Installation of A Natural Green Structure in A University Classroom - Indoor Air Quality and Occupational Well-Being Assessment

Teresa Miranda, Maria Idália Gomes, and Alexandra S. Rodrigues

***Abstract*—**According to the World Health Organization, good air quality is a basic requirement for life, being a determining factor for the health and well-being of occupants in indoor spaces. In schools, and due to the complex and diversified activities carried out, indoor air quality (IAQ) can also have a direct impact on student performance and well-being. Good indoor air quality can be ensured, among other measures, using plants capable of absorbing indoor contaminants. In addition to improving indoor air quality, plants also have numerous benefits in terms of occupant performance and well-being.

The present study aimed to analyze the impact of the installation of a natural green structure (NGS) on the indoor air quality of a classroom at the Instituto Superior de Engenharia de Lisboa, through the monitoring of several chemical and physical parameters, namely volatiles organic compounds (VOC´s), carbon dioxide (CO_2), carbon monoxide (CO), particulate matter suspended in the air (PM_{10} and $PM_{2.5}$), temperature (T) and relative humidity (RH). It was also evaluated the well-being of students, through the application of online questionnaires. The results of the specific IAQ measurements allowed to verify that, despite the existence of some non-compliance, the indoor air quality of the classrooms is, in general, acceptable and, after the installation of the NGS, there was a slight decrease in the VOC´s, CO_2 and $PM_{2.5}$ concentrations, which seems to suggest a slight but positive influence of the plants on the IAQ in the classroom. On the other hand, the results of the applied questionnaires, allowed to verify a positive effect of the NGS in the students' perception in relation to the classroom, in the reduction of the anxiety levels and in the decrease of the negative feelings.

***Keywords*—** Environmental sustainability, indoor air quality, natural green structures, university buildings, effects on health, well-being.

I. Introduction

According to the World Health Organization (WHO), a good air quality is a basic requirement for life, being a determining factor for the health and well-being of occupants of indoor spaces. Continued exposure to indoor pollutants has a direct impact on the health and well-being of occupants, assuming greater relevance because children and adults spend about 90% of time, indoors [1, 2]. According to the Portuguese Environment Agency (APA) [3], the number of complaints related to indoor air quality (IAQ) has grown in recent years, mainly due to the increased density of buildings in cities, the increasing use of synthetic materials and the current energy conservation measures in buildings, which reduces natural ventilation, leading to a lower amount of outdoor air provided [4].

Schools are one of the most important and critical infrastructures in society, one of the first places for the development of social activities, and one of the places where children and young people spend more time indoors. A bad IAQ in schools, in addition to the adverse effects on health, in the short and long term, can also affect the productivity, concentration and performance of the occupants of these spaces. The Environmental Protection Agency (US EPA) even suggests that poor indoor air quality can reduce occupants' ability to perform mental tasks that require concentration, calculation, or memorization.

Although IAQ in schools is a problem that affects millions of students, it is still a neglected topic, which has taken on some importance with the recent COVID-19 pandemic. Ensuring good air quality in schools is, for the reasons given above, a current need and one that should be on the priority list of those responsible for building management and maintenance.

A good IAQ can be ensured through several action strategies, namely: removal or reduction of polluting sources; localized air extraction; cleaning or filtering the air and dilution of pollutants with fresh air, by strengthening natural ventilation [5]. Recently, the Chair on Health Education and Sustainable Development of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Italian Society of Environmental Medicine (SIMA) presented a series of recommendations aimed to improve air quality indoor in schools that include, among other measures, the use of plants as natural filters, capable of absorbing some indoor contaminants [6].

Although the benefit of using some plants to remove

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pollutants from indoor air has already been studied, through numerous studies and laboratory tests, there is still little information available about the efficiency of natural green structures in a real context, namely in university environments. In this work, it was evaluated the contribution of a natural green structure (NGS) (composed of plants with recognized capacity to remove pollutants), and what was the improvement in the air quality of a classroom, in a higher education institution, and consequent impact on students' well-being.

II. Case Study

In this case study, it was analyzed the impact of installing a natural green structure (NGS) on the indoor air quality of a classroom at the Instituto Superior de Engenharia de Lisboa (ISEL), through the monitoring of various indoor pollutants, and evaluated, as well, the impact on well-being, comfort, and stress reduction in students.

