 m³).

Sansevieria	Poto	Spathiphyllum	Ficus Benjamina	Kentia	Areca

Figure 3: Vegetable species included in the study

In the third stage, the number of plants within PR-01 is reduced (six per test) in order to carry out an individual analysis of the plant species. The temperature and the prescence of CO_2, VOCs and formaldehyde in the indoor air are recorded in continuous monitoring every 10 minutes.

3 RESULTS AND DISCUSSION

3.1 Equality determination

The interior of the rooms shows an acceptable equality in terms of CO_2 and temperature. Fig. 4 shows that the CO_2 concentrations in the rooms are very similar, with booth showing figures close to 400ppm practically during the whole monitoring period.

The temperatures present important differences in the schedule from 8:00 to 10:00, these can be attributed to the presence of a tree next to room PR-01 (See Fig.1), which casts a shadow that prevents the same temperature rise as room NR-02. Without considering these time slots, the average temperature difference between both spaces is 0.6ºC.

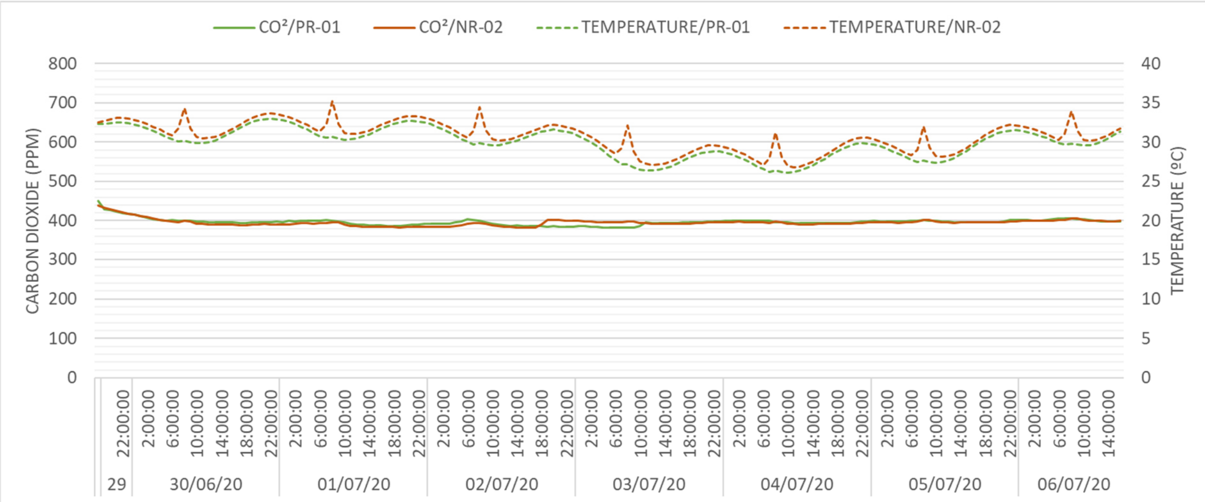

Figure 4. Stage 1, Comparison of preliminary conditions

3.2 Plants presence

The second stage of the analysis shows a higher CO_2 concentration in the room where the 30 plants were introduced. The maximum record of CO_2 in both rooms can be disregarded, due to the human presence of the preceding period (irrigation, window opening, preparation of the area or introduction of plants). Outside of these records, the inclusion of many plants means that PR-01 registers up to 129ppm, while NR-02 registers 31ppm at that time. Practically during the whole period, PR-01 registers its highest figures between 22:00 and 24:00 h. The increase could be due to the nocturnal release of CO_2 by vegetation and microbial activity due to the decomposition of organic matter present in the substrates. This result indicates the need to carry out tests using different types of substrates as in (Armijos Moya et al., 2021).

In addition, passive tubes monitoring showed a significant difference between the formaldehyde concentrations in both rooms. Room PR01 showed an average value of 14.45 microgr/m3, while room NR-02 showed an average value of 30.14 microgr/m3. The values obtained for VOC were below the detection limit, so differences between the two rooms were not detected.

