

Article

Indoor Environmental Quality in Portuguese Office Buildings: Influencing Factors and Impact of an Intervention Study

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Abstract: Office workers spend a considerable part of their day at the workplace, making it vital to ensure proper indoor environmental quality (IEQ) conditions in office buildings. This work aimed to identify significant factors influencing IEQ and assess the effectiveness of an environmental intervention program, which included the introduction of indoor plants, carbon dioxide (CO₂) sensors, ventilation, and printer relocation (source control), in six modern office buildings in improving IEQ. Thirty office spaces in Porto, Portugal, were randomly divided into intervention and control groups. Indoor air quality, thermal comfort, illuminance, and noise were monitored before and after a 14-day intervention implementation. Occupancy, natural ventilation, floor type, and cleaning time significantly influenced IEQ levels. Biophilic interventions appeared to decrease volatile organic compound concentrations by 30%. Installing CO₂ sensors and optimizing ventilation strategies in an office that mainly relies on natural ventilation effectively improved air renewal and resulted in a 28% decrease in CO₂ levels. The implementation of a source control intervention led to a decrease in ultrafine particle and ozone concentrations by 14% and 85%, respectively. However, an unexpected increase in airborne particle levels was detected. Overall, for a sample of offices that presented acceptable IEQ levels, the intervention program had only minor or inconsistent impacts. Offices with declared IEQ problems are prime candidates for further research to fully understand the potential of environmental interventions.

Keywords: indoor environmental quality; intervention study; modern office buildings; pollution assessment; ventilation



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1. Introduction

Increasing urbanization and the current advances in information and communication technologies have contributed to a growth in office workers [1]. According to the OECD, in 2022, the working population spent between 35 and 48 h per week at work [2]. As a substantial portion of the day is spent at the workplace, it is crucial to ensure the quality of the environmental conditions in these settings while promoting decent work for all, as described in the Sustainable Development Goal (SDG) 8 [3]. There has been a growing interest in investigating indoor environmental quality (IEQ) at the workplace because it significantly impacts workers' health, well-being, and productivity [4]. Post-occupancy evaluations (POE) have been carried out [5] to achieve a comprehensive understanding of building performance, particularly regarding IEQ, occupant satisfaction, productivity, and

energy use [6]. IEQ typically includes multiple environmental aspects related to indoor air quality (IAQ), thermal comfort, lighting, and acoustics.

Modern office buildings are often located in urban areas with high levels of traffic-related ambient air pollution. Many of these buildings have sealed facades without openable windows, which can compromise indoor ventilation and IAQ conditions [7]. Most existing literature on office IEQ uses carbon dioxide (CO₂) as a proxy for the quality of ventilation, showing that some offices may have inadequate fresh air rates during working hours [8]. In addition, office environments typically include printers and other electronic equipment, which can be sources of indoor air pollutants, such as ozone (O₃), volatile organic compounds (VOCs), particles, and ultrafine particles [9]. Limited studies on Portuguese offices have found that VOC levels constitute a critical IAQ parameter, with levels exceeding recommendations in many offices (three out of seven buildings studied) [10]. Indeed, occupational exposure to high levels of particles, CO₂, and O₃ has been associated with an increased prevalence of health symptoms [4]. Beyond objective assessments, evaluating perceived air quality among occupants can yield relevant information to identify opportunities to promote well-being and productivity. High levels of air pollutants can be perceived and associated with people's discomfort in relation to odors [11]. Nevertheless, the potential positive perceptual effects induced by pleasant odors can also occur [12]. According to the outcomes from a European study that included a sample of Portuguese office buildings, in addition to IAQ, complaints about thermal comfort, lighting, and noise are common in shared office spaces [13]. Electronic equipment, occupancy, and lighting can increase the indoor temperature in offices [14], be related to thermal conditions outside of the recommended comfort ranges, and impact workers' health [4]. Existing evidence also shows that lighting levels at the workplace can widely vary across surveyed workstations and, in some offices, be lower than the requirements [4,15]. Low lighting levels at the workplace can be linked to an increase in eye symptoms and a decrease in performance [4]. Noise levels in office environments typically range from 30 to 65 dBA [4]. Although these levels are considered acceptable [16], evidence shows that increased noise levels can cause stress and reduce concentration capacity [17].

Environmental intervention studies have been conducted in various indoor settings to gather data supporting the effectiveness of specific corrective measures in promoting improvements in IEQ [18]. For offices, interventions typically focus on three basic strategies: source control, optimization of ventilation rates, and air cleaning. Regardless of the indoor setting, the preferred approach is source control to eliminate or reduce sources of pollution and emissions from indoors and/or outdoors [19]. In offices, this strategy can include reducing, removing, or replacing identified sources of indoor pollution (e.g., changes in cleaning procedures or flooring material). As it is not always feasible to control indoor sources, ventilation is considered a crucial strategy for diluting indoor air contaminants and improving IEQ. In this regard, CO₂ sensors have been recognized as a good and low-cost method for monitoring ventilation and personal exposure in office environments [20].

The strategies targeting improvements to ventilation tested in offices include adjustments to outdoor air supply rates through mechanical ventilation. In some cases, these adjustments are implemented along with changes in temperature or air filters [18] and the promotion of increased natural ventilation (through opening windows) [21]. Evidence from these studies has suggested that ventilation-based interventions might positively impact workers' outcomes, including productivity at work [18]. However, the analysis of the impact of interventions on IEQ is not always considered, even though evidence shows that these interventions can alleviate indoor-generated pollutants [21]. When ventilation is insufficient to improve IAQ, air cleaning strategies can be implemented, including technological and nature-based (biophilic) solutions [22].

In offices, interventions focused on promoting air cleaning include heating, ventilating, and air conditioning (HVAC) component renovation, filter replacement, and the introduction of plants [18]. Existing evidence shows that biophilic interventions involving indoor plants in office environments can reduce CO₂ concentrations [23]. Additionally, the

reported potential of indoor green plants to improve the indoor environment also includes reducing the concentration of air pollutants, such as VOCs, carbon monoxide (CO), and airborne particles [24,25]. However, the results of experiments conducted in controlled conditions (chambers) indicate that indoor plants may have a negligible impact on reducing indoor VOCs due to the low air cleaning delivery rates observed [26]. Furthermore, existing evidence also shows that plants may play a role in regulating indoor air temperature and relative humidity levels [25].

There is a notable lack of evidence regarding the effectiveness of environmental interventions in improving IEQ, especially comprising the concomitant assessment of IAQ (air pollution and ventilation), thermal comfort, lighting, and noise parameters. Indeed, research that takes a structured approach considering IEQ characterization, the design of interventions adjusted to identified risk factors, and the assessment of their effects on both IEQ and occupants is currently lacking. To address these gaps, this study aimed to implement an environmental intervention program through a randomized controlled trial (RCT) involving 30 offices from 6 office buildings. The goal was to assess the effect on IEQ conditions by applying previously identified interventions based on preliminary IEQ assessments [27]. In particular, the framework developed in this study aims to holistically characterize IEQ (air quality, ventilation, thermal comfort, illumination, and noise) and generate evidence to answer two main research questions: What are the significant influencing factors of IEQ in office buildings? What is the potential of source control, ventilation, and biophilic interventions for improving IEQ and reducing hazardous exposure in modern Portuguese office buildings?

2. Materials and Methods

2.1. Environmental Intervention Program

This study was conducted in 30 modern offices (six office buildings, five open spaces each) located in Porto (Portugal). The intervention program was conducted through an RCT, with the offices being randomly and equally distributed between the intervention group (Group A, $n = 15$) and the control group (Group B, $n = 15$). The intervention measures to implement were defined based on the results obtained from a preliminary IEQ characterization of the 15 intervention offices. The outcomes of preliminary characterization work, the screening tool used to derive putative interventions, and the eligibility criteria employed for selecting study offices are described elsewhere [27]. Among the improvement opportunities identified, the following interventions were chosen to be implemented in offices of Group A based on the risk factor identified and the feasibility and cost of implementation:

1. Source control by relocating existing printers from the office spaces to a separate room without permanent occupants (preferentially with proper ventilation); this was implemented in one office. This intervention was selected due to the identification of printers as an avoidable source of air pollutants in the office space.
2. Optimizing ventilation strategies using real-time data low-cost CO₂ sensors with a display screen (e.g., to increase airflow, the percentage of fresh air introduced indoors, or natural ventilation (taking into consideration the point above) in periods when CO₂ concentrations exceed 1000 ppm). A commercially available sensor was used to monitor CO₂ levels continuously during the intervention period. The sensor was AirokCO₂ (Entidad IDV Consulter, Ciudad Real, Spain) with a display screen, whose specifications are presented in Table S1 in Supplementary Materials. The equipment was calibrated with outdoor air (around 400 ppm) in constant temperature and relative humidity conditions. Additionally, tests were performed with reference equipment (IAQ-CALC monitors, model 7545, TSI, Inc., Shoreview, MN, USA) before the installation of low-cost CO₂ sensors. This intervention was implemented in 2 out of 15 intervention offices due to the identification of work periods with elevated CO₂ concentrations. When CO₂ levels exceeded 1000 ppm in one of the offices, the workers were instructed to open windows. In the other office, the occupants were requested to turn on/increase the ventilation flow (office with mechanical ventilation with local

control was allowed). In the case of natural ventilation, occupants were instructed to open windows, preferentially in periods of low traffic, and prioritize windows that are not oriented to the main road. In both cases, a log sheet was used together with the CO₂ sensors so that workers could register periods of ventilation change due to high CO₂ concentrations.

3. Biophilic intervention by introducing indoor plants in office spaces. This was the predominant intervention implemented (12 office spaces). To potentiate possible air pollutant removal, three plant species with the potential to improve IAQ were selected for this study: *Sansevieria trifasciata*, *Dracaenas fragrans*, and *Chlorophytum comosum*. These species have been documented to absorb air pollutants, namely, formaldehyde, benzene, toluene, particulate matter, and CO₂ [28]. Potted plants were used, and one pot (average height of 40 cm) was placed per 9 m² according to recommendations focused on the air purification effects [29]. Whenever possible, plants were positioned on office workers' desks and, in other cases, on the floor. They were always placed in locations with visibility for workers. The researcher ensured plant watering. This intervention was implemented in office spaces where the levels of IEQ parameters met the established requirements and avoidable sources of pollution were not noticed. This allowed for an exploration of the potential of indoor plants to improve IEQ.

Some of the corrective measures identified in the preliminary assessment of intervention offices [27] were unsuitable for implementation in the current intervention program. The measure of correcting desk positions in alignment with ceiling lamps was not feasible due to the lack of energy plugs in the suggested positions (immediately below ceiling lamps), and no authorization was obtained from the building manager to promote the change. The study groups and intervention type implemented per study office are summarized in Table 1. Some outputs from the photographic records kept during the fieldwork for implementing the interventions are presented in Figure S1 in Supplementary Materials.

