Improving Indoor Air Quality through Nature-Based Solutions Using Treated Wastewater

Alexandra S. Rodrigues, Ana Maria Barreiros and Maria Idália Gomes

Abstract— The implementation of nature-based solutions (NBS) in urban environments, whether within or outside buildings, has been demonstrated to enhance biodiversity, indoor air quality (IAQ) and the well-being of the population, among other benefits. In the present study, conducted in a classroom of a higher education institution, the objective was to demonstrate how the implementation of a nature-based solution contributed to the improvement of the indoor air quality and, simultaneously, to increase awareness regarding the utilization of alternative water sources, such as the reuse of treated wastewater, for the irrigation of plants. During the study half of the plants were irrigated with treated wastewater, and the other half with drinking water, being plant growing monitored by image capture and image analysis. The utilization of plants in this context resulted in IAQ improvement and enhancement in water efficiency and the sustainability of buildings in urban areas.

Keywords - water reuse, treated wastewater, plant growing monitoring, indoor air quality.

I. Introduction

The implementation of nature-based solutions (NBS) has been demonstrated that contributes to an increase in biodiversity, improvements in air quality and an enhancement of the well-being of the population. As defined by the European Commission, NBS are technological solutions inspired and supported by nature that mimic natural processes and contribute to increasing biodiversity in cities, enhancing the resilience and sustainability of urban environments through systemic, efficient interventions tailored to the local context [1].

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Although indoor air quality (IAQ) in schools represents a significant issue, affecting approximately 64 million students in Europe, it remains a relatively neglected topic, even in the wake of the recent global pandemic caused by the SARS-CoV-2 virus. The exposure of building occupants to poor IAQ has been demonstrated to have direct effects on people's health, being the illnesses problems dependent on the exposure time and concentration of pollutants in the building [2], [3]. The United States Environmental Protection Agency states that poor IAQ inhibit the ability of individuals to perform tasks that require concentration, calculation, or memorization [4], [5]. This is due to a notable decline in individuals' ability to concentrate following an increase in CO_2 levels [6]. Similarly, studies have demonstrated that students exposed to elevated levels of volatile organic compounds (VOCs) and fine particles, including PM_{10} and $PM_{2.5}$, have exhibited analogous outcomes [4], [7].

The Italian Society for Environmental Medicine and UNESCO have presented a series of recommendations with the objective of improving IAQ in educational establishments. Among other measures, the use of plants as natural filters, capable of absorbing some indoor contaminants was proposed [7].

The deployment of non-potable water is of paramount importance, particularly considering this fact that water scarcity is already a reality in several regions across the globe. As reported by the United Nations [8], over two billion individuals reside in countries experiencing a considerable degree of "water stress". Portugal is one of the countries that faces considerable risks of water scarcity as a result of high demand and climate change, which is leading to an increase in the frequency and intensity of dry periods. The European Union has implemented a program entitled "A Blueprint to Safeguard Europe's Water Resources" [9], which is aligned with the Portuguese "Action for Adaptation to Climate Change", line of action number 3 [10]. It is important to note that the utilization of treated wastewater (TWW) represents an alternative source of water and a commendable practice in the field water management, with the objective of minimizing and addressing this significant issue [11]. The utilization of TWW, provided that it is treated at a level compatible with certain uses and does not present a risk to public health or to the environment, contributes to the sustainable utilization of water resources [12]. This increase in water efficiency, using TWW, promotes the consumption reduction of drinking water, preserving it for future uses, contributing to the circular economy.

The objective of this study was to implement an NBS in a classroom, at a higher education institution, and observe their impact on IAQ. The work involved the installation of a set of plants of several species, using TWW and drinking water (DW) for irrigation. During the study, the growth of the plants was monitored and analyzed by capture and image analysis, and the impact of the plants on the IAQ was observed. In the initial phase of the study, an enhancement in indoor air quality (IAQ) was discernible, albeit not statistically significant [13], [14]. However, as the plants grew, considerable improvement in IAQ was observed. It is noteworthy that the reuse of TWW in plant irrigation results in the promotion of urban sustainability, as it reduces the consumption of DW. Furthermore, this study aimed to raise awareness among the student community about the importance of utilizing alternative sources of drinking water.

II. Materials and methods

A. Characterization of the Study Site

Two classrooms were selected for the study (Green Room - GR and Neutral Room - NR), located on the second floor of building G of the ISEL Campus, facing southwest. The two classrooms have an area of 74 m2 and a glazing area of 12.84 m² on the southwest facade. The classrooms do not have air conditioning, and the door opens directly onto an outdoor patio on the northeast facade. An NBS was installed in the GR classroom, which is referred in this paper as a natural green structure (NGS).

B. Natural Green Structure

The NGS was installed on the back wall of the GR (the wall opposite the whiteboard) and on the lateral walls. The NGS was designed and installed considering the classroom's geometry, the arrangement of the furniture, and the minimization of restrictions on student movement.

The selection and number of plants to integrate the natural green structure were based on their recognized ability to absorb certain indoor pollutants [15]-[17], and the available classroom space.

In consideration of the number and variety of plants selected, a range of support structures was selected, including pots placed on the floor (of varying sizes and volumes), pots suspended from the ceiling, and trellises for climbing plants (Figure 1).

Initially NGS were watered with DW and from February 2023, half of the plants were watered with TWW.