The date of irrigation was the 29th at 14:00h, according to figure 5, the previous entry of the staff in charge has caused a peak in the CO_2 records within the PR-01 and a lower one in NR-02. As of this day, no more temperature peaks were recorded in NR-02, although a relationship with this action is not attributable. According to the figures, the humidity increases considerably on the day of irrigation in PR-01 although later it presents lower peaks than in the first six days. In NR-02, the pronounced drops in humidity that occurred during temperature peaks disappear. During the rest of the week there is also a lower CO_2 concentration attributable to the reduction in temperature over the last few days. In PR-01 there is a correlation between humidity and CO_2, both present their maximum figures at similar times.

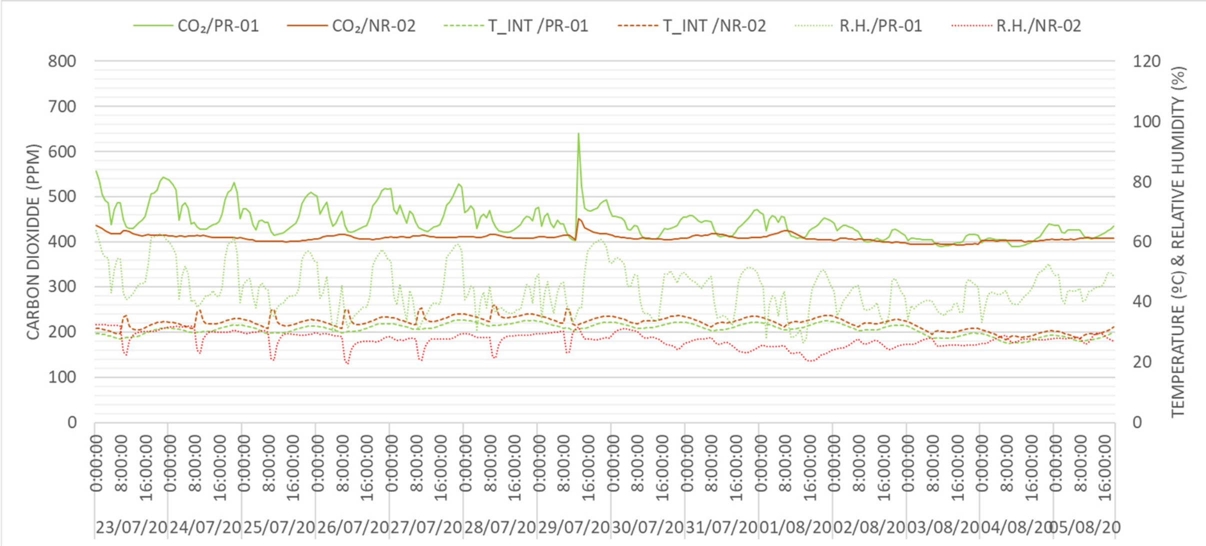

Figure 5. Analysis of the influence of the presence of plants in temperature, humidity and CO_2 concentration in the rooms during stage 2

The third stage, each plant species is studied individually. Every time a plant species was changed within PR-01 it was watered, with the exception of the entry of the *kentias* and *arecas*, because these plants were previously wet. In general, reducing the number of plants reduces CO_2 in the room. On average the decrease of this gas is only 1.6%, however, Fig. 6 shows that some species seem to have a higher reduction capacity. Despite its low initial impact at the end of the analysis period *Sansevieria* shows the highest CO_2 reductions, reaching reductions of up to 32ppm. Other species such as *Poto* and *Ficus benjamina* show smaller but more continued reductions. However, the results cannot be considered conclusive due to the precision of the equipment (±50ppm). In future tests it will be necessary to use more accurate sensors.