The study was carried out in two phases, a first phase, "*before the installation of the NGS*", in which indoor air quality (IAQ) measurements were carried out and questionnaires were applied to the students, and a second phase, "*after the installation of the NGS"*, where IAQ measurements were performed again and (the same) questionnaires were applied to the students. For the study, two classrooms in Building G on the ISEL Campus were selected: the "Green Room" (GR), the classroom where the NGS was installed, and the "Neutral Room" (NR), where the initial conditions were maintained, and which was used for comparison with the green room. The study was carried out in the months of May and June, which corresponds to the spring period in Portugal.

The selection of the classrooms to be studied was based on the highest occupancy, having selected two of the classrooms used by the classes with the highest number of enrolled students. In addition to this criterion, four other conditions were also considered, namely, equal area, same number of maximum occupancy of students, sun exposure and identical glazing area. Two classrooms facing southwest were selected, with a considerable area of glass (southwest facade with 12.84 m^2 of glass). Both classrooms had similar furniture, equipment, coatings, and window frames.

The selection and number of plants to integrate the NGS was made based on their recognized ability to absorb certain indoor pollutants. The NGS was designed taking into account the geometry of the classroom and furniture arrangement, in order to cause the least constraint on circulation to the students. Considering the number and type of plants selected, different types of support were selected, namely: vases placed on the floor (of different sizes and volumes), vases suspended from the ceiling and trellises, for climbing plants. The NGS was installed on the back wall (wall opposite the whiteboard) and on the side walls of the GR room, as shown in Figure 1 and Figure 2.

The analysis of the students' well-being was carried out through the application of online questionnaires, developed for the effect, which were submitted to the ethics committee prior to the start of the study and within the scope of the GreenAir/RESpira projects. Filling of questionnaires were completely optional.

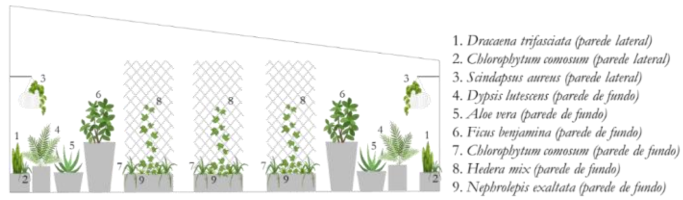


Fig. 1 Scheme of the NGS installed in the GR

Fig. 2 Green classroom with NGS installed

A. Indoor Air Quality Monitoring

The monitoring of indoor air quality was carried out in accordance with the methodology defined in the Technical Guide prepared by the APA [3], through portable direct reading equipment, in places and periods that are representative of the activities normally carried out, in this case, in classrooms, during the class period.

The following parameters were measured: total volatile organic compounds (VOC), carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM_{10} fraction), particulate matter ($PM_{2.5}$ fraction), temperature (T) and relative humidity (RH).

The equipment used for the measurements was the following: GrayWolf, AdvancedSense BE model, for measuring VOC_T, CO_2, CO and T; and the Lighthouse brand, Handheld model, for measuring RH, $PM_{2.5}$, PM_{10}. The treatment of the collected data was carried out through a simplified statistical analysis, with calculation of averages and standard deviation, using the Microsoft Excel program.

The indoor air quality monitoring was carried out through punctual measurements in two phases: "Before the installation of the NGS" and "After the installation of the NGS". The measurements were carried out in different moments of the class and points of the classroom (according to a sequence of pre-defined sampling and with different measurement times), in order to guarantee greater representativeness. Samplings were carried out over the 90 minutes of the class, at three different times after class starts: 15, 45 and 75 minutes.

B. Assessment of Student Well-Being

The assessment of the students' well-being was carried out through the application of online questionnaires, developed within the scope of the GreenAir/RESpira projects, having collected demographic, COVID-19 and ISEL elements, and measures of ecological identity, physical and mental health, productivity, and self-efficacy, associated with the physical environment of the classroom. A comparison analysis of average results was made, between the different classrooms, using data analysis software. In this article, only a part of this study will be presented.

