

Article

Indoor Air Quality Assessment in Grocery Stores

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Abstract: Indoor Air Quality (IAQ) is a public and occupational health concern, as we are exposed to air pollutants daily given that we spend a great amount of our time in indoor environments. IAQ can be affected by numerous factors, from outdoor pollutants that get indoors through ventilation to building materials, furnishings, and activities carried by the building occupants. Exposure to air pollutants has been linked to a panoply of adverse effects on our health, well-being, and performance. The aim of this study was to assess the IAQ in grocery stores (GSs) in the municipality of Cascais in the Lisbon metropolitan area (Portugal) to characterize the workers' occupational exposure to air pollutants. The study was conducted in 13 small "family" grocery stores. The IAQ monitoring campaign was conducted using low-cost sensor technologies and focused on several parameters, namely: carbon dioxide (CO₂), volatile organic compounds (VOCs), particulate matter (PM₁₀ and PM_{2.5}), temperature (T), and relative humidity (RH). Overall, the IAQ of the studied GSs complied with Portuguese legislation, except for PM_{2.5}, where 23% of GSs presented levels above the established limit value. The mean inhaled dose of workers during a workday was estimated to be 157.7 ± 57.2 µg for PM_{2.5} and 165.8 ± 56.0 µg for PM₁₀. The IAQ assessment allowed the identification of the best strategies to improve worker experience in indoor workplace environments.

Keywords: indoor air quality; grocery stores; occupational health; particulate matter; human exposure



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1. Introduction

Unlike other resources, air is not scarce, rather, its vulnerability lies mainly in its risk of deterioration [1]. Indoor Air Quality (IAQ) has a significant impact on our well-being and health, with several adverse impacts on health being found, such as respiratory and cardiovascular illnesses, among others [2]. Indoor air hosts a complex mixture of non-biological and biological contaminants along with outdoor and indoor pollutants. Outdoor pollutants are mainly associated with vehicular traffic and industrial activities, whereas indoor pollutants are influenced by the behavior of occupants, building and furniture materials, consumer and cleaning products, and pollutants that manage to get inside through ventilation systems [2–5].

Changes in lifestyle have made us more subjected to these pollutants, as we spend most parts of our days in indoor environments (for instance, for Portuguese children, it is estimated that they spend 86% of their time indoors [6]), from public to private environments, namely home, workplace, leisure, building and commuting, where we are exposed to a panoply of pollutants that may negatively affect health welfare and productivity [3,7].

Studies by the United States Environmental Protection Agency (EPA) ranked indoor air pollution as a top five environmental risk to public health [8]. Efforts have been done to

understand IAQ complexity and its impact on human health specially focused on exposure levels in different environments and activities [9,10].

As a result of the energy crisis in the 1970s, many changes in building design have been implemented, including in construction and operation, focused on making buildings as airtight as possible, to prevent “leaks” and minimize thermal energy losses. Moreover, along with these building design advancements, numerous new sources of air pollutants emerged, based, for example, on changes in lifestyle and building materials used. A change in composition and complexity of pollutants in the indoor air has been acknowledged, due, for example, to the use of more synthetic materials and chemicals in construction, decoration, cleaning agents, and consumer products [7,11]. These changes have led to low ventilation rates that impact IAQ since it promotes the indoor accumulation of pollutants, which leads to high indoor pollution levels, often 2 to 5, or even 100, times higher than the levels found in outdoor environments [7]. Moreover, indoor exposure to different indoor air pollutants may have a significant impact on occupants’ health, even at low concentrations [12]. Therefore, in the 1980s, IAQ started to be an issue of public interest when buildings’ occupants started to exhibit several sick building syndromes and efforts were conducted to understand, minimize, and/or correct those issues.

According to the United Nations Environment Programme, in 2020, IAQ was responsible for nearly 3.2 million premature deaths, and, in 2021, around 4 million [13].

In 2020, the Eurostat statistical atlas estimated that a regular person has an average duration of working life in the European Union of 35.2 years, while in Portugal, the estimative is 38.2 years [14]. Considering that an adult spends around 8 h per day at work (5 days of the week), and considering the lifetime working period, a Portuguese individual spends, on average, around 71,800 h (considering 47 working weeks per year) at work, and in some cases, even more, depending on the profession and type of work. Therefore, IAQ at workplaces may have a significant impact on worker well-being, productivity, and health due to prolonged exposure [15]. It is also important to highlight that, according to the International Labour Organization (ILO), it is estimated that around 2.3 million people endure work-related accidents and diseases every year, with around 160 million a victim of work-related illnesses [16].

Workplaces, such as shopping malls, retail stores, and supermarkets, have been studied extensively regarding IAQ [17–21], however, there are very few studies of grocery stores available [22,23].