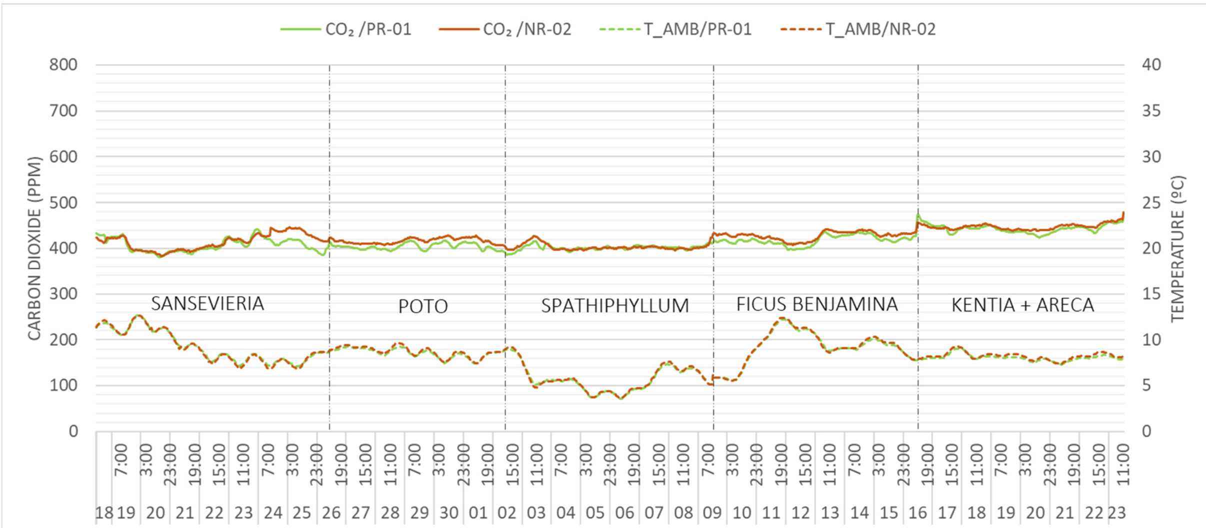

Figure 6. CO_2 and temperature analysis by plant species (Stage 3)

In terms of temperature, there is no variation between rooms. The reduced number of introduced species does not generate a significant variation in the degrees within the PR-01 environment.