Table 1. Office space distribution per intervention and the control group.

Study Groups	Environmental Interventions	Office Spaces
Group A: Intervention (n = 15)	Indoor plants (n = 12)	B1O1, B1O3, B1O4, B2O3, B4O1, B4O2, B4O5, B5O1, B5O4, B5O5, B6O1, B6O5
	CO ₂ sensors (n = 2)	B3O3, B6O3
	Source control (n = 1)	B2O4
Group B: Control (n = 15)	Not applicable	B1O2, B1O5, B2O1, B2O2, B2O5, B3O1, B3O2, B3O4, B3O5, B4O3, B4O4, B5O2, B5O3, B6O2, B6O4

Two IEQ assessment campaigns were conducted: one before the implementation of the interventions (pre-intervention phase) and one 2 weeks later, when the intervention had run for 14 days (intervention phase). The environmental intervention program was implemented from February 2022 to March 2024, mainly during the heating season periods. The complete study design scheme is represented in Figure 1.

2.2. Building Survey and IEQ Assessments

The fieldwork included the evaluation of building characteristics and occupancy and the identification of possible sources of pollution by a walkthrough inspection and a building survey using a checklist developed to carry out a detailed and standardized characterization of the indoor spaces and the surrounding environments in the office buildings. The checklist aided in the collection of information on the location and potential sources of outdoor air pollution, construction materials, flooring and furniture, electronic equipment (printers, scanners, computers, etc.), occupation patterns, ventilation conditions, presence of visible pathologies, cleaning products and procedures, and refurbishing activities, among other factors that can impact indoor conditions, as well as occupants' complaints about IEQ.

The survey was performed at the building, outdoor surroundings, and office space levels. A log sheet was also completed for each office regarding the following data for the study days: weather, occupancy, opening of windows, cleaning, and relevant outdoor events.

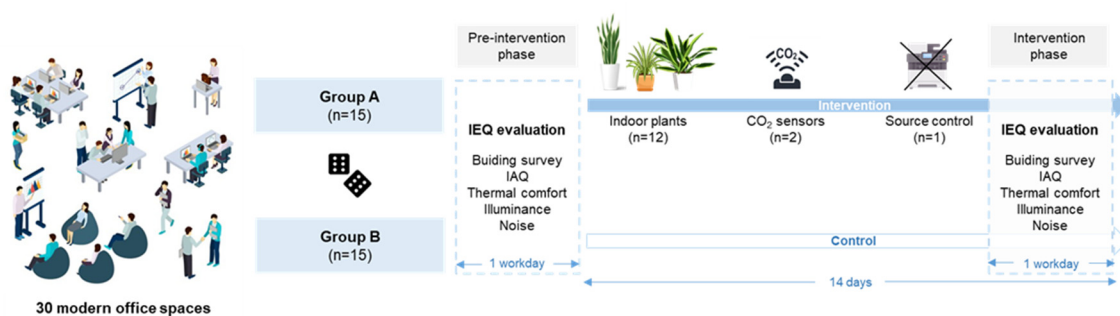


Figure 1. Randomized controlled trial for environmental intervention program implementation in 30 modern office spaces.

Further, IEQ evaluations were performed in the 30 selected office spaces. A comprehensive set of parameters was assessed for IAQ (particulate matter of less than 2.5 and 10 μm in diameter ($\text{PM}_{2.5}$ and PM_{10}), ultrafine particles (UFPs) (less than 0.1 μm in diameter), carbon dioxide and monoxide (CO_2 and CO), ozone (O_3), and volatile organic compounds (VOCs)), thermal comfort (air temperature, relative humidity (RH), predicted mean vote (PMV), and predicted percentage of dissatisfied (PPD)), lighting (illuminance), and acoustic (mean and peak noise) using portable monitors. The equipment used, range of operation, and accuracy are presented in Table S2 in Supplementary Materials for each parameter assessed. The equipment was operated in accordance with the manufacturer's instructions and sent for an external calibration by an accredited laboratory within the 12 months preceding the works. PMV and PPD were determined following ISO 7730 [30] to assess thermal conditions and lighting conditions following the requirements established in ISO 8995-1 [31].

All IAQ parameters (except for O_3), air temperature, and RH were monitored minute by minute, approximately from 9 a.m. to 6 p.m., during a typical workday. In some offices, monitoring was carried out for 24 h. The thermal comfort indexes PMV and PPD were measured twice (morning and afternoon), and data were collected for each 20 s for 20 min. For this assessment, thermal clothing insulation ranging from 0.5 to 1.0 clo was considered based on the type of workers' clothes observed in the offices. In addition, a metabolic rate of 1.2 met (sedentary activity) was used. The noise level was also measured twice (morning and afternoon) for 1 min. For each room, a central location was selected to perform the monitoring, and the equipment was positioned at a table/desk with a height of 0.9–1.3 m to be placed at the workers' representative breathing zone. The equipment remained at least 1 m from occupants, walls, windows, doors, partitions, other vertical barriers, insufflation grilles, air diffusers, fans or heaters, and potential pollution sources, except for illuminance. Four measures were performed for illuminance of workstations and immediate surrounding areas, covering the maximum number of desks possible (80% average) and minimizing the risk of disturbing normal office activities. An example of the equipment position within the study offices is presented in Figure S2 in Supplementary Materials.

The monitoring plan was harmonized to ensure that a similar approach was conducted during the pre-intervention and intervention phases and to not disregard the possible effect of environmental interventions on all IEQ factors.

2.3. Data Management and Statistical Analysis

Descriptive statistics of the assessed environmental parameters were calculated for each study phase using data collected during working hours (around 9 a.m. to 6 p.m.) to guarantee a representative time in which office workers are in open spaces. For offices in

which monitoring was carried out for approximately 24 h (19 out of 30 offices), averages for the period of non-occupancy (6 p.m. to 9 a.m.) were also calculated. Values below the limit of detection (LOD) were assumed as 0. To investigate the relationship between indoor and outdoor concentrations, indoor-to-outdoor (I/O) ratios were estimated for the PM₁₀ parameter using outdoor air quality data obtained from the nearest local monitoring station [32]. In addition, data on outdoor temperature were obtained from the Portuguese Institute for Sea and Atmosphere for the Porto area [33].

Statistical analysis was performed with IBM SPSS Statistics software (version 27), considering a statistical significance level of $p < 0.05$. Data normality was tested using the Shapiro–Wilk and Kolmogorov–Smirnov tests for datasets with ≤ 50 samples and > 50 samples, respectively. Non-parametric tests were applied for variables with skewed distribution, while parametric tests were used for normal distribution variables. The Mann–Whitney U test and t -test were used to explore differences between (1) study group characteristics (collected during the building survey); (2) occupancy and non-occupancy periods for PM_{2.5}, PM₁₀, VOCs, CO₂, air temperature, and RH parameters; and (3) checklist dichotomic variables for IEQ parameters. In addition, Pearson and Spearman correlation methods were applied to test associations (1) between checklist metric variables and IEQ parameters and (2) among IAQ parameters. The investigation of differences in IEQ parameters between study phases (pre-intervention vs. intervention) was conducted using Wilcoxon and t -tests. This investigation was conducted per type of environmental intervention, and for the control group, a selection was made for offices of Group B located in buildings where each intervention was applied.

3. Results

3.1. Characterizing Offices Assigned to Intervention and Control Groups

All offices in the study had an open space design, presenting areas ranging from 35 to 150 m². The rooms that were randomly assigned to groups A and B presented, in general, similar characteristics (Table 2). For instance, based on information collected during the initial building survey, no statistically significant differences were detected between groups for average values obtained for office dimensions, number of workstations, openable windows, indoor plants, window orientation, glassed facade area, electronic equipment (computers and printers), and cleaning frequency.

Table 2. Summary of the characteristics of office spaces randomly assigned to intervention and control groups.

Offices' Characteristics	Group A (n = 15)			Group B (n = 15)			p Value
	n (%)	Mean (SD)	Min–Max	n (%)	Mean (SD)	Min–Max	
Area (m ²)		92 (37)	35–150		103 (28)	63–150	0.356 ^b
Ceiling height (m)		3 (0)	3–4		3 (1)	3–5	0.850 ^a
Number of workstations		25 (12)	8–48		27 (8)	18–42	0.250 ^a
Location of the office space within the building							
Ground floor	0 (0)	n.a.	n.a.	2 (13)	n.a.	n.a.	
1st floor	4 (27)	n.a.	n.a.	1 (7)	n.a.	n.a.	
2nd floor	4 (27)	n.a.	n.a.	3 (20)	n.a.	n.a.	
3rd floor	4 (27)	n.a.	n.a.	4 (27)	n.a.	n.a.	
4th floor	1 (7)	n.a.	n.a.	2 (13)	n.a.	n.a.	
5th floor	1 (7)	n.a.	n.a.	2 (13)	n.a.	n.a.	
7th floor	1 (7)	n.a.	n.a.	1 (7)	n.a.	n.a.	
Fenestration/windows							
Number of openable windows		5 (4)	0–14		4 (4)	0–12	0.639 ^a
0	4 (27)	n.a.	n.a.	6 (40)	n.a.	n.a.	
1–5	6 (40)	n.a.	n.a.	5 (33)	n.a.	n.a.	
6–10	3 (20)	n.a.	n.a.	3 (20)	n.a.	n.a.	
11–15	2 (13)	n.a.	n.a.	1 (7)	n.a.	n.a.	

Table 2. Cont.