The goal of the present study is to understand the IAQ (based on a multi-parameter approach) that workers in grocery stores are exposed to while working, including its compliance with relevant Portuguese legislation and international guidelines, and to define the best practices to minimize worker exposure in those workplaces. The information gathered in this study also increases the available knowledge in the field of health and safety in this type of workplace environment.

2. Materials and Methods

2.1. Study Sites and Characterisation of the Grocery Stores

The study was carried out in 13 grocery stores (GSs) in the municipality of Cascais, in the Lisbon District (Portugal). Cascais has a population of about 200,000 people. The municipality is divided into four parishes: Alcabideche, Carcavelos e Parede, Cascais e Estoril, and São Domingos de Rana. The study area has a moderate Mediterranean climate influenced by the Atlantic Ocean.

A total of 13 small “family” GSs participated voluntarily in the study, and the GSs were randomly selected from the different parishes. The location of the studied GSs is shown in Figure 1.

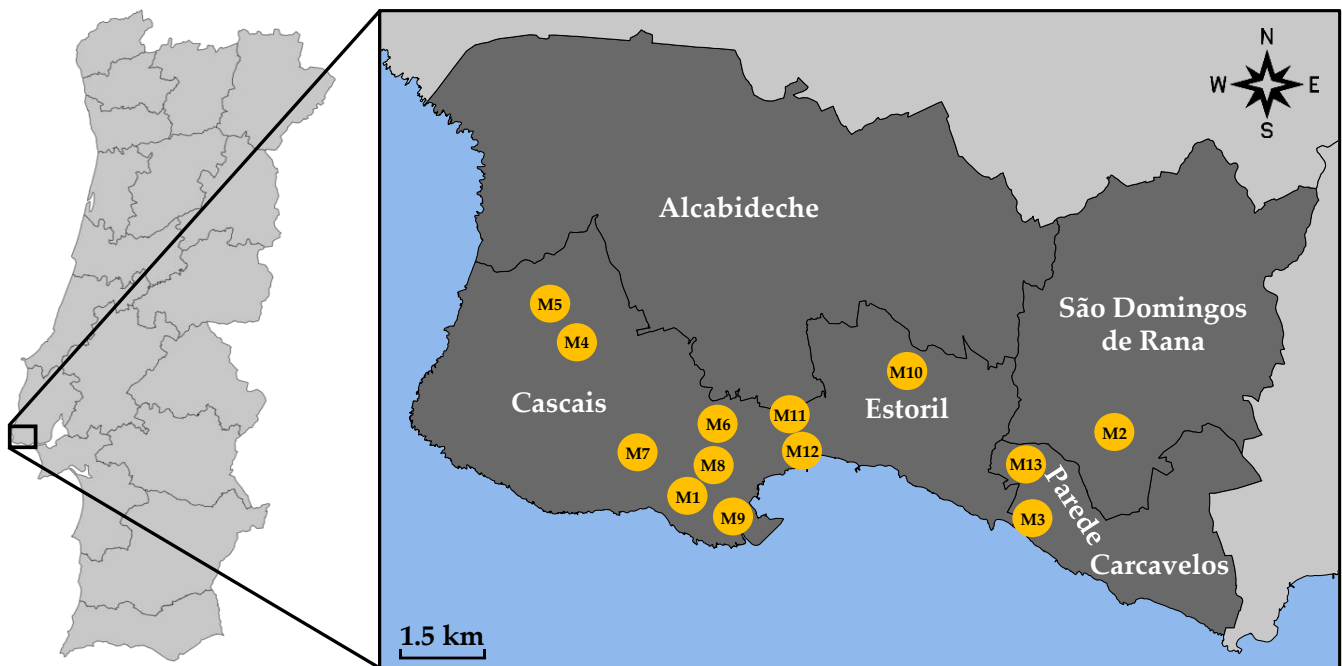


Figure 1. Locations of the 13 studied GSs in the Cascais municipality (delimitation defined by dark grey area), within the Lisbon metropolitan area.

A survey was applied to characterize each GS in terms of the type of facilities, products, sales, and storage area, cleaning period and products, working days and hours, ventilation strategies, and the number of employees and clients per day. Regarding ventilation, it is important to highlight that, since there is a high flow of customers going in and out throughout the day, many of the GSs kept their doors open, and in the case of the ones that did not keep the door open, the door was constantly opening. Table S1 (in the Supplementary Information section) provides an overview of the characteristics of the studied GSs.