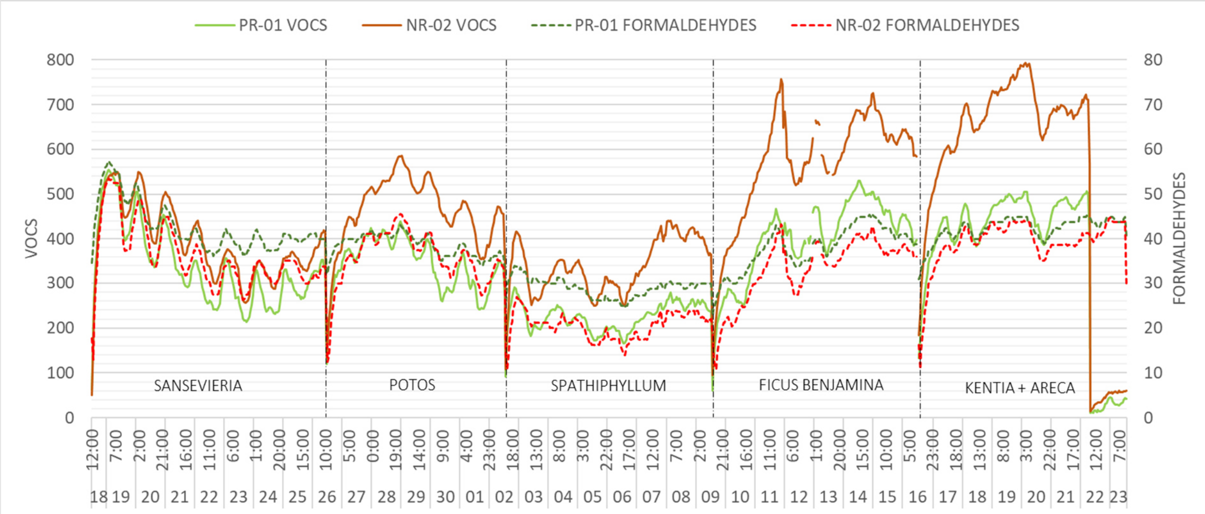

Figure 7.- VOCs and formaldehydes presence analysis by plant species

The third stage includes analysis of the concentration of formaldehyde and VOCs. Regarding the first one, during the presence of the *Poto* specie, the greatest reduction of the compound and the longest period where the NR-02 curve is above PR-01 curve were recorded. Most of the time, the room with plants has a higher concentration of formaldehydes. During the week of analysis of the *Spathiphylum* species, while the lowest indoor temperatures are present, the greatest average decrease in formaldehydes and the wider differences in the curves of the two rooms are recorded. For the new experiment it is proposed to incorporate mechanical systems to keep the temperature constant within the two rooms to eliminate this variable from the analysis.

Regarding VOCs, all plant species managed to reduce them. *Kentia* and *Areca* show the most favorable figures especially at the end of the week, while *Sansevieria* has the lowest reduction during the whole phase. However, the general reduction presented during the 5 weeks makes it necessary to consider a cumulative environmental improvement, where *Sansevieria* was the most disadvantage species as it was studied at the beginning of this stage.

It is important to note that in the monitoring of VOCs and formaldehyde there has been a loss of records, especially in the week where the *Ficus benjamina* species has been placed, as can be seen in Fig.7. Despite this, the trend of the records has allowed us to see the behavior of the pollutants.

4 CONCLUSIONS

This analysis allows the design of an experiment to perform a detailed analysis to determine the role of plants in improving air quality within a space. Equality in the preliminary experimental conditions is necessary for an efficient comparative analysis. The peak in temperature that occurs between 8:00 and 10:00 can easily be avoided by using a sunshade for the room exposed to solar radiation during that time or by eliminating this period of the comparative analysis, considering that the curves are subsequently equalized. It is also proposed to use active systems to maintain constant temperature within the rooms to eliminate this variable from the analysis. In the new experiment, door blower tests can be added to determine if air infiltration caused by the difference in the number and area of windows in the two rooms is involved in the recorded indoor temperature difference and determine if there is a fresh air intake that may be reducing CO_2.

The results of stage 2 show that including a large number of plants causes an increase in CO_2 during the night, while stage 3 showed that reducing vegetation can have positive results on the air quality inside the room. Although the case study shows acceptable levels of CO_2, it is assumed that the vegetation can behave positively in scenarios with high levels of this compound, which will be required for the new experiment. Furthermore, to counteract the increase in CO_2 during the night, ventilation can be added at that time. Regarding emissions originating from substrates, it is planned to use non-organic (inert) substrates, or to perform specific CO_2 emission measurements for substrates so that it can be differentiated from the share of plant species.

The results of stage 3 suggest that *Ficus benjamina* and *Poto* have the greatest capacity to reduce CO_2 within the room of the species used. *Poto* also performed best in formaldehyde reduction and recorded higher VOCs reduction than *Sansevieria*. In contrast, *Spathiphyllum* had the lowest performance in improving air quality with a low CO_2 and formaldehyde reduction.

It is necessary to establish characteristics such as leaf area index, stomatal resistance and growth of each species of houseplant in order to deepen and substantiate the results obtained in this study. Regarding the number of plants needed to obtain favorable overall results, monitoring days with low, medium, and high plant density can be carried out in the new experiment. The monitoring will be carried out before and after the incorporation of the plants during an annual period in order to evaluate the effect of the vegetation in the different seasonal conditions (summer, winter and temperate seasons). In this way, it will also be possible to discriminate the emitting effect of pollutants inherent in the room (furniture, paint, etc.). Additionally, continuous monitoring of VOCs will be carried out with contamination injections in both rooms. Under these conditions, the concentration will exceed the detection limits of the equipment and will permit to evaluate the air cleaning capacity of vegetation, in addition to the influence of temperature and VOC emissions.

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