ISBN 978-989-9121-31-7
2nd International Conference on Challenges in Engineering, Medical, Economics and Education: Research & Solutions (CEMEERS-23b)
Istanbul (Turkiye) Nov. 23-24, 2023

Impact of Irrigation with Treated Wastewater on Plant Development in a Natural Green Structure and Indoor Air Quality

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***Abstract*:** *Indoor air quality (IAQ) in buildings has a significant influence on the health of occupants, and one of the strategies to improve it is the use of plants, which need water to survive. However, due to water scarcity, it is necessary to rethink the use of drinking water (DW), and evaluate sustainable alternatives, such as treated wastewater (TWW).*

The present study aimed to verify the impact of irrigation with TWW on the development of plants in a green structure and on IAQ in a classroom. It was observed that the growth of Aloe vera irrigated with TWW was similar to plants irrigated with DW, while in the case of Scindapsus aureus, growth was superior in the plant irrigated with TWW. Regarding the IAQ, it was found that it was within the parameters defined in the legislation as adequate, with no significant differences being observed between the two monitored rooms

Keywords: *Indoor Air Quality, Natural Green Structures, Treated Wastewater, Water Efficiency;*

1. Introduction

According to data published by the United Nations (UN), atmospheric pollution is responsible, annually, for around 7 million deaths, with 90% of the world's population breathing air with levels of pollutants that far exceed the limits indicated by the World Health Organization.

Air pollution is not just restricted to outdoor air, as the indoor air quality (IAQ) of buildings has a significant influence on the health of the occupants of the spaces, both from a physical and psychological point of view.

Currently, a large part of the population spends long periods of time indoors, whether during school activities, sports, work, or rest periods at home, with an estimate of around 87% to

90% being spent indoors. Often, these environments do not have adequate air quality, as there are no appropriate ventilation, air purification, temperature, and humidity conditions. Poor indoor air quality can cause discomfort or even serious health problems, such as respiratory problems. In addition to affecting the health of occupants, several studies demonstrate that poor IAQ can have negative impacts on the cognitive abilities and productivity of occupants of these spaces [1], [2].

In recent years, there has been an attempt to make buildings more sustainable, reducing energy and water consumption and the environmental impact of material extraction. Factors such as thermal comfort, indoor air quality, ventilation, andvisual and acoustic comfort have been the parameters evaluated, aiming to determine their influence on the health, comfort. and productivity of occupants. In addition to these factors, there are others that are interesting to evaluate, such as the connection between building occupants and nature [1].

Some studies have shown that the application of natural green structures (NGS) inside buildings has benefited IAQ by eliminating significant amounts of volatile organic compounds (VOC), reducing carbon dioxide (CO2) levels by up to 25%, improving acoustics in the room (since plants absorb, diffract, and reflect sound), removing toxins, and balancing humidity. Furthermore, plants convey visual comfort, providing physical and psychological well-being, improving cognitive capacity, and stimulating the productivity of occupants [3].

However, like all living beings, plants need water for their survival. Each plant has a different need for water to develop, and the amount of water to apply to the plant varies depending on the season and climatic conditions.

Currently, periods of drought and water scarcity are becoming more frequent and longer. Population growth, forest clearing, urbanization, industrialization, intensive agriculture and livestock, and pollution are some of the reasons why fresh water has become scarce, forcing the search for alternatives to irrigation with drinking water (DW), which can satisfy the water needs of existing plants in both outdoor and indoor areas.

The development of circularity of use and the improvement of water efficiency constitute good water management practices, taking into account the increase in the frequency and intensity of periods of drought and water scarcity [4].

The efficient management of water resources has been greatly encouraged since the beginning of the 21st century, constituting one of the paradigms for the sustainability of socioeconomic development.

The efficient management of water resources has existed since the beginning of the 21st century as one of the paradigms for the sustainability of socioeconomic development. Applying the concept of sustainability to the use of water resources can mean optimizing the use of this resource in the present so as not to affect future generations.