Offices' Characteristics	Group A (n = 15)			Group B (n = 15)			p Value
	n (%)	Mean (SD)	Min–Max	n (%)	Mean (SD)	Min–Max	
Orientation (number of windows)							
North (N, NW, and NE)	2 (18)	3 (1)	2–4	2 (22)	3 (1)	2–4	1.000 ^a
South (S, SW, and SE)	4 (36)	4 (3)	2–8	4 (44)	6 (2)	4–8	0.810 ^a
West (W)	7 (64)	3 (2)	1–6	5 (56)	3 (2)	1–6	0.411 ^a
East (E)	7 (64)	4 (2)	1–6	4 (44)	5 (3)	2–9	0.290 ^a
Opening windows during cleaning procedures							
Always	1 (9)	n.a.	n.a.	3 (33)	n.a.	n.a.	
Often	1 (9)	n.a.	n.a.	0 (0)	n.a.	n.a.	
Sometimes	3 (27)	n.a.	n.a.	2 (22)	n.a.	n.a.	
Never	6 (55)	n.a.	n.a.	4 (44)	n.a.	n.a.	
Glassed facade area (m ²)		31 (20)	6–77		33 (19)	14–90	0.662 ^a
Solar shading							
Internal	15 (100)	n.a.	n.a.	15 (100)	n.a.	n.a.	
External	2 (13)	n.a.	n.a.	1 (7)	n.a.	n.a.	
Solar control		n.a.	n.a.		n.a.	n.a.	
Individual	15 (100)	n.a.	n.a.	15 (100)	n.a.	n.a.	
Automatic	0 (0)	n.a.	n.a.	0 (0)	n.a.	n.a.	
Indoor plants (number of pots)	3 (20)	2 (4)	0–14	8 (53)	6 (8)	0–22	0.061 ^a
Electronic equipment							
Computers (number of devices)	15 (100)	20 (7)	8–30	15 (100)	18 (4)	12–24	0.549 ^b
Printers (number of devices)	5 (33)	1 (0)	1–1	2 (13)	1 (0)	1–1	0.203 ^a
Use of cleaning products							
Without bleach and ammonia	15 (100)	n.a.	n.a.	15 (100)	n.a.	n.a.	
Spray	9 (60)	n.a.	n.a.	9 (60)	n.a.	n.a.	
Liquid	6 (40)	n.a.	n.a.	8 (53)	n.a.	n.a.	
Frequency (times per week)		5 (0)	5–5		5 (0)	5–5	1.000 ^a
Signs of indoor pathologies							
Physical	0 (0)	n.a.	n.a.	2 (13)	n.a.	n.a.	
Moisture-related	0 (0)	n.a.	n.a.	1 (7)	n.a.	n.a.	
Surface walls							
Painted	15 (100)	n.a.	n.a.	15 (100)	n.a.	n.a.	
Total glassed	3 (20)	n.a.	n.a.	2 (13)	n.a.	n.a.	
Surface floor							
Plastic (vinyl/PVC)	8 (53)	n.a.	n.a.	7 (47)	n.a.	n.a.	
Wood/parquet	2 (13)	n.a.	n.a.	1 (7)	n.a.	n.a.	
All carpet	5 (33)	n.a.	n.a.	7 (47)	n.a.	n.a.	
Surrounding outdoor sources at distance up to 100 m							
Traffic-related	15 (100)	n.a.	n.a.	15 (100)	n.a.	n.a.	
Busy road	13 (87)	n.a.	n.a.	12 (80)	n.a.	n.a.	
Highway	3 (20)	n.a.	n.a.	2 (13)	n.a.	n.a.	
Car parking	15 (100)	n.a.	n.a.	15 (100)	n.a.	n.a.	
Gas stations	3 (20)	n.a.	n.a.	2 (13)	n.a.	n.a.	
Commercial	4 (27)	n.a.	n.a.	6 (40)	n.a.	n.a.	
Laundry	3 (20)	n.a.	n.a.	2 (13)	n.a.	n.a.	
Coffee bar	4 (27)	n.a.	n.a.	6 (40)	n.a.	n.a.	
Other	4 (27)	n.a.	n.a.	6 (40)	n.a.	n.a.	
Green/forested area	3 (20)	n.a.	n.a.	2 (13)	n.a.	n.a.	

Group A: intervention group; Group B, control group (resulting from random assignment). n (%), where n refers to the total number of office spaces assigned to the respective group that presents the referred characteristic; %, the respective percentage in the total number of the valid cases. For characteristics that are metric variables, the mean, minimum, and maximum values registered are presented. Max, maximum; Min, minimum; n.a., not applicable; PVC, polyvinyl chloride; SD, standard deviation. ^a Mann–Whitney U test; ^b t-test.

Concerning the information collected during the monitoring work, the number of occupants/workers in the offices slightly varied between groups (average number of

workers: intervention group—13; control group—11). The observed occupancy density was 0.15 person/m² for the intervention group, while in the control group, it was 0.12 and 0.11 person/m² in the pre-intervention and intervention phases, respectively. From the comparison between groups, in the pre-intervention phase, similar occupancy levels were observed ($U = 70.5$, $z = -1.745$, $p = 0.081$); however, significant differences were found ($t(28) = -2.40$, $p = 0.023$) for the intervention phase. In all offices, cleaning procedures were carried out once per working day, typically using products without bleach or ammonia. Cleaning procedures occurred before the working period (before 9 a.m.) in 20 (67%) offices (Group A, $n = 11$; Group B, $n = 9$) and after the working period (after 6 p.m.) for the remaining (33%) offices (Group A, $n = 4$; Group B, $n = 6$).

The characteristics of the six office buildings of which the 30 offices are part are described in the preliminary IEQ assessment work [27].

3.2. Indoor Environmental Quality in the Offices Surveyed and Influencing Factors

Indoor environmental data obtained for offices of both study groups are presented in Table 3.

Table 3. Descriptive statistics for IAQ, thermal comfort, lighting, and acoustic conditions obtained for the sample of study offices during each assessment phase.

		Pre-Intervention Phase				Intervention Phase			
		Group A (n = 15)		Group B (n = 15)		Group A (n = 15)		Group B (n = 15)	
Parameter		Mean (SD)	Min–Max	Mean (SD)	Min–Max	Mean (SD)	Min–Max	Mean (SD)	Min–Max
Indoor air quality									
PM _{2.5} , µg/m ³		8.4 (2.7)	5.0–13.0	12.7 (6.9)	2.0– 27.0	11.7 (4.6)	5.0–19.0	8.4 (3.9)	4.0–19.0
PM ₁₀ , µg/m ³		10.2 (2.5)	6.0–14.0	15.7 (8.4)	2.0–34.0	13.7 (5.4)	5.0–22.0	10.2 (4.6)	5.0–23.0
UFPs, pt/cm ³		4112 (2873)	522– 10,705	4189 (2939)	1251– 10,254	4093 (2932)	459– 11,239	3741 (2822)	724–9426
CO ₂ , ppm		788 (204)	538– 1277	791 (192)	518– 1214	787 (198)	565– 1278	815 (208)	546– 1290
O ₃ , µg/m ³		5 (6)	<LOD–18	7 (8)	<LOD–23	5 (6)	<LOD–22	7 (11)	<LOD–36
VOCs, µg/m ³		161 (183)	41– 719	123 (89)	<LOD–279	139 (105)	32–376	149 (76)	74–355
Thermal comfort									
Temperature, °C		22.7 (1.2)	20.3– 24.6	23.3 (0.8)	22.3– 24.7	23.4 (1.4)	20.2– 25.2	22.7 (1.5)	19.6– 25.0
RH, %		45.1 (7.4)	34.1–55.2	42.2 (8.4)	27.7–57.5	44.5 (10.8)	23.8– 65.4	47.4 (9.9)	26.5– 62.3
PMV	Morning	0.01 (0.26)	−0.38–0.59	0.19 (0.28)	−0.11–0.84	0.03 (0.28)	−0.47–0.53	−0.03 (0.35)	−0.79–0.51
	Afternoon	0.25 (0.23)	−0.18–0.62	0.39 (0.25)	0.08–0.95	0.22 (0.22)	−0.09–0.60	0.26 (0.20)	−0.20–0.59
PPD, %	Morning	6.4 (2.0)	5.0–12.3	7.3 (4.1)	5.0–19.8	6.6 (1.7)	5.1–11.0	7.4 (3.6)	5.0–18.0
	Afternoon	7.3 (2.5)	5.0–13.1	9.5 (5.1)	5.2–24.2	6.9 (2.4)	5.0–12.6	7.3 (2.0)	5.1–12.4
Lighting									
Illuminance, lux	Task areas	688 (132)	509–959	652 (232)	182 –1126	712 (213)	468 –1260	823 (826)	184 –3726
	Surroundings	651 (145)	470–922	639 (226)	181 –1058	685 (217)	439–1246	802 (786)	191 –3544
Acoustics									
LAeq, dB(A)	Morning	49.2 (4.1)	43.4–56.4	48.4 (4.3)	43.4–56.4	49.0 (4.6)	43.3–60.2	49.8 (4.1)	41.8–56.2
	Afternoon	49.3 (3.1)	44.5–56.1	49.1 (4.2)	42.9–57.6	49.0 (3.5)	45.3–57.7	50.1 (4.4)	40.7–56.4
LCpeak, dB(C)	Morning	70.6 (3.8)	62.8–75.7	68.7 (3.7)	65.0–74.5	69.5 (3.6)	63.0–76.7	70.6 (4.2)	64.2–77.0
	Afternoon	70.4 (3.9)	62.7–77.0	70.2 (4.3)	64.5–78.2	70.5 (2.8)	66.2–76.5	70.6 (4.5)	63.7–78.5

Group A: intervention group; Group B, control group. CO₂, carbon dioxide; LAeq, A-weighted sound level (average); LCpeak, C-weighted peak sound level; LOD, limit of detection; Max, maximum; Min, minimum; O₃, ozone; PM, particulate matter; PMV, predicted mean vote; PPD, predicted percentage of dissatisfied; RH, relative humidity; SD, standard deviation; UFPs, ultrafine particles; VOCs, volatile organic compounds. Values in **bold** represent results out of recommendations.

As shown in Table 3, the measured levels of most IEQ parameters varied significantly across the surveyed offices. Notably, based on the lowest and highest average levels obtained, UFPs was the parameter that exhibited the greatest variation. In turn, concentrations of CO below the LOD were recorded in all the offices.

Airborne particle concentrations (PM_{2.5} and PM₁₀; Figure 2) were, in general, below national (PM_{2.5}: 25 µg/m³ (8 h mean); PM₁₀: 50 µg/m³ (8 h mean) [34]) and WHO (PM_{2.5}: 15 µg/m³ (24 h mean); PM₁₀: 45 µg/m³ (24 h mean) [35]) recommendations. Mean values exceeding the WHO guideline values were only obtained for PM_{2.5} in 10 (33%) offices. Regarding UFPs, one office had high mean UFP levels (above 20,000 pt/cm³ [35]) but for

a period of less than an hour (for around 20 min). Low mean UFP levels (<1000 pt/cm³) were only found in two (7%) offices (Figure 2).