III. Analysis and Discussion of Results

A. Indoor Air Quality Monitoring

Tables I and II present the average concentrations of the pollutant's measurements, performed before NGS installation, in the GR and NR.

Analyzing the results, it can be observed that NR has a higher amount of non-compliance with the protection thresholds Portuguese ordinance legislation n.º 138-G/2021, with five non-compliance being recorded and four non-compliance at GR. Both in GR and NR, there were only non-compliances for the VOC, CO_2 and PM_{10} parameters, with the highest number of non-compliance being recorded for the PM_{10} parameter (four non-compliance of PM_{10}, in the total of the two classrooms).

Although occasionally common non-compliance is observed in the two classrooms, it is not possible to observe a pattern of non-compliance for most of the parameters. Although NR registered a higher number of non-compliance, a global comparison of the averages of VOC, CO_2, CO and $PM_{2.5}$ and PM_{10} pollutants shows that it is in GR that higher concentrations of pollutants are registered. However, the number of occupants in this classroom is also higher, which significantly influence the results obtained.

The analysis of standard deviations also allows observing a wide variation in the concentrations of VOC and CO_2 in both classrooms, with values varying between 27.3 – 858.9 µg/m^3 for the parameter VOC and 453.0 – 1490.1 µg/m^3 for the CO_2 parameter.

TABLE I
AVERAGE CONCENTRATIONS OF VOC_T, CO_2, CO, PM_{10}, $PM_{2.5}$, T AND HR PARAMETERS, FOR THE MEASUREMENTS CARRIED OUT IN THE GR, "BEFORE THE INSTALLATION OF THE NGS"

Date	**N.º of occu-pants**	**Time-table**	**VOC_T**	**CO_2**	**CO**	**PM_{10}**	**$PM_{2.5}$**	**T/RH**
Protection thresholds Portuguese ordinance legislation n.º 138-G/2021			***600*** µg/m^3	***1250*** ppm	***9*** ppm	***50*** µg/m^3	***25*** µg/m^3	- °C/%
03/05/2022	*Unoccu-pied*	08H00 - 09H30$^{(1)}$	**858.9**	453.0	1.00	34.0	19.4	20.5/51.5
03/05/2022	27	11H00 - 12H30$^{(1)}$	268.1	878.4	0.84	49.8	11.8	20.8/47.5
03/05/2022	20	15H30 - 17H00$^{(1)}$	109.1	921.3	0.67	**52.2**	10.7	22.3/51.8
05/05/2022	15	15H30 - 17H00$^{(1)}$	**678.7**	**1490.1**	0.84	47.8	14.3	26.8/46.7
05/05/2022	23	18H30 - 20H00$^{(1)}$	203.4	993.0	0.73	43.0	16.2	25.2/44.3
03/05/2022	8	20H00 - 21H30$^{(1)}$	27.3	589.7	0.63	50.0	13.0	21.2/48.8

Ventilation conditions: $^{(1)}$Windows closed and door open; $^{(2)}$Windows closed and door closed.

Values in **bold** refer to values above the protection thresholds.

TABLE II
AVERAGE CONCENTRATIONS OF THE PARAMETERS VOC_T, CO_2, CO, PM_{10}, $PM_{2.5}$, T AND HR, FOR THE MEASUREMENTS CARRIED OUT IN THE NR, "BEFORE THE INSTALLATION OF THE NGS"

Date	**N.º of occu-pants**	**Time-table**	**VOC_T**	**CO_2**	**CO**	**PM_{10}**	**$PM_{2.,5}$**	**T/RH**
Protection thresholds Portuguese ordinance legislation n.º 138-G/2021			***600*** µg/m^3	***1250*** ppm	***9*** ppm	***50*** µg/m^3	***25*** µg/m^3	- °C/%
03/05/2022	*Unoccu-pied*	08H00 - 09H30$^{(1)}$	**777.1**	498.0	0.90	17.8	8.7	20.6/51.8
03/05/2022	19	11H00 - 12H30$^{(2)}$	218.1	**1325.3**	0.78	**50.7**	9.7	20.2/57.5
05/05/2022	15	11H00 - 12H30$^{(1)}$	225.1	914.3	1.03	**56.8**	14.8	23.4/51.9
03/05/2022	12	15H30 - 17H00$^{(1)}$	81.8	850.9	0.76	**53.2**	10.7	22.6/50.0
05/05/2022	6	18H30 - 20H00$^{(1)}$	121.0	924.4	0.78	31.0	10.6	25.3/43.9
03/05/2022	5	20H00 - 21H30$^{(2)}$	72.7	524.1	0.69	41.3	13.4	21.1/48.2

Ventilation conditions: $^{(1)}$Windows closed and door open; $^{(2)}$Windows closed and door closed.