On the other hand, technological developments are also important factors in this management, namely the construction of dams or the desalination of sea water. However, due to climate change, such strategies are not enough. Therefore, there is a need to adopt other management strategies in order to conserve existing water resources through the implementation of more efficient water use measures, namely its reuse.

The reuse of water has grown in recent years as a paradigm for the sustainability of water resources management.

In addition to being an adaptation measure to climate change, the use of Treated Wastewater (TWW) incorporates circular economy challenges in managing the urban water cycle and generates environmental, social, and economic benefits.

The use of TWW as an alternative to the use of DW will lead to a need for less abstraction and, consequently, lower water treatment needs for human consumption, allowing the satisfaction, with a reduction in resources/treatments, of the water needs of ornamental plants or other crops, as well as its use in other urban uses that do not require potable water [4]- [7].

2. Case Study

The present study aimed to evaluate the growth of a set of plants irrigated with TWW, which are part of an NGS located in a classroom, compared to other plants under the same conditions but irrigated with DW.

In addition to evaluating plant growth, the aim was also to evaluate the impact of this NGS on IAQ through monitoring various air quality parameters.

To carry out this study, it was necessary to choose two classrooms, both located at the Instituto Superior de Engenharia de Lisboa (ISEL), which is a higher education school.

The choice of rooms considered several criteria, namely the selection of rooms that housed a greater number of students, room area, and glass area with equal and identical solar exposure. Rooms facing the southwest of ISEL, located in Building G were selected and designated as Neutral Room (NR – room without plants) and Green Room (GR – room with plants (NGS). Both rooms have capacity for 50 people, with desks, chairs, two whiteboards (fixed to the wall), and a projection system (fixed to the ceiling). The GR also has an NGS, which was placed at the back of the room and in the side areas, as can be seen in Fig. 1.

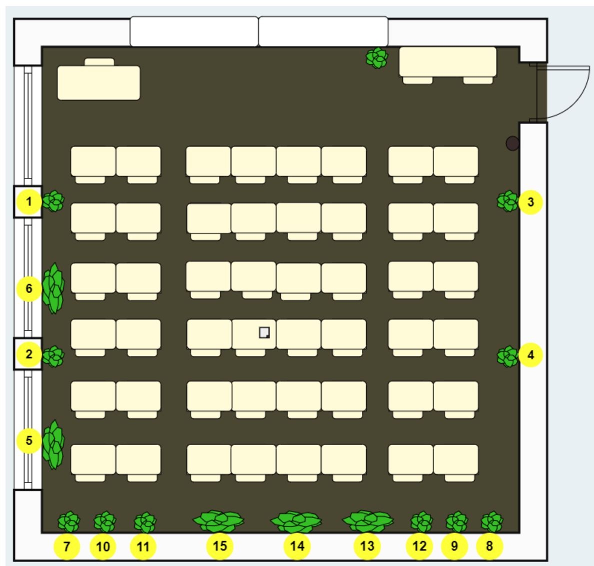

Fig. 1 Green Room plan with indication of the plants placement and the Indoor Air Quality measuring device, in the center of the room

The NGS was placed so as not to hinder the movement of the room's occupants or disturb them during classes. The NGS is made up of different elements, namely pots on the floor of different dimensions, pots suspended on the wall, and pots on the floor to support plant growth on trellis (Fig. 2). It is possible to check in Fig. 3 the arrangement of the plants in the GR.