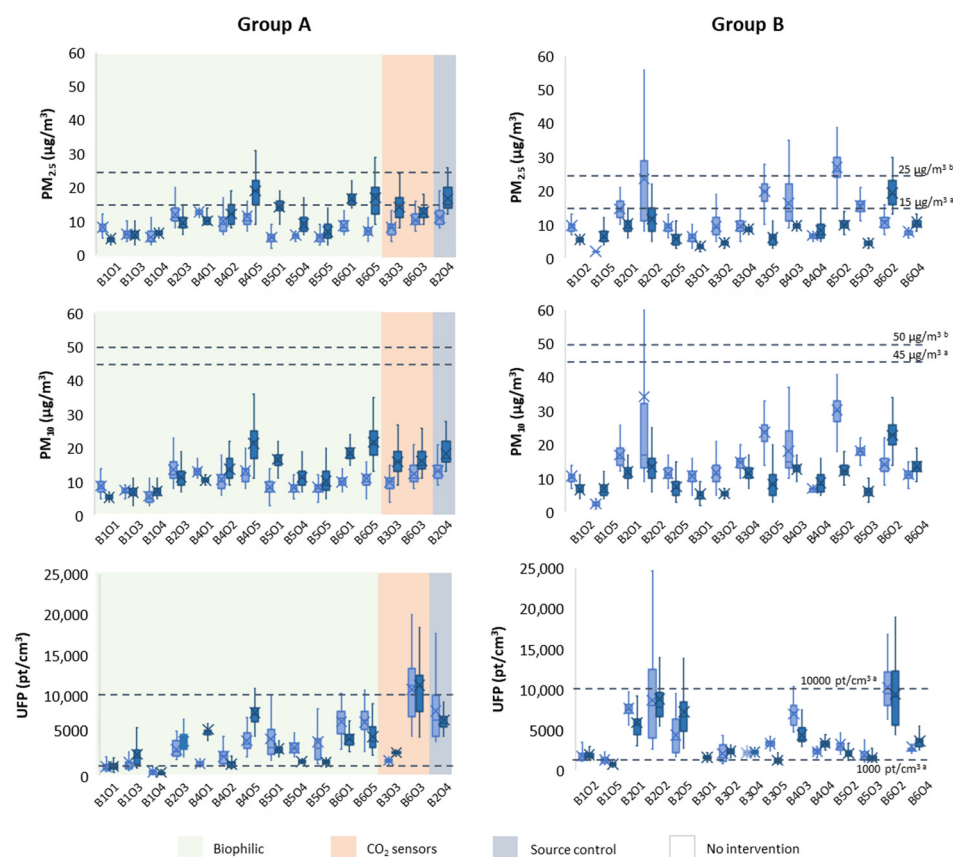


Figure 2. Box plot representing particulate matter (PM_{2.5} and PM₁₀) and ultrafine particle (UFP) levels obtained for offices of intervention (A) and control (B) groups. The **bottom** and the **top** of the boxes represent the 25th and 75th percentiles. The band near the middle of the box and the X represent the median and the mean values, respectively. The ends of the whiskers indicate the 10th and 90th percentiles. Outliers values are not represented. ^a WHO [35] and ^b national recommended limit values [34].

In terms of VOCs, total mean concentrations that exceeded the Portuguese limit of 600 µg/m³ (8 h mean) [34] were only found in one office space (Figure 3). O₃ concentrations consistently remained below the WHO guideline of 100 µg/m³ (8 h mean) [35] for both study groups and phases.

Figure 4 shows indicators of ventilation and hygrothermal conditions in each office and study phase. Mean CO₂ concentrations above 1000 ppm, which is considered a good or excellent IAQ level for indoor environments [36], were found in six (20%) offices, while two (7%) offices presented levels above the national limit of 1250 ppm for the 8 h mean [34]. The hygrothermal conditions widely varied among the sample of offices evaluated. However, the majority of office spaces had air temperature and relative humidity levels within the recommended ranges set by OSHA (20–24.4 °C and 20–60%) [37]. Mean air temperature slightly outside of the recommended range was recorded for six (20%) offices, and mean RH levels above 60% were recorded for three (10%) offices. The PMV and PPD indexes for calculated thermal comfort are shown in Figure 5, with only two (7%) offices in Group B out of comfort categories.

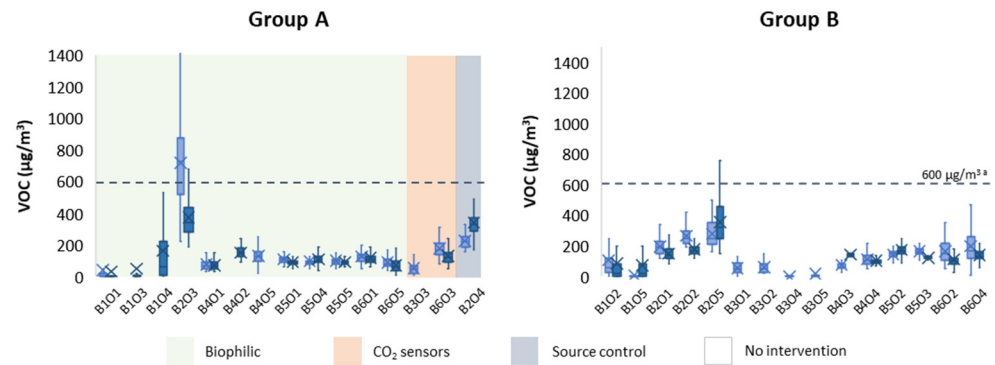


Figure 3. Box plot representing volatile organic compound (VOC) concentrations obtained for offices of intervention (A) and control (B) groups. The boxes' bottom and top represent the 25th and 75th percentiles. The band near the middle of the box and the X represent the median and the mean values, respectively. The ends of the whiskers indicate the 10th and 90th percentiles. Outliers values are not represented. ^a National recommended limit value [34].

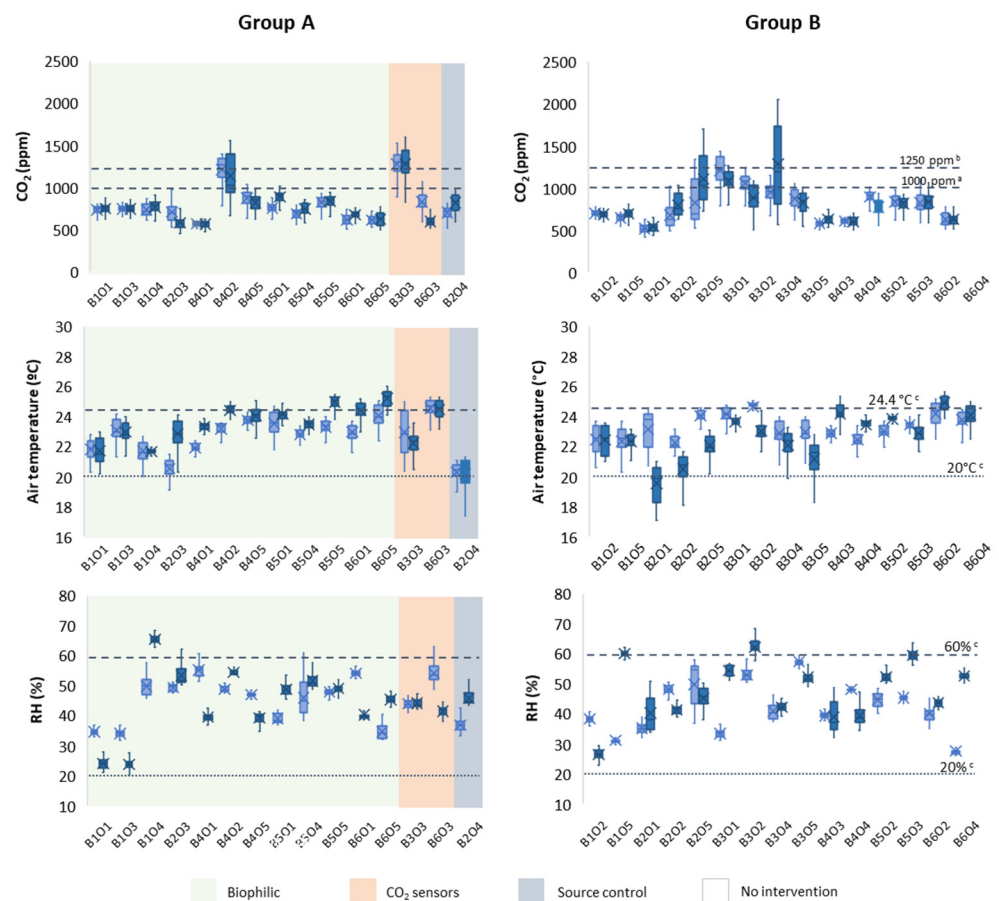


Figure 4. Box plot representing ventilation conditions (CO₂), air temperature, and relative humidity (RH) levels obtained for offices of intervention (A) and control (B) groups. The boxes' bottom and top represent the 25th and 75th percentiles. The band near the middle of the box and the X represent the median and the mean values, respectively. The ends of the whiskers indicate the 10th and 90th percentiles. Outliers values are not represented. ^a Level for excellent or good IAQ [36], ^b national recommended limit value [34], and ^c OSHA recommended ranges [37].

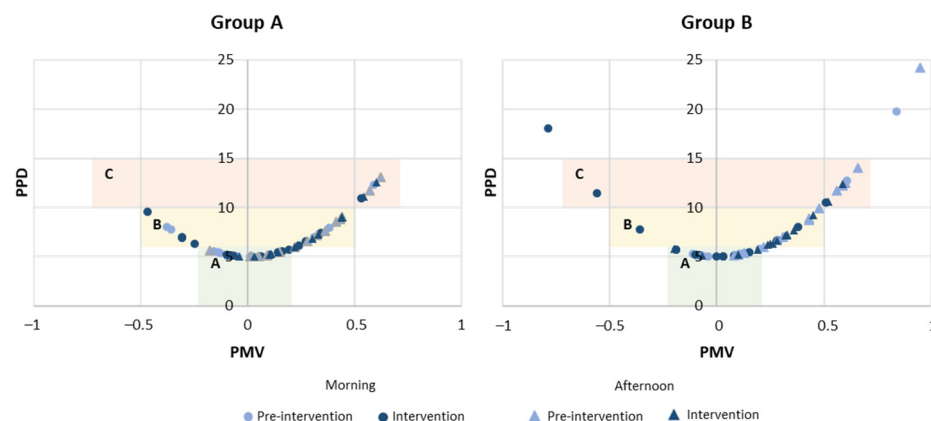


Figure 5. Thermal comfort indexes PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) obtained for offices of intervention (A) and control (B) groups, distributed by categories of thermal environmental (A—green, B—yellow, and C—orange) [30].

Illuminance levels assessed in the task and surrounding areas are presented in Figure 6. The mean illuminance levels were mostly above the minimum limits of 500 and 300 lux in task areas (activity of writing, typing, reading, and data processing) and surrounding areas, respectively, defined in ISO 8995-1 [31]. Exceptions were observed for five (17%) of the offices regarding task area illuminance and in two (7%) of the offices for surroundings illuminance levels. Illuminance uniformity assessed in the task areas was consistently 0.9, while in the surrounding areas, it ranged from 0.7 to 0.9.