Values in **bold** refer to values above the protection thresholds.

It should be noted that, at this stage, the two classrooms had exactly the same infrastructure, although the number of students varied throughout the day and it was not possible to control the opening and closing of doors and windows, which is expected to influence the parameter's measurements.

Comparing the two shaded lines in table I e II, which were measured in the same day with the same number of students, it can be observed that there are differences too. However, one was measured in the morning and another in the afternoon, with change in temperatures, which influences the VOCs liberation. Also, the CO_2 presented completely different values, which was probably due to the opening of windows and also the temperature variation. The remaining values did not showed significative differences.

To verify the impact of installing the NGS in the GR room, the global averages of the parameter's measurements "After installing the NGS" were compared with the ones measured "Before the installation of the NGS", as can be observed in Table III.

TABLE III
GLOBAL AVERAGES OF THE PARAMETERS VOC_T, CO_2, CO, PM_{10}, $PM_{2.5}$, T AND HR, IN THE GR, "BEFORE THE INSTALLATION OF THE NGS" AND "AFTER THE INSTALLATION OF THE NGS"

		Average n.º of occupants	VOC_T µg/m³	CO_2 ppm	CO ppm	PM_{10} µg/m³	$PM_{2,5}$ µg/m³	T/RH °C/%
Before the installation of the NGS	averages	19	**357.6**	**887.6**	0.79	46.1	**14.2**	22.8/48.4
	standard deviation		304.7	292.0	0.09	3.1	1.9	2.3/2.5
After the installation of the NGS	averages	18	304.1	809.1	**0.81**	**46.4**	4.8	23.8/41.8
	standard deviation		239.4	316.6	0.31	14.9	2.5	3.9/9.3

Values highlighted in bold refer to the maximum monitored values.

Analyzing the global mean concentrations of pollutants in the GR, before and after the installation of the NGS, it appears that for the parameters VOCs, CO_2 and $PM_{2.5}$, the mean concentrations of pollutants are higher in the first phase of the study, "Before of the EVN installation", which is not verified for the CO and PM_{10} parameters, whose concentrations of pollutants are higher in the second phase of the study, although with very similar values. It is important to note that the sampling conditions were not similar in each of the phases, since both the average class occupancy and the classroom occupancy pattern (hours of daily occupancy) were different between the two phases, and it was not possible control opening of the door or windows, which constitutes a limitation of the study.

These results seem to indicate a positive influence of NGS on the IAQ of the classroom, since there is a decrease in the concentration of VOCs, CO_2 and $PM_{2.5}$ in the GR.

The results are consistent with the results obtained in several investigations, where the effect of installing green walls on IAQ was studied. Tudiwer & Korjenic [7], found a decrease in CO_2 in a study carried out in a school building in Vienna, Austria; Peterková et al. [8] also observed a decrease in CO_2 concentrations in a classroom at the Faculty of Civil Engineering at the Technical University of Brno, Czech Republic; Pettit et al. [9], in a school in Beijing, observed a decrease in VOCs concentrations; and Shao et al. [10], at a university in China, observed a reduction in CO_2 and $PM_{2.5}$ levels after installing a green structure in a small corridor.

In the present study, despite observing a reduction in the mean global concentrations of VOCs, CO_2 and $PM_{2.5}$ in the GR after the installation of the NGS, the same was not verified for the CO and PM_{10} parameters, although the values are slightly different (differences of 0.1 and 0.3 µg/m³ respectively).