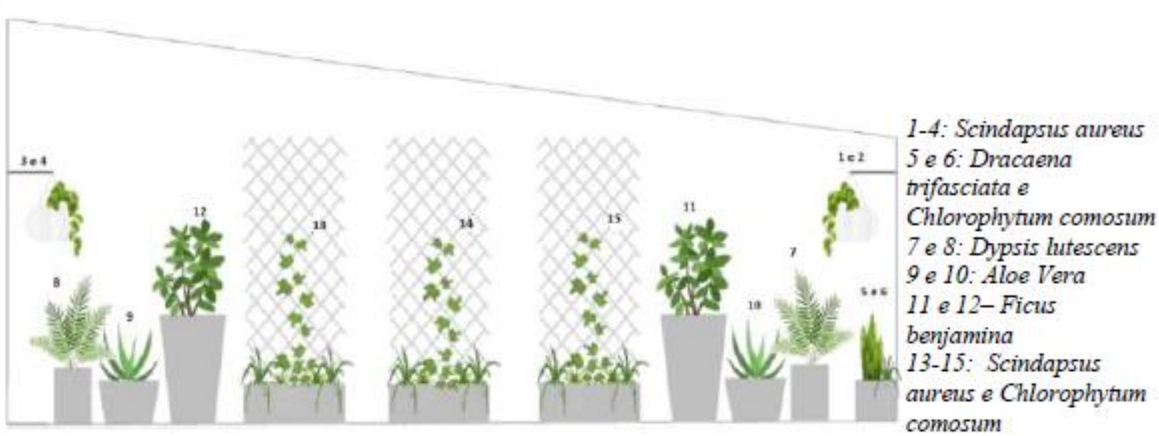

Fig. 2 Scheme of the green structure in Green R (adapted from [3])

The plants to be included in the NGS were chosen based on their recognized ability to absorb certain indoor pollutants, as can be seen in the study carried out by Wolverton et al. [8].

This study was carried out in two phases. In the first phase, the NGS plants were watered with DW (already existing in the room and always watered with DW), and IAQ monitoring was carried out. This monitoring was carried out in June, during summertime, in Portugal.

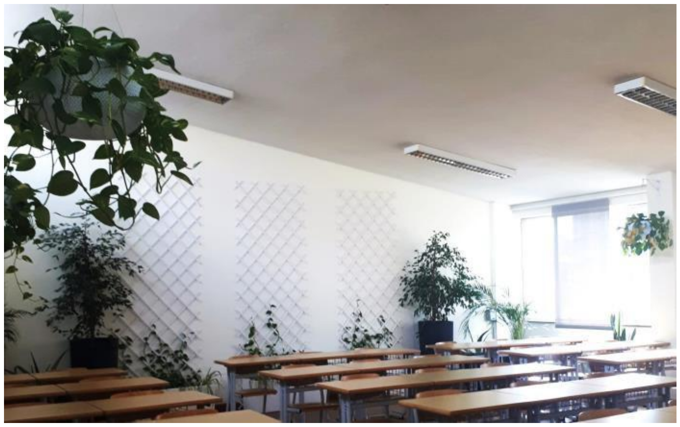

Fig. 3 Green Room photograph showing part of the Natural Green Structure

After this monitoring, the second phase began, where the plants were divided into 2 separate lots: 6 plants watered with TWW (plants 1, 3, 6, 7, 10, 11, and 14) and 7 plants watered with DW (plants 2, 4, 5, 8, 9, 12, 13, 15), Fig. 1 and Fig. 2, trying to maintain the same conditions in all of them (temperature, humidity, and sun exposure).

During the study, the plants were monitored through photographic records, carried out monthly, using Paint.NET software, which allows image analysis to be carried out to determine the areas of the plants (frontal projection of them) to verify whether TWW influenced, or not, their development.

In the future, a second IAQ monitoring will be carried outto check whether irrigation with TWW has influenced the air quality in any way.

2.1. Monitoring plant growth

Monitoring plant growth began in February 2023, and these were always watered with DW until June. In July, part of the plants began to be watered with TWW. The plants were divided, as previously mentioned, into 2 groups and marked, using colored flags in order to differentiate between plants irrigated with TWW and plants irrigated with DW.