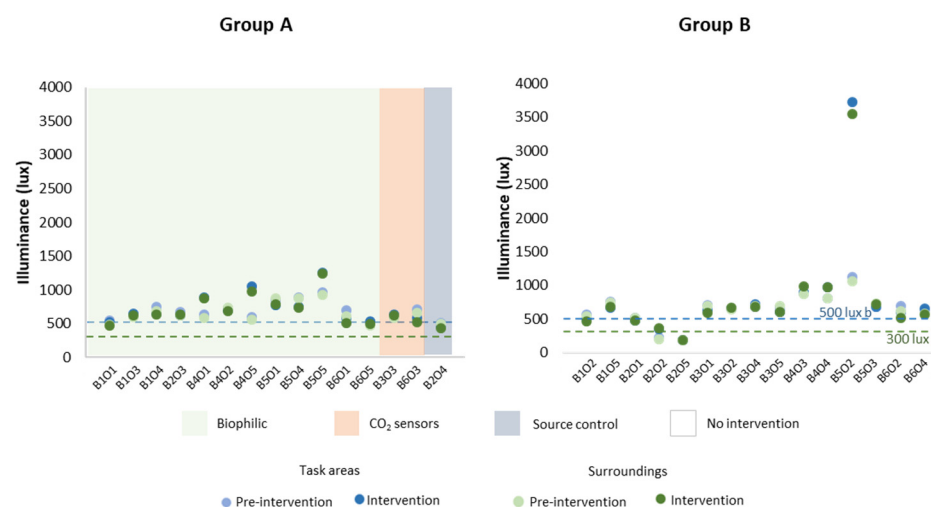


Figure 6. Mean illuminance levels registered in task areas and immediate surroundings obtained for offices of intervention (A) and control (B) groups. ^{a,b} Minimum required illuminance levels for immediate surroundings and task areas, respectively [31].

The noise levels were low for both study groups, as shown in Figure 7. The mean noise levels were consistently below both OSHA [16] and the national exposure limits [38] of 90 (A) and 87 (A) dB for 8 h mean, respectively. The peak noise levels also remained below the national limit of 140 dB (C) for all study groups and phases.

IEQ data collected during the pre-intervention assessment phase were used to test the existence of statistical associations with building and office characteristics to investigate the impact of influencing factors not related to interventions. The findings revealed a significant correlation between CO₂ levels and density of occupancy ($r_s = 0.604$, $p < 0.001$), with lower CO₂ concentrations associated with a greater glass area ($r_s = -0.395$, $p = 0.031$) and greater number of windows ($r_s = -0.575$, $p < 0.001$). Additionally, the analysis of daily

log sheet data showed that opening windows resulted in a decrease in mean CO₂ levels (798 to 682 ppm) but led to a significant increase in airborne particles (PM_{2.5}, PM₁₀, and UFPs) and O₃ concentrations (PM_{2.5}: 10 to 14 µg/m³, $U = 35.0$, $z = -2.494$, $p = 0.013$; PM₁₀: 12 to 17 µg/m³, $U = 38.5$, $z = -2.334$, $p = 0.020$; UFPs: 27,936 to 7798 pt/cm³, $U = 6.0$, $z = -3.806$, $p < 0.001$; O₃: 4 to 10 µg/m³, $U = 42.0$, $z = -2.094$, $p = 0.036$).

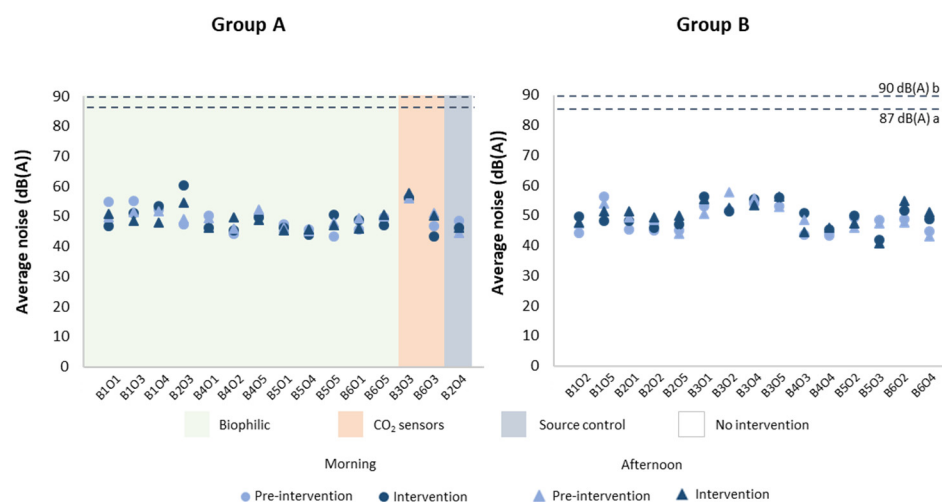


Figure 7. Average noise levels obtained in the morning and afternoon for offices of intervention (A) and control (B) groups. ^a Portuguese exposure maximum limit [38] and ^b OSHA permissible exposure limit [16].

The mean I/O PM₁₀ concentration ratio for the pre-intervention phase was 0.57, ranging from 0.19 to 1.36. Although there was no significant correlation between indoor particle concentrations and offices with carpeted floors, there were significantly higher I/O PM₁₀ ratios in carpeted offices (0.68 vs. 0.41, $t(22) = -2.683$, $p = 0.014$). Offices with carpeted floors also had a higher indoor air temperature (23.4 vs. 22.6 °C, $t(28) = -2.248$, $p = 0.033$). Additionally, significantly higher VOC levels were measured in offices with wooden floors (380 vs. 110 µg/m³: $U = 5.0$, $z = -2.392$, $p = 0.017$). Offices cleaned before the working period had 1.8 times higher VOC concentrations compared to offices cleaned after 6 p.m. ($U = 26.0$, $z = -2.830$, $p = 0.005$), indicating the influence of cleaning procedures on IAQ during working hours.

Offices with printers showed a trend of higher levels of PM_{2.5} and PM₁₀ in 11% and 7%, compared to office spaces without printer equipment. Additionally, buildings with green certifications (B1—LEED and B5—BREEAM) were found to have low levels of UFPs (2385 vs. 5078 pt/cm³), VOCs (96 vs. 159 µg/m³), and CO₂ (756 vs. 807 ppm) compared to conventional buildings.

The investigation of the associations between the levels of environmental (IAQ and hygrothermal) parameters (Table 4) showed that levels of CO₂ were strongly correlated with indoor air temperature but negatively correlated with O₃ concentrations. Additionally, positive associations were estimated between PM_{2.5} and PM₁₀ fractions and between PM₁₀ and UFPs for particles. Moreover, levels of UFPs were linked to VOC concentrations.

For the set of offices where monitoring was carried out for 24 h ($n = 19$), the influence of occupants on indoor environmental conditions was also investigated. The study found that VOC concentrations were significantly higher during working hours compared to periods of non-occupancy (pre-intervention (mean: 128 vs. 64 µg/m³): $U = 83.5$, $z = -2.101$, $p = 0.036$; intervention (mean 149 vs. 62 µg/m³): $U = 47.0$, $z = -2.717$, $p = 0.007$). Similarly, significantly higher levels of CO₂ were recorded during working hours (pre-intervention (mean 770 vs. 509 ppm): $U = 18.0$, $z = -4.744$, $p < 0.001$; intervention (mean 814 vs. 584 ppm): $U = 39.0$, $z = -4.131$, $p < 0.001$). In addition, significantly higher temperatures

were observed during occupancy compared to non-occupancy periods, specifically for the pre-intervention phase (mean 22.9 vs. 21.5 °C: $t(36) = 4.148$, $p < 0.001$).

Table 4. Spearman correlation coefficients for IAQ and hygrothermal conditions parameters in the pre-intervention phase.

	CO ₂	Temperature	RH	O ₃	VOCs	PM _{2.5}	PM ₁₀	UFPs
CO ₂	1							
Temperature	0.419 *	1						
RH	0.162	−0.037	1					
O ₃	−0.678 ***	−0.225	−0.284	1				
VOCs	−0.227	0.066	0.144	0.161	1			
PM _{2.5}	0.027	−0.092	0.299	0.119	0.347	1		
PM ₁₀	0.114	0.066	0.196	0.142	0.284	0.944 ***	1	
UFPs	−0.150	0.351	0.079	0.309	0.553 **	0.337	0.416 *	1

CO₂, carbon dioxide; O₃, ozone; PM, particulate matter; RH, relative humidity; UFPs, ultrafine particles; VOCs, volatile organic compounds. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at 0.01 level (2-tailed). *** Correlation is significant at 0.001 level (2-tailed).

3.3. Results of the Effects of the Intervention Plan on Office IEQ

To assess the impact of environmental interventions, the intervention offices were grouped according to the type of intervention conducted. The potential effects of the interventions were investigated, focusing on the parameters that are known to be impacted by the respective interventions (source control: PM_{2.5}, PM₁₀, UFPs, VOCs, and O₃; CO₂ sensors: CO₂; indoor plants: CO₂, PM_{2.5}, PM₁₀, and VOCs). The results of specific environmental interventions on IEQ conditions are discussed below and presented in Table 5.

Table 5. Offices with reduction in target pollutants and respective reduction percentage observed from the pre-intervention phase to the intervention phase.

Reduction in the Parameter Levels	PM _{2.5}		PM ₁₀		UFPs		VOCs		O ₃		CO ₂	
	Offices n (%)	Percentage	Offices n (%)	Percentage	Offices n (%)	Percentage	Offices n (%)	Percentage	Offices n (%)	Percentage	Offices n (%)	Percentage
Indoor plants												
Group A (n = 12)	3 (25%)	24%	3 (25%)	25%	7 (58%)	36%	7 (88%) *	30%			3 (25%)	10%
Group B (n = 11)	7 (64%)	47%	7 (64%)	50%	6 (55%)	23%	6 (55%)	5%			5 (45%)	4%
CO ₂ sensors												
Group A (n = 2)											1 (50%)	28%
Group B (n = 6)											2 (33%)	13%
Source control (printer relocation)												
Group A (n = 1)	0 (0%)	0%	0 (0%)	0%	1 (100%)	14%	0 (0%)	0%	1 (100%)	85%		
Group B (n = 3)	2 (66%)	9%	2 (66%)	13%	1 (33%)	23%	2 (66%)	29%	1 (33%)	65%		

CO₂, carbon dioxide; O₃, ozone; PM, particulate matter; UFPs, ultrafine particles; VOCs, volatile organic compounds. * Data available for 8 offices.