A. Assessment of student well-being

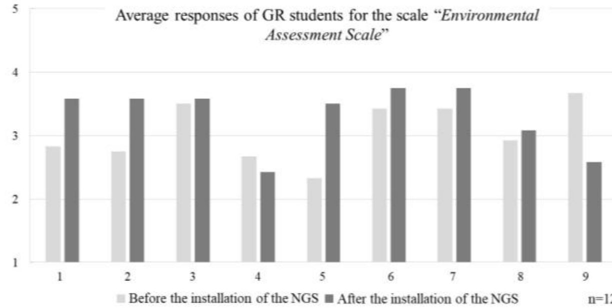
The results of the online applied questionnaires were treated and analyzed, comparing average results before and after the installation of the NGS.

In the initial exploratory analysis, the average results between the Green Room and Neutral Room responses were compared, for a sample n=12, for the following scales: Indoor Climate Rating Scale, Environmental Assessment Scale, Subjective Well-being in class, General Anxiety Disorder, Positive Affect Negative Scale and Psychological capital. In this article, however, we will present only two of the studied scales.

B. Environmental Assessment Scale

In this question, students were asked to describe, through 17 pairs of adjectives, and on a scale of 1 to 5, the classroom where they were. Data analysis (Figure 3) identified statistically relevant results for the pairs: Boring - Interesting, Sad - Happy, Heavy air - Fresh air, Crowded - Empty, Monotonous - Colored, Confused - Relaxing, Unpleasant - Pleasant, Noisy - Quiet, Little Spacious - Spacious, Ugly - Attractive, Scary - Safe, Uncomfortable - Comfortable, With drafts – Without drafts, Messy - Tidy, Uninviting - Inviting, Simple - Decorated, Ordinary - Elegant. All these pairs, with the exception of the pair Little Spacious - Spacious, were evaluated more positively "After installing the NGS". These results seem to indicate a positive effect of the NGS on the students' perception of the classroom, which is now considered more Interesting, Happy, Colored, Attractive, Inviting, Decorated and Elegant.

These observations are also consistent with those obtained by Lohr & Pearson-mims [11], in a study carried out in a classroom with various conditions, including the presence and absence of plants, in which they observed that, with the presence of plants, the classroom was associated with positive characteristics such as "happy", "calm" and "attractive". Positive attitudes towards classrooms with plants have also been demonstrated in a number of other studies, including those developed by Laviana et al. [12], Shoemaker et al. [13], Larsen et al. [14] and Fjeld [15].



1. Boring - Interesting | 2. Sad - Happy | 3. Heavy air - Fresh air | 4. Crowded - Empty | 5. Monotonous - Colored | 6. Confusing - Relaxing | 7. Unpleasant - Pleasant | 8. Noisy – Quiet | 9. Little spacious - Spacious

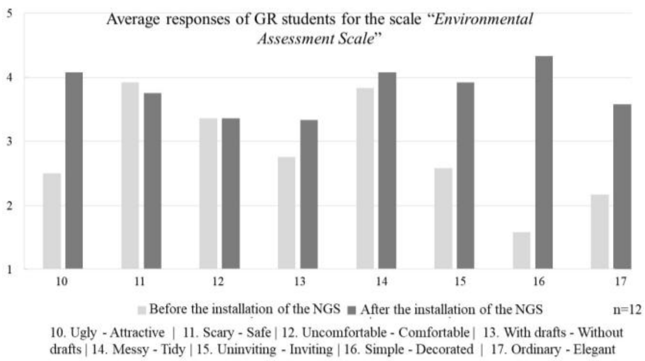


Fig. 3 Average responses of SV students for the scale "Environmental Assessment Scale", "Before and after installation of NGS": a) for the first 9 pairs of adjectives; b) for the remaining 8 pairs of adjectives

Positive Affect Negative Affect Scale

On this scale, students were asked to identify, on a scale of 1 to 5, where 1 is "Not at all" or "very slightly" and 5 is "Extremely", their feelings about a set of emotions. The results of the Positive Affect Negative Affect scale are shown in Figure 4. The data analysis that identified the statistically relevant results are: Interested, Nervous Enthusiastic, Frightened, Inspired, Active, Scared, Guilty, Determined and tormented.