Plant growth was monitored through photographic recording. In order to reduce parallax errors in measurements, the photographic recording was always carried out in the same way, that is, with the plant always in the same position and with the camera always at the same distance, horizontal and vertical, from the plant. The photographic record was made with the aid of a tripod and a *kapaline,* placed behind the plant, in order to reduce visual noise and increase the contrast of the plants' green, thus facilitating measurements (Fig. 4). Subsequently, the photographs were subjected to image analysis, using the program Paint.NET, which allows surface areas to be determined over the months.

On the white *kapaline,* colored squares measuring 10x10 cm were placed, which served as a scale to determine the number of pixels and determine the frontal areas of the plants (Fig. 4).

Fig. 4 Representation of how the photographic record was taken

3. Analysis and Discussion Of Results

During the monitoring carried out, the temperature in the GR presented values of 27.83±0.19 ºC and the NR presented values of 27.77±0.21 ºC. Regarding HR, in GR it varied between 53% and 56%, while in NR it varied between 55% and 61%.

Some studies point to a reduction in CO2, VOC, and PM2.5, parameters in the presence of NGS, given that plants have the ability to absorb some pollutants, while also helping to regulate temperature and humidity [9]–[15]. However, in the present study, when comparing the IAQ values of GR and NR, it was found that, in general, the values of the monitored parameters do not differ much from each other, being generally within the limits defined in Portuguese legislation, as appropriate.

Analyzing the variation in CO2 (Fig. 5), it is observed that, in some periods, the level of CO2 measured was slightly higher in GR . This effect may be due to the fact that the monitoring was carried out at the end of the day with reduced sunlight, meaning that the plants no longer carried out photosynthesis. Even so, the presence of plants did not negatively affect the CO2 values in the room.

Regarding the concentration of VOCs in the GR (Fig. 6), it was observed that with the door and windows closed, the concentration of this parameter increased significantly. This situation may be due to the fact that, before monitoring, the GR was cleaned (something that did not occur at the NR), and cleaning products were used, which are a source of VOC, and the negative influence of this type of products on this parameter can be observed.

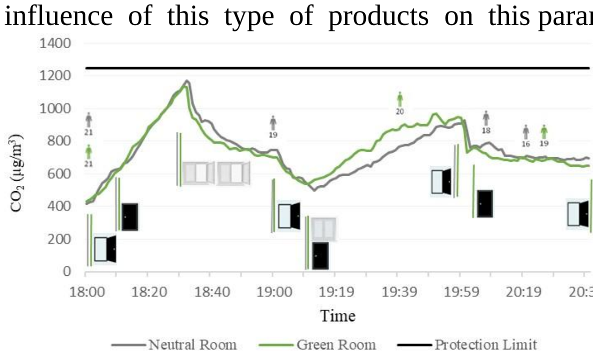

Fig. 5 CO_2 monitoring in the Green Room and in the Neutral Room

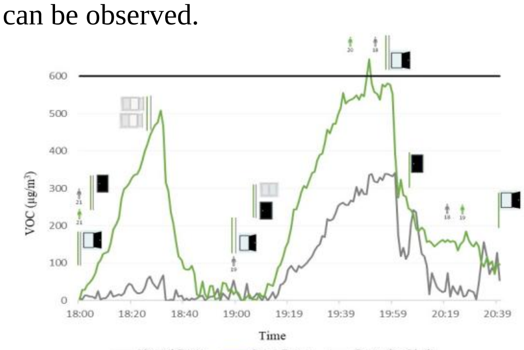

Fig. 6 VOC monitoring in the Green Room and in the Neutral Room

Regarding the analysis of PM2.5 concentration (Fig. 7), similar values were observed in the two monitored rooms. However, the values are slightly higher in the GR, which may also be related to room cleaning (with floor sweeping) carried out before monitoring.

When monitoring plant growth, the projected areas of two pairs of plants of the same species were compared, as previously mentioned, with one of the plants being watered with TWW and the other with DW.