3.3.1. Indoor Plants

Indoor plants were placed in 12 offices in locations agreed upon with building managers and office occupants. This biophilic intervention in open-space offices had no statistically significant effect on concentrations of any target air pollutants. For instance, the average CO₂ concentration remained similar between the study phases (751 vs. 760 ppm), and the potential reduction of 10% from pre-intervention phase to intervention phase was only observed for 25% of offices in Group A. In comparison, mean CO₂ levels in control offices increased from 706 to 740 ppm and decreased by 4% in 45% of the office spaces (Table 5). In both phases of the study, occupancy levels of offices in both Group A and Group B remained consistent (0.16 and 0.09 person/m², respectively). In terms of natural ventilation, on average, windows were opened for shorter periods in offices of Group A (pre-intervention: 4 h, intervention: 6 h) than in offices of Group B (pre-intervention: 6 h, intervention phase: 6.5 h).

On average, the levels of airborne particles (PM_{2.5} and PM₁₀) increased slightly, with only 25% of the intervened offices showing a reduction from the pre-intervention phase to

the intervention phase (Table 5). Unexpectedly, the percentage of offices with a reduction in PM concentrations in Group B was even higher than that observed in Group A. For UFP levels, while 58% of offices experienced alleviation of UFP concentration between study phases, an overall non-significant reduction in UFP counts (36%) was obtained. Unfortunately, this outcome cannot be validated as an intervention effect because a similar trend was observed for offices in Group B (mean reduction: 23%), with a reduction detected in 55% of the assessed spaces.

Interestingly, a potential intervention-related effect was more evident for VOC levels (Table 5), with 88% of the offices that underwent intervention showing a decrease (mean reduction of 30%) in VOC concentrations from the pre-intervention phase ($p = 0.069$). While a reduction was observed in offices in Group B, it was only by 5% on average. The difference between the percentage reduction in VOC concentrations in Group A and Group B was not statistically significant. Furthermore, the highest VOC concentration obtained in the pre-intervention phase ($719 \mu\text{g}/\text{m}^3$) decreased by about half. Regarding hygrothermal conditions, significantly higher air temperatures were found in offices of Group A during the intervention phase compared to the pre-intervention phase (23.6 vs. 22.7 °C; $t(11) = -3.936$, $p = 0.002$). Also, no significant changes were observed in RH, thermal comfort indexes, illuminance, or noise levels.

3.3.2. CO₂ Sensors

CO₂ sensors were installed in two open spaces (B3O3 and B6O3). Office B3O3 relied solely on a mechanical ventilation system, while office B6O3 had both mechanical and natural ventilation options. In the case of office B6O3, occupants were instructed to open windows when CO₂ levels exceeded 1000 ppm. CO₂ levels remained similar between study phases for B3O3 (pre-intervention phase: 1277 ppm; intervention phase: 1278 ppm). However, a substantial reduction of 28% was observed in B6O3 (pre-intervention phase: 831 ppm; intervention phase: 597 ppm; $U = 7179$, $z = -26.5$, $p < 0.001$). For offices of Group B, very similar CO₂ levels were measured in both study phases (B3: 1026 and 1022 ppm, B6: 730 and 734 ppm, in pre-intervention and intervention phases, respectively), with only 33% showing a reduction (Table 5). Considering occupancy periods, actions in B3O3 did not have the desired effect, resulting in mean CO₂ levels of 979 ppm without ventilation changes and 1193 ppm with ventilation changes (i.e., turning on or increasing airflow).

Further, it was observed that air particulate matter levels (PM_{2.5} and PM₁₀) significantly increased in the offices that were part of the intervention from the pre-intervention phase to the intervention phase ($p < 0.001$). This increase was more evident in office space B3O3, which relied on mechanical ventilation, than in office B6O3, which promoted natural ventilation. In the control offices of B3, a decrease in particle levels was observed. UFP levels also showed a significant increase between phases in B3O3 ($p < 0.001$). Occupancy remained similar between the study phases (0.13 person/m² in pre-intervention and 0.12 person/m² in intervention).

For space B6O3, because there is robust evidence for the influence of urban ambient particles in naturally ventilated spaces, occupants were instructed to open windows during periods of low traffic and to prioritize windows not facing the main road. During the intervention, there was a decrease in the I/O PM₁₀ ratio from pre-intervention levels of 0.80 to 0.55. In space B3O3, the I/O PM₁₀ ratios were similar (0.42 and 0.43) in the pre-intervention and intervention phases, respectively. In the control offices of B6, an increase in airborne particles was observed, along with an increase in the I/O PM₁₀ ratios (from 0.75 to 0.79).

Changes in thermal comfort were observed for the afternoon period, showing a decrease of 31 and 56% of PPD in B3O3 and B6O3, respectively. In the pre-intervention phase, PPD was already quite low (<7%) in the morning, but there was more room for improvement during the afternoon as levels were almost double (12–13%).

3.3.3. Source Control—Printer Relocation

A potential source of air pollutants (the printer) was moved from an open space to a separate and unoccupied room (office B2O4). The analysis of the impact of the intervention on indoor pollution using minute-by-minute data showed positive results for the UFP and O₃ levels (Table 5), showing a decrease in the mean levels of 14% (from 8072 to 6982 pt/cm³) and 85% (from 13 µg/m³ to <LOD), respectively. In contrast, in control offices, the mean levels increased by 6% for UFPs (from 6891 to 7310 pt/cm³) and 36% for O₃ (from 11 to 15 µg/m³). However, 33% of the control offices also exhibited a reduction in the airborne levels, by 23% and 65% for UFPs and O₃, respectively (Table 5).

Despite this, the concentrations of airborne particles (PM_{2.5} and PM₁₀) significantly increased (PM_{2.5}: $U = 12069$, $z = -25.7$, $p < 0.001$; PM₁₀: $U = 23697$, $z = -23.3$, $p < 0.001$) in the offices of Group A but significantly decreased in offices of Group B ($p < 0.001$). As natural ventilation was common in this building, it is important to consider the levels of ambient particles. In fact, the I/O PM₁₀ ratio was 0.68 in the pre-intervention phase and 0.82 in the intervention evaluation. In offices of Group B in that building, I/O PM₁₀ ratios also increased between phases (from 0.49 to 0.84). VOC concentrations also significantly increased ($U = 17408$, $z = -24.2$, $p < 0.001$), while no significant change was observed for offices belonging to Group B.

4. Discussion

This is the first study to implement an environmental intervention program tailored to the improvement opportunities identified for each study office, incorporating source control, ventilation, and biophilic-based solutions. A comprehensive set of IEQ parameters was continuously monitored in real office conditions for a full workday during the pre-intervention and intervention phases.

This study found that in a few offices, measured levels of air pollutants were above the recommended exposure limit values defined in the national and international standards [34,35]. Airborne PM_{2.5} and PM₁₀ concentrations obtained were 2.5 and 4 times lower compared to the concentrations reported by previous worldwide studies [8] but similar to the levels measured in a European office studies [39]. For the samples of offices assessed, opening windows significantly contributed to the increase in indoor PM levels. For instance, it was observed that the majority of offices (90%) had PM₁₀ I/O concentration ratios lower than 1, indicating that ambient air was the main contributor to indoor particle levels. However, there were instances where the I/O ratio exceeded 1, demonstrating the existence of important indoor sources of air pollutants. Among the assessed office characteristics, the presence of carpets was identified as a significant influencing factor. In addition, PM_{2.5} and PM₁₀ levels were correlated, which was also detected for schools located in the same region [40]. The UFP levels showed a wide range, about twice the levels obtained in recent studies [41]. The VOC concentrations were in line with the results for Finnish offices [42] but 2.6-fold lower than levels reported in other Portuguese offices located in urban areas [10]. This study provides evidence suggesting that levels of VOCs in offices significantly increase due to occupancy, the presence of wooden floors, and cleaning procedures conducted immediately before working hours. In fact, it is well known that products used during floor cleaning can emit VOCs, such as limonene [43]. In relation to O₃, the concentrations assessed were, on average, eight times lower than those reported for other Portuguese offices [10], but two times higher than the levels found in European-wide study [39]. O₃ levels seemed to be impacted by natural ventilation. In this study, the opening of windows promoted an increase in indoor O₃ concentrations. Using CO₂ as a proxy for ventilation, some offices presented poor ventilation conditions. Mean CO₂ levels were slightly higher than those obtained in other works [8]. Levels of CO₂ in the studied offices were influenced by the density of occupancy, glass area, number of windows, and natural ventilation (through window openings). These levels were also negatively linked with O₃ concentrations, as reported in previous work in schools of the same region [40].

This could be due to the influence of natural ventilation through opened windows, as reported in the literature [44].

The hygrothermal conditions were similar to previous measurements in national offices [10], but RH was higher compared to European offices during the same season [45]. Higher temperatures were detected for carpeted offices and in spaces with greater occupancy. In terms of the thermal environment categories [30], most of the offices fell within the thermal comfort category A. Overall, a neutral to slightly warm sensation was obtained, consistent with previous findings [4]. The mean illuminance levels obtained for the sample of studied offices, illuminance uniformity, and noise levels were similar to those in previous studies [4,41].

Regarding the effect of environmental interventions, indoor plants are known to have the potential to reduce CO₂, PM, and VOC [24,25] levels. However, the findings from this study do not strongly support this, as a non-significant decreasing trend in 88% and 58% of the studied offices was observed for VOCs and UFPs and none for CO₂ and PM. The decrease in VOC and UFP concentrations was more significant for offices of Group A than Group B. It is of utmost importance to note that these outcomes were obtained from the implementation of a well-defined study design that included the combination of *Sansevieria trifasciata*, *Dracaenas fragrans*, and *Chlorophytum comosum* plant species and one pot per 9 m² in a sample of offices that presented, in general, acceptable levels of IEQ. The use of different criteria (e.g., employing other indoor plant species, a higher number of pots per area [22], etc.) could result in different outcomes.

It is well known that CO₂ levels can be strongly impacted by occupancy and ventilation conditions. During the intervention phase, on average, windows were kept open for longer periods (+2 h) than in the pre-intervention phase. However, because the fieldwork only focused on whether windows were open and did not collect data on the number of windows or the size of the openings, the possibility that differing ventilation patterns may have influenced the CO₂ outcomes obtained should not be excluded. Previous studies have indicated that higher light intensity appears to increase CO₂ assimilation rates by indoor plants [28]. In this study, in the intervened offices with high illuminance levels (two offices with levels above 1000 lux at task areas), the average CO₂ levels decreased from 845 in the pre-intervention phase to 826 ppm in the intervention phase. In contrast, in offices with illuminance below 1000 lux, CO₂ levels increased from 733 to 746 ppm.

Although several studies have presented evidence of plants' ability to absorb airborne particles [25], the findings from this study do not align with that perspective. In this regard, previous studies have reported that indoor plants can remove particles in stable environments during periods of non-occupancy [46], which was not the case in the current study. Additionally, the obtained increase in particles in offices of the intervention group was also observed for the I/O PM₁₀ ratios (from 0.50 to 0.71), indicating a greater contribution of indoor sources from the pre-intervention phase to the intervention phase. A previous study by Hong et al. also found an increase in PM concentration after introducing potted plants in two daycare facilities, which they attributed to fluctuations in outdoor PM levels during the monitoring period [47]. For instance, although the evidence in the literature is limited, based on the evidence provided in this study it cannot be ruled out that indoor plants could serve as a significant source of particles in indoor environments.