C. Monitoring

Plant Growth Monitoring

The growth of the plants was monitored using photographic records over time. To minimize the impact of parallax errors on measurements, the recording process was standardized. This entailed maintaining consistent positioning of the plants and maintaining a fixed distance from the camera, both horizontally and vertically, to ensure accurate representation of the plants' dimensions. A tripod and a white kapaline were employed in order to reduce visual noise and enhance the contrast of the plants' green, thereby facilitating subsequent measurements. Subsequently, the photographs were subjected to image analysis using the Paint.NET program, which allows surface areas to be determined. This analysis was carried out over a 12-month period. Red squares measuring 10x10 cm were placed on the kapaline, which served as a scale to determine the number of pixels and aid in determining the frontal areas of the plants.

Indoor Air Quality Monitoring

The monitoring of indoor air quality was conducted in an identical and simultaneous manner in the two study classrooms (GR and NR) using portable direct-reading equipment. The Kaiterra Sensedge Mini 5-in-1 equipment was calibrated and positioned in the center of the classrooms. The following parameters were monitored: carbon dioxide (CO_2), total volatile organic compounds (VOC), particles with an average diameter of 2.5 and 10 µm ($PM_{2.5}$, PM_{10}), temperature (T) and relative humidity (RH).

To ensure the consistency of conditions throughout the monitoring period, the number of occupants in each classroom was maintained at a constant level, and the opening of doors was synchronized.

D. Irrigation Water

The plants were watered manually once a week, with the exception of the summer months, when plants were watered twice a week due to the heat. None of the pots have water collection, that is, all the water is retained inside the pots, preventing the accumulation of stagnant water and minimizing the risk of direct contact. The TWW used in irrigation was collected in an Urban Wastewater Treatment Plant (UWWTP) with secondary treatment, filtration with sand filters and disinfection. The TWW was characterized by the UWWTP within the scope of the operational quality control plan, the average values during the collection period are: BOD_5 = 6.9±1.3 mg/L O_2; TSS = 7.6±2.8 mg/L; Total nitrogen = 11.5±0.5 mg/L N; Total phosphorus = 2.8±0.8 mg/L P; pH = 7.4±0.2 in Sörensen scale; Coliforms = 16682±8049 MPN/100 mL. These parameters values are within the recommended by the Portuguese legislation (Decree Law No. 119/2019) for irrigation of private gardens (class A) [12].

III. Analysis and Discussion Results

The NGS was installed in May 2022 (Figure 1a) and underwent a series of modifications over time, as evidenced by the photographic documentation presented in Figure 1. The growth of the plants can be observed over the two-year period, resulting in an expansion of the area occupied by the foliage.

The monitoring of plant growth started in February 2023 with the objective of evaluating plant development and determining the impact of TWW irrigation. Until June 2023, all plants were irrigated with DW. From this date onwards, the plants were divided into two groups: one group was irrigated with DW, while the other was irrigated with TWW. Given that the leaf area is a significant indicator of a plant's capacity to adapt and respond to its external environment [18], the impact of irrigation with TWW was assessed by comparing the growth of the surface area of plants (surface projection) of the same species, situated in locations with identical sun exposure.

b)

Fig. 1. Evolution of the natural green structure: a) May 2022; b) October 2024.

During the monitoring period, the plants exhibited uniform and regular growth, with occasional decreases in area due to the loss of leaves associated with the high temperatures that were recorded in the classroom during the summer period of 2023. No significant differences in growth were observed between the plants irrigated with the two different types of water and no evidence of damage or disease in the plants was observed, that could be associated with the type of water used in irrigation. In figure 2, it can be observed a graphic, with the area growing monitorization, for the two *Scindapus aureus* plant, placed near the windows.

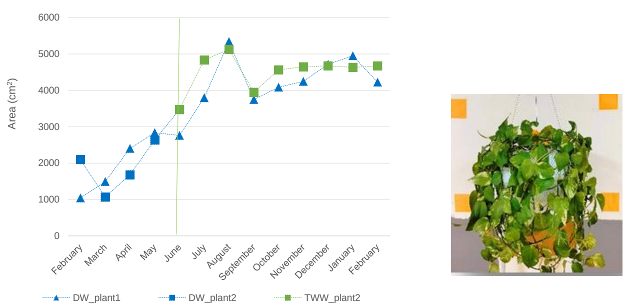

Fig. 2. Evolution of two *Scindapus aureus* plant growth.

The growth of NGS had a direct consequence on IAQ. As already mentioned, in the first monitoring carried out, when the plants were not yet fully developed, the improvement in IAQ was not significant [14]. However, in subsequent monitoring, with a larger green area, a significant improvement in air quality was observed, namely in the evolution of the VOC_T and CO_2 concentration when compared to the IAQ of the classroom without NGS [13], [19].

In the GR CO_2 was significantly lower than in the NR, which was expectable due to the plant's photosynthesis process, which absorbs CO_2 and releases O_2 during daylight. However, CO_2 levels exceeded the protection threshold of 1250 ppm (set by Portuguese ordinance legislation nº 138-G/2021) in both classrooms.

Regarding VOCTs in the GR, levels below the limit of 600 mg/m³ (stipulated by Portuguese legislation) were observed, while this limit was exceeded in the NR, reaching a value of 1400 mg/m³.

IV. Conclusions

The study carried out allowed to conclude that the introduction of NBS in a school environment contributes significantly to an improvement in IAQ.

The utilization of TWW, when employed in accordance with the requisite standards of quality, does not negatively impact the growth and development of plants. Furthermore, it facilitates the reduction of DW consumption and the minimization of water abstraction from water bodies.

No significant difference in growth was noted between the batch of plants irrigated with TWW and the batch irrigated with DW, probably because the TWW used had already undergone a treatment that substantially reduced the phosphorus and nitrogen contents in the water.

The utilization of TWW, in this case study, was also intended to enhance awareness and disseminate information to ISEL students, professors and other workers regarding the significance of identifying alternative water sources as a strategy to promote water efficiency and the sustainability of buildings in urban areas.

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