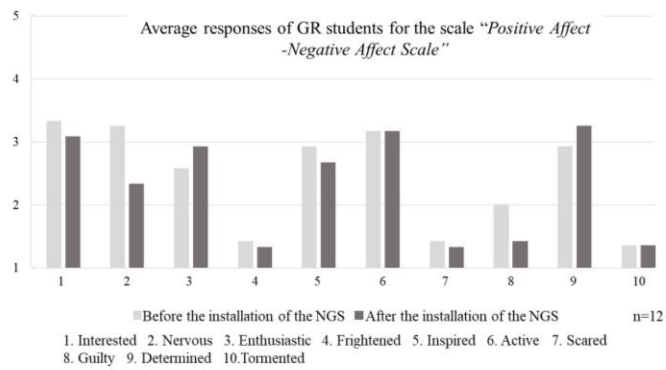


Fig. 4 Average student responses to the scale "Positive Affect - Negative Affect Scale", "Before and after installation of NGS"

Although, for most emotions, was not possible to find results with great statistical relevance, in general, emotions were evaluated more positively "After installing the NGS", with students feeling less Nervous, Scared and Guilty, and more Enthusiastic and Determined, and it is also possible to verify a decrease in the average of negative feelings "After the installation of the NGS".

These results are consistent with those observed by Fjeld [15], in a study in which he observed that students in classrooms with plants rated the classroom more positively than students in classrooms without plants, and by Doxey et al. [16], who suggest that passive contact with nature can improve students' levels of satisfaction and mood. These are also the conclusions of a series of other studies, which associate the presence of plants with positive feelings, such as those developed by Laviana et al. [12], Shoemaker et al. [13], Larsen et al. [14], Fjeld [15] and Lohr & Pearson-mims [11]. The results obtained are still consistent with the results of similar studies that suggest the existence of a relationship between the presence of indoor plants and the reduction of anxiety levels in occupants [17, 18, 19, 20]. Han [18] even suggests that larger amounts of plants, with greater and better visibility by occupants, are capable of producing more expressive effects in reducing anxiety.

IV. Conclusion

The results of the IAQ measurements carried out in the first phase of the study, before installation of the NGS, made it possible to verify the existence of non-compliance with the protection thresholds defined in the Portuguese Legislation Ordinance n.º 138-G-2021 in both classrooms evaluated, for the parameters COVs, CO_2 and PM_{10}. In this phase, the highest number of non-compliance was registered in "NR" for parameter PM_{10}, however, it was in "GR" that higher concentrations of pollutants were registered, namely in parameters VOCs, CO_2, PM_{10}, $PM_{2.5}$. Despite the non-compliance identified, most measurements were below the respective protection thresholds, and the IAQ of the classrooms can be considered, in general, as acceptable.

In the second phase of the study, after installation of NGS in the GR, the existence of non-compliance with the protection thresholds continued to be observed and, although in a smaller number, non-compliance was verified in the same parameters where non-compliance was verified in the first phase, namely VOCs, CO_2, and PM_{10}, although in different classes.

In order to verify the impact of installing the NGS in the GR, the global averages of the IAQ measurements in each of the phases were compared and, although it was not possible to ensure the same sampling conditions in the two phases of the study, it was verified a decrease in the concentrations of VOCs, CO_2 and $PM_{2.5}$ in the GR, after the installation of the NGS, which seems to indicate a positive influence of the NGS on the IAQ of the classroom.

The results of the questionnaires applied to the students of the GR, despite the reduced statistical relevance, allowed to verify a positive effect of the NGS in the students' perception in relation to the classroom, in the levels of negative feelings. After installing the NGS, the classroom began to be evaluated more positively, being considered more Interesting, Happy, Colored, Attractive, Inviting, Decorated and Elegant, and the students' feelings became less negative.

Despite the various limitations of the study, it is believed that this work constitutes a contribution of great relevance to a first approach to the study of IAQ in a university context, and that it will help to highlight the importance of NGS in classrooms, whether for the improvement of QAI, as well as for the well-being of its occupants.

Considering the importance of IAQ for the physical and mental health of occupants of indoor spaces, and in particular of students who use school spaces, it is also hoped that this study can contribute to the integration of natural green structures in schools, as a solution economically and environmentally sustainable for solving problems related to indoor air quality.

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