Indoor plants may have varying capacities to absorb different species of pollutants. For instance, they can have an impact in reducing only some specific VOCs [47]. This study does not address this variation, as VOC identification was not conducted and the intervention effect was only assessed based on the total VOC concentration.

Indoor air temperature also increased from the pre-intervention phase to the intervention phase. Although the literature suggests that indoor plants help regulate indoor temperature [25], the current study indicates that temperature changes appear to be more closely related to outdoor temperatures. In that regard, ambient temperature also increased between the study phases (from 13.4 to 15.0 °C), and indoor air temperatures were signifi-

cantly correlated with outdoor temperature in the intervention phase ($r = 0.737$, $p = 0.006$), suggesting the influence of ambient temperature, as described in previous works [48].

The results obtained for interventions with CO₂ sensors suggest that natural ventilation can effectively reduce CO₂ concentrations in the workplace, provided that occupants are educated in identifying high CO₂ situations, aligning with previous studies [49]. In fact, the office ventilated exclusively by a mechanical system had higher CO₂ levels than office spaces with both mechanical and natural ventilation options. Additionally, actions were taken to dilute CO₂ concentrations more frequently in the office with natural ventilation. Moreover, results appeared to indicate that CO₂ concentrations continued to increase despite ventilation changes in offices ventilated exclusively by a mechanical system, and the decrease was only observed for low and non-occupancy periods. The increase in airborne particles could be related to the intervention implemented. In fact, according to the association reported in Section 3.2, these findings strongly indicate that while interventions implementing CO₂ sensors and natural ventilation have a high potential to dilute CO₂ levels, they can also introduce urban ambient air pollutants into the indoor environment. According to outdoor data, a higher contribution of outdoor particles to the office with both ventilation strategies occurred. Thermal comfort change suggests that these interventions could help remind office workers to actively adjust thermal conditions.

In previous studies, interventions implementing source control-based approaches investigated the impact of replacing carpet flooring with a low-emitting vinyl floor on workers' perception, comfort, and health symptoms but did not evaluate the effect on IEQ conditions [41]. Although printers are recognized as a potentially significant source of pollutants [50], this is the first study to implement a source control-based intervention consisting of the removal of the printer from an office room. The results showed that, although UFP and O₃ levels reduced from the pre-intervention phase to the intervention phase, PM_{2.5}, PM₁₀, and VOC levels increased. In fact, outdoor particles were higher than indoor levels in both study phases. The contradictory findings may be attributed to the assembly of new furniture taking place near the open office during the intervention period. It cannot be ruled out that this event may have had a significant influence on these outcomes.

Overall, some inconsistent results were observed for all the interventions implemented, likely due to limited room for improvement, as most of the office spaces studied exhibited acceptable IEQ conditions with no significant issues identified. Additionally, the numerous factors that can influence IEQ levels make evaluating the effects of interventions quite challenging. Indeed, potential avenues for improvement may arise from the weaknesses identified in the obtained results. Specifically, the number of offices included in the study design is in line with previously published works, in which 1–24 offices and 1–6 buildings were typically selected for intervention studies [18]. However, a larger number of intervened offices would be needed to obtain more extensive and representative data, allowing for a clearer depiction of the achieved IAQ improvements while offering a greater statistical significance of the findings. Similarly, extending the assessment period beyond a single workday and collecting information on relevant influencing factors—including those not addressed in this study, such as the number of windows opened, their area, and location—could improve representativity and reduce the impact of sources of uncertainty in future research.

5. Conclusions

This study implemented an intervention program designed to cover the entire process, from the identification of risk factors to the evaluation of the effect of low-cost and easy-to-implement actions to promote IEQ. Significant factors influencing IEQ conditions in modern Portuguese office buildings were identified. The main findings are as follows:

- The type of flooring material seems to be an important determinant of IEQ. Offices with carpeted floors showed significantly higher I/O PM₁₀ concentration ratios and indoor temperatures of about 1 °C. This suggests that although the existence of carpets

can contribute to improving thermal comfort in offices during the heating season, they can also increase exposure to indoor-originated suspended particles. On the other hand, offices with wooden floors had significantly higher total VOC concentrations.

- Offices with opened windows during the assessments had 14% lower CO₂ concentrations but 40–200% higher levels of airborne particles (PM and UFPs) and O₃, indicating that while natural ventilation can improve air renewal, it can also increase the contribution of outdoor pollutants to indoor air.
- The timing of cleaning appears to affect the air quality during working hours. Cleaning procedures conducted just before working hours were found to significantly increase exposure to VOCs by almost two times and thus should be avoided.
- Occupants are likely to be a relevant source of VOCs, as concentrations were two times higher during working hours than in non-occupancy periods.

In addition, only a few office spaces under study presented IEQ conditions outside of recommended exposure limits, namely, for airborne particles, VOCs, CO₂, and illuminance. Despite limited room for improvement, as anticipated in the pre-intervention assessments, an environmental intervention program was conducted to explore the potential impacts on IEQ of low-cost and easy-to-implement measures by executing an RCT. Even though the effectiveness of interventions in promoting improvements in IEQ was generally inconsistent, the study identified the following key findings:

- Biophilic interventions involving the introduction of plant species having a documented potential for cleaning the air (*Sansevieria trifasciata*, *Dracaenas fragrans*, and *Chlorophytum comosum*) in 12 offices did not lead to significant changes in airborne particles, VOCs, and CO₂ levels between the pre-intervention and intervention phases. However, a trend suggested lower UFP and VOC concentrations (observed in 58% and 88% of offices in the intervention group), while PM levels increased.
- Installing CO₂ sensors to improve ventilation rates resulted in a 28% decrease in CO₂ levels in the office with natural ventilation, but no significant impact was shown in the office relying solely on mechanical ventilation. This intervention also resulted in a significant increase in indoor air particulate matter levels.
- Relocating the printer in one office resulted in an unexpected increase in PM and VOC concentrations, likely due to uncontrollable events during the study, such as furniture assembly. Notably, this intervention was also characterized by a trend suggesting a reduction in UFP and O₃ levels of 14% and 85%, respectively.

Overall, this work enhances the understanding of factors determining IEQ in offices and the effectiveness of environmental interventions in promoting improvements to IEQ. In particular, the outcomes provided can serve as valuable contributions to guide building managers in identifying actions to promote sustainable practices in offices. Although the evidence collected suggests that the beneficial impact of low-cost interventions on IEQ levels is limited in offices with acceptable IEQ, strategies centered on air pollution source control, ventilation optimization, and the use of indoor plants as a cost-effective and environmentally friendly air cleaning solution should still be considered. These approaches are essential for promoting decent working conditions in alignment with SDG 8. The evidence gathered in this study also offers valuable insights for future research. To reduce uncertainty, it is recommended that an extended monitoring campaign and/or intervention period be considered and a greater number of offices be included in further studies. Specifically, for interventions involving indoor plants, increasing the number of pots per area and identifying VOC species could enhance analysis of the pollutants' absorption capabilities. Similarly, it is expected that offices with declared IEQ problems are leading candidates for exploring the potential of environmental interventions to achieve measurable impacts on IEQ.

To gain a broader understanding of the impacts of the intervention program implemented in this work, further steps of the study will include assessing the effects of the interventions on workers' outcomes.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/su16219160/s1>, Figure S1: Implementation of the environmental intervention program: (A) introduction of indoor plants, (B) CO₂ sensors, and (C) source control (printer removal), Figure S2: Example of the equipment position in the office space, Table S1: Specifications of the nondispersive infrared AirokCO₂ sensor; Table S2: Specifications of the equipment used in the IEQ assessments.

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References

- Choi, H.; Kim, H.; Hong, T.; An, J. An individual weightage for indoor environmental quality component to enhance work performance in office buildings. *Build. Environ.* **2023**, *236*, 110278. [\[CrossRef\]](#)
- OECD. Average Usual Weekly Hours Worked on the Main Job. 2024. Available online: <https://data-explorer.oecd.org/> (accessed on 27 May 2024).
- United Nations. The 17 Goals: Sustainable Development Goals. Available online: <https://sdgs.un.org/goals> (accessed on 7 October 2024).
- Felgueiras, F.; Mourão, Z.; Moreira, A.; Gabriel, M.F. Indoor environmental quality in offices and risk of health and productivity complaints at work: A literature review. *J. Hazard. Mater. Adv.* **2023**, *10*, 100314. [\[CrossRef\]](#)
- Lamberti, G.; Boghetti, R.; Fantozzi, F.; Leccese, F.; Salvadori, G. Analysing the potential of open hotel review databases for IEQ assessment: A text mining approach. *Build. Res. Inf.* **2024**, 1–19. [\[CrossRef\]](#)
- Li, P.; Froese, T.M.; Brager, G. Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review. *Build. Environ.* **2018**, *133*, 187–202. [\[CrossRef\]](#)
- Zender-Świercz, E. Review of IAQ in premises equipped with façade-ventilation systems. *Atmosphere* **2021**, *12*, 220. [\[CrossRef\]](#)
- Felgueiras, F.; Mourão, Z.; Moreira, A.; Gabriel, M.F. A systematic review of ventilation conditions and airborne particulate matter levels in urban offices. *Indoor Air* **2022**, *32*, e13148. [\[CrossRef\]](#)
- Kagi, N.; Fujii, S.; Horiba, Y.; Namiki, N.; Ohtani, Y.; Emi, H.; Tamura, H.; Kim, Y.S. Indoor air quality for chemical and ultrafine particle contaminants from printers. *Build. Environ.* **2007**, *42*, 1949–1954. [\[CrossRef\]](#)
- Faria, T.; Almeida-Silva, M.; Dias, A.; Almeida, S.M. Indoor air quality in urban office buildings. *Int. J. Environ. Technol. Manag.* **2016**, *19*, 236–256. [\[CrossRef\]](#)
- Peng, C.Y.; Lan, C.H.; Wu, T.J. Investigation of indoor chemical pollutants and perceived odor in an area with complaints of unpleasant odors. *Build. Environ.* **2009**, *44*, 2106–2113. [\[CrossRef\]](#)
- Torriani, G.; Torresin, S.; Lara-Ibeas, I.; Albatici, R.; Babich, F. Perceived air quality (PAQ) assessment methods in office buildings: A systematic review towards an indoor smellscape approach. *Build. Environ.* **2024**, *258*, 111645. [\[CrossRef\]](#)
- Bluyssen, P.M.; Roda, C.; Mandin, C.; Fossati, S.; Carrer, P.; de Kluizenaar, Y.; Mihucz, V.G.; de Oliveira Fernandes, E.; Bartzis, J. Self-reported health and comfort in ‘modern’ office buildings: First results from the European OFFICAIR study. *Indoor Air* **2016**, *26*, 298–317. [\[CrossRef\]](#) [\[PubMed\]](#)
- Harvey, L.D.D. Using modified multiple heating-degree-day (HDD) and cooling-degree-day (CDD) indices to estimate building heating and cooling loads. *Energy Build.* **2020**, *229*, 110475. [\[CrossRef\]](#)