The pairs of plants monitored were: plants 1 and 2 (*Scindapsus aureus*) and plants 9 and 10 (*Aloe vera*), with 1 and 10 watered with TWW and 2 and 9 watered with DW (see Fig. 8).

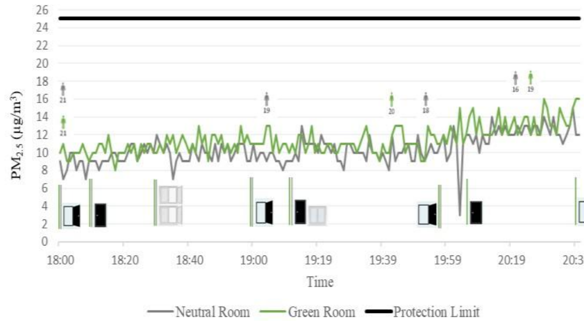

Fig. 7 $PM_{2.5}$ monitoring in the Green Room and in the Neutral Room

During the monitoring period, it was observed that the plants grew regularly overall, with occasional decreases in area due to the loss of leaves associated with the high temperatures that were felt in the rooms, during some periods, in the monitoring months. After the start of irrigation with TWW, similar growth was observed for Aloe Vera plants. However, regarding Scindapsus aureus plants, growth was much higher for the plant irrigated with TWW (see Fig. 8). This higher growth may be due to the fact that TWW contains nutrients such as nitrogen and phosphorus, which are not found in DW.

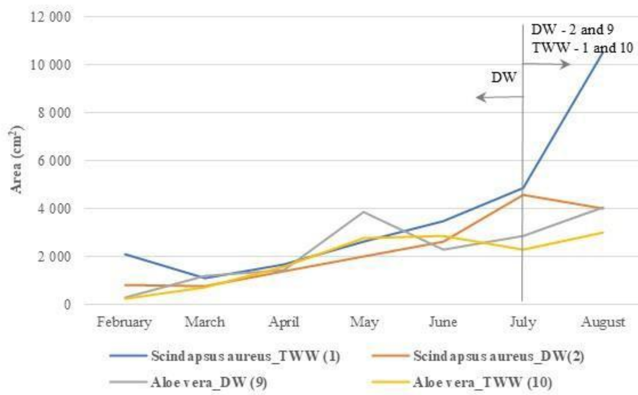

Fig. 8 Monitoring plant area evolution over time

4. Conclusion

The results obtained in this first phase of the study made it possible to verify that overall, the IAQ values are within the protection limit values of Ordinance No. 138-G/2021 for the monitored parameters.

Occasionally, there was a peak above the established protection limit value, referring to the VOC parameter in the GR, which probably occurred due to the cleaning carried out in the room before the measurements.

The CO2 and PM2.5 values were similar in both rooms, and no influence from NGS was observed. However, it was also possible to observe that the presence of plants breathing, at the end of the day, did not worsen CO2 levels in the GR.

It was also observed that opening the windows and door

contributed to significantly reducing CO2 and VOC concentrations in the rooms, evidencing the importance of natural ventilation for obtaining a good IAQ.

Regarding plant development, regular plant development was observed, with similar growth being observed for Aloe vera, but greater growth for Scindapsus aureus irrigated with TWW. However, it must be noted that the irrigation period with TWW is still short, meaning monitoring must continue in the coming months.

Overall, given the data analyzed, it can be stated that the use of TWW for watering plants constitutes a good alternative to irrigation with DW, contributing to the water and energy efficiency of institutions

5. Acknowledgment

The authors would like to thank the support and funding from the following institutions: ISEL – Instituto Superior de Engenharia de Lisboa, for the GreenAir project, IPL - Instituto Politécnico de Lisboa and to the Foundation for Science and Technology's support through funding UIDB/04625/2020 from the research unit CERIS.

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