15. Woo, J.; Rajagopalan, P.; Francis, M.; Garnawat, P. An indoor environmental quality assessment of office spaces at an urban Australian university. *Build. Res. Inf.* **2021**, *49*, 842–858. [\[CrossRef\]](#)
16. OSHA. Occupational Noise Exposure, (n.d.). Available online: <https://www.osha.gov/noise> (accessed on 3 January 2023).
17. Mujan, I.; Anđelković, A.S.; Munćan, V.; Kljajić, M.; Ružić, D. Influence of indoor environmental quality on human health and productivity—A review. *J. Clean. Prod.* **2019**, *217*, 646–657. [\[CrossRef\]](#)
18. Felgueiras, F.; Cunha, L.; Mourão, Z.; Moreira, A.; Gabriel, M.F. A systematic review of environmental intervention studies in offices with beneficial effects on workers' health, well-being and productivity. *Atmos. Pollut. Res.* **2022**, *13*, 101513. [\[CrossRef\]](#)
19. Kelly, F.J.; Fussell, J.C. Improving indoor air quality, health and performance within environments where people live, travel, learn and work. *Atmos. Environ.* **2019**, *200*, 90–109. [\[CrossRef\]](#)
20. Yun, S.; Licina, D. Investigation of indicators for personal exposure and occupancy in offices by using smart sensors. *Energy Build.* **2023**, *298*, 113539. [\[CrossRef\]](#)
21. Schulze, T.; Gürllich, D.; Eicker, U. Performance assessment of controlled natural ventilation for air quality control and passive cooling in existing and new office type buildings. *Energy Build.* **2018**, *172*, 265–278. [\[CrossRef\]](#)
22. Mata, T.M.; Martins, A.A.; Calheiros, C.S.C.; Villanueva, F.; Alonso-Cuevilla, N.P.; Gabriel, M.F.; Silva, G.V. Indoor Air Quality: A Review of Cleaning Technologies. *Environments* **2022**, *9*, 118. [\[CrossRef\]](#)
23. Chuang, K.-J.; Lee, C.-Y.; Wang, S.-T.; Liu, I.-J.; Chuang, H.-C.; Ho, K.-F. The Association between Indoor Carbon Dioxide Reduction by Plants and Health Effects. *Indoor Air* **2023**, *2023*, 1558047. [\[CrossRef\]](#)
24. Liu, F.; Yan, L.; Meng, X.; Zhang, C. A review on indoor green plants employed to improve indoor environment. *J. Build. Eng.* **2022**, *53*, 104542. [\[CrossRef\]](#)
25. Bui, H.-T.; Park, J.; Lee, E.; Cho, W.; Kwon, H.; Park, B.-J. Assessment of the Air Cleaning Performance and Humidity and Temperature Control by Five Evergreen Woody Plants. *Atmosphere* **2023**, *14*, 1819. [\[CrossRef\]](#)
26. Cummings, B.E.; Waring, M.S. Potted plants do not improve indoor air quality: A review and analysis of reported VOC removal efficiencies. *J. Expo. Sci. Environ. Epidemiol.* **2020**, *30*, 253–261. [\[CrossRef\]](#) [\[PubMed\]](#)
27. Felgueiras, F.; Mourão, Z.; Moreira, A.; Gabriel, M.F. Characterizing indoor environmental quality in Portuguese office buildings for designing an intervention program. *Build. Environ.* **2024**, *254*, 111393. [\[CrossRef\]](#)
28. Weerasinghe, N.H.; Silva, P.K.; Jayasinghe, R.R.; Abeyrathna, W.P.; John, G.K.P.; Halwatura, R.U. Reducing CO₂ level in the indoor urban built environment: Analysing indoor plants under different light levels. *Clean. Eng. Technol.* **2023**, *14*, 100645. [\[CrossRef\]](#)
29. Wolverton, B. *How to Grow Fresh Air: 50 Houseplants That Purify Your Home or Office*; Penguin Books: New York, NY, USA, 1996.
30. ISO 7730; Ergonomics of the Thermal Environment. Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. ISO: Geneva, Switzerland, 2005.
31. ISO 8995-1; Lighting of Indoor Work Places—Part 1: Indoor. ISO: Geneva, Switzerland, 2002.
32. APA. QualAR-Qualidade do AR. 2024. Available online: <https://qualar.apambiente.pt/indices> (accessed on 1 April 2024).
33. IPMA. IPMA-Monitorização Diária. 2024. Available online: <https://www.ipma.pt/pt/oclima/monitoriza.dia> (accessed on 22 March 2024).
34. Portaria n.º 138-G/2021 de 1 de Julho, Saúde e Ambiente e Ação Climática. *Diário da República*, 1 July 2021; 2–6.
35. WHO. WHO Global Air Quality Guidelines. Particulate Matter (PM_{2.5} and PM₁₀), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide; World Health Organization: Geneva, Switzerland, 2021.
36. Lowther, S.D.; Dimitroulopoulou, S.; Foxall, K.; Shrubsole, C.; Cheek, E.; Gadeberg, B.; Sepai, O. Low Level Carbon Dioxide Indoors—A Pollution Indicator or a Pollutant? A Health-Based Perspective. *Environments* **2021**, *8*, 125. [\[CrossRef\]](#)
37. OSHA. OSHA Technical Manual (OTM)—Section III: Chapter 2 Indoor Air Quality Investigation, Occupational Safety and Health Administration. Available online: <https://www.osha.gov/otm/section-3-health-hazards/chapter-2#rftc> (accessed on 2 December 2021).
38. Decreto-Lei n.º 182/2006 de 6 de Setembro. Ministério do Trabalho e da Solidariedade Social, *Diário da República*, 1.a Série—N.º 172. 2006. Available online: <https://dre.pt/dre/detalhe/decreto-lei/182-2006-539986> (accessed on 12 January 2023).
39. Sakellaris, I.; Saraga, D.; Mandin, C.; de Kluizenaar, Y.; Fossati, S.; Spinazzè, A.; Cattaneo, A.; Mihucz, V.; Szigeti, T.; de Oliveira Fernandes, E.; et al. Association of subjective health symptoms with indoor air quality in European office buildings: The OFFICAIR project. *Indoor Air* **2021**, *31*, 426–439. [\[CrossRef\]](#)
40. Gabriel, M.F.; Paciência, I.; Felgueiras, F.; Cavaleiro Rufo, J.; Castro Mendes, F.; Farraia, M.; Mourão, Z.; Moreira, A.; de Oliveira Fernandes, E. Environmental quality in primary schools and related health effects in children. An overview of assessments conducted in the Northern Portugal. *Energy Build.* **2021**, *250*, 111305. [\[CrossRef\]](#)
41. Sultan, Z.; Li, J.; Pantelic, J.; Schiavon, S. Indoor Air Pollution of Outdoor Origin: Mitigation Using Portable Air Cleaners in Singapore Office Building. *Aerosol Air Qual. Res.* **2022**, *22*, 220204. [\[CrossRef\]](#)
42. Salonen, H.J.; Pasanen, A.-L.; Lappalainen, S.K.; Riuttala, H.M.; Tuomi, T.M.; Pasanen, P.O.; Bäck, B.C.; Reijula, K.E. Airborne Concentrations of Volatile Organic Compounds, Formaldehyde and Ammonia in Finnish Office Buildings with Suspected Indoor Air Problems. *J. Occup. Environ. Hyg.* **2009**, *6*, 200–209. [\[CrossRef\]](#)
43. Nørgaard, A.W.; Kofoed-Sørensen, V.; Mandin, C.; Ventura, G.; Mabilia, R.; Perreca, E.; Cattaneo, A.; Spinazzè, A.; Mihucz, V.G.; Szigeti, T.; et al. Ozone-initiated terpene reaction products in five European offices: Replacement of a floor cleaning agent. *Environ. Sci. Technol.* **2014**, *48*, 13331–13339. [\[CrossRef\]](#) [\[PubMed\]](#)

44. Walker, I.S.; Sherman, M.H. Effect of ventilation strategies on residential ozone levels. *Build. Environ.* **2013**, *59*, 456–465. [[CrossRef](#)]
45. Mandin, C.; Trantallidi, M.; Cattaneo, A.; Canha, N.; Mihucz, V.G.; Szigeti, T.; Mabilia, R.; Perreca, E.; Spinazzè, A.; Fossati, S.; et al. Assessment of indoor air quality in office buildings across Europe—The OFFICAIR study. *Sci. Total Environ.* **2017**, *579*, 169–178. [[CrossRef](#)] [[PubMed](#)]
46. Peng, Z.; Deng, W.; Hong, Y. Investigation of Indoor Air Quality and Identification of Plant’s Capabilities in Removing Air Pollutants in Urban Residential Buildings. In *IOP Conference Series: Earth and Environmental Science*; Institute of Physics Publishing: Bristol, UK, 2019; p. 012018. [[CrossRef](#)]
47. Hong, S.-H.; Hong, J.; Yu, J.; Lim, Y. Study of the removal difference in indoor particulate matter and volatile organic compounds through the application of plants. *Environ. Health Toxicol.* **2017**, *32*, e2017006. [[CrossRef](#)] [[PubMed](#)]
48. Villanueva, F.; Felgueiras, F.; Notario, A.; Cabañas, B.; Gabriel, M.F. Indoor Environmental Quality and Effectiveness of Portable Air Cleaners in Reducing Levels of Airborne Particles during Schools’ Reopening in the COVID-19 Pandemic. *Sustainability* **2024**, *16*, 6549. [[CrossRef](#)]
49. Fan, X.; Liao, C.; Bivolarova, M.P.; Sekhar, C.; Laverge, J.; Lan, L.; Mainka, A.; Akimoto, M.; Wargocki, P. A field intervention study of the effects of window and door opening on bedroom IAQ, sleep quality, and next-day cognitive performance. *Build. Environ.* **2022**, *225*, 109630. [[CrossRef](#)]
50. Barrese, E.; Gioffrè, A.; Scarpelli, M.; Turbante, D.; Trovato, R.; Iavicoli, S. Indoor Pollution in Work Office: VOCs, Formaldehyde and Ozone by Printer. *Occup. Dis. Environ. Med.* **2014**, *2*, 49–55. [[CrossRef](#)]

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