2.2. IAQ Monitoring Equipment

Indoor levels of air pollutants and comfort parameters were monitored using air quality monitoring units (MBs) based on low-cost sensors. The MBs collected real-time data of CO₂, PM_{2.5}, PM₁₀, VOCs, RH, and T, with a 5 min monitoring frequency. These MBs were already applied with success in previous studies [10]. Figure S1 (in the Supplementary Information section) provides a description of the layout of the different sensors and components in the MBs. The sensors used in the MBs were (i) an SCD30 for CO₂ (with a measuring range of 400–10,000 ppm, and accuracy of ±30 ppm), (ii) a MiCS-VZ-89TE for VOCs (with a measuring range of 0–1000 ppb in isobutylene), (iii) an HPMA115s0 for PM_{2.5} and PM₁₀ (with a measuring range of 0–1000 µg·m⁻³, and an accuracy of 15%), and (iv) an SHT31 for temperature (T) and relative humidity (RH) (precision: ±2% RH and ±0.3 °C). After being plugged in, the MBs sent data to an online platform instantaneously via wireless, which stored the data in a cloud. Simultaneously, the data were available visually online in real time. A total of three MBs were used in this study, with the following ID: AirQ1 (A), AirQ2 (B), and AirQ3 (C).

The hardware platform that was used to manage all sensors was running by an Arduino bootloader on an ATSAM21G18A Cortex-M0+ processor, which was responsible for measuring all the sensors, controlling airflow, and interacting with the GSM Modem (Quectel M66). Open software libraries were used to drive the used low-cost sensors, namely, for CO₂, Sparkuns SCD30 (available online: https://github.com/sparkfun/SparkFun_SCD30_Arduino_Library, accessed on 2 November 2021) and for comfort parameters, Adafruits SHT31 (available online: https://github.com/adafruit/Adafruit_SHT31,

accessed on 2 November 2021). For PM_{2.5} and PM₁₀ (sensor HPMA115s0) and VOCs (sensor MiCS-VZ-89TE), the used libraries were developed in-house since no open-source libraries were available from mainstream hardware developers.

The performance and data reliability (Table 1) were assessed by inter-comparison with reference real-time instruments (using a monitoring frequency of 5 min), namely, a DustTrak DRX monitor (8533 model, TSI, Shoreview, MN, USA) to assess PM_{2.5} and PM₁₀, and a Graywolf (IQ-610 probe, WolfSense Solutions, Shelton, CT, USA) to assess CO₂, VOCs, T, and RH. Table 1 presents the intercomparison results, including the correction factors (m and b) applied to each MB.

Table 1. Intercomparison results between MBs and the reference equipment for all the studied parameters. RMSE stands for root mean square error (assessed as described elsewhere [24]). Range REF stands for the range of the pollutant as measured by the reference equipment (REF).

Monitoring Unit	Parameter	Unit	m	b	R ²	RMSE	Range REF	n Points	Ratio MB/REF
AirQ1 (A)	PM _{2.5}	µg.m ⁻³	3.5262	3.5003	0.977	61.2	4.2–382.2	763	0.26
	PM ₁₀	µg.m ⁻³	3.4709	1.6958	0.973	56.7	4.2–383.0	884	0.28
	CO ₂	ppm	1.0389	−12.427	0.986	37	369–2549	1336	0.98
	VOCs	ppb	0.4529	−191.69	0.426	535.7	60.0–139.3	278	6.77
	T	°C	1.1421	−4.4108	0.936	1.5	15.0–31.7	1418	1.07
	RH	%	1.2837	−9.0300	0.927	4.7	36.1–69.6	1430	1.09
AirQ2 (B)	PM _{2.5}	µg.m ⁻³	2.0717	1.3919	0.993	26.5	3.0–198.1	1206	0.46
	PM ₁₀	µg.m ⁻³	2.0024	0.9004	0.992	23.1	3.0–190.3	1289	0.48
	CO ₂	ppm	1.0259	−78.503	0.987	70	369–2549	1461	1.11
	VOCs	ppb	0.3484	−63.02	0.635	355.2	60.0–122.0	281	4.82
	T	°C	1.144	−3.9528	0.931	1.1	15.0–31.7	1470	1.04
	RH	%	1.2346	−8.2152	0.931	3.6	36.1–69.6	1470	1.06
AirQ3 (C)	PM _{2.5}	µg.m ⁻³	1.8409	1.7687	0.992	21.2	3.0–176.2	1246	0.50
	PM ₁₀	µg.m ⁻³	1.7658	1.2891	0.992	16.8	3.0–164.7	1267	0.53
	CO ₂	ppm	0.9917	−128.65	0.982	139	369–2549	1471	1.24
	VOCs	ppb	0.3138	−134.26	0.677	581.2	60.0–110.0	238	7.87
	T	°C	1.0334	−1.3159	0.949	1.0	15.0–31.7	1467	1.03
	RH	%	1.1233	−3.2509	0.938	3.1	36.1–69.6	1473	1.06

Very strong correlations were obtained (R² ranging from 0.80–1.00) for all the parameters, except for VOCs, which was considered moderate for AirQ1 (0.43) and strong for AirQ2 and AirQ3 (0.64 and 0.68, respectively).

The raw monitoring data were downloaded from the online platform and, afterward, the correction factors of each sensor and each MB were applied to the raw data, by using Microsoft Excel.

2.3. Monitoring Campaign

The MBs were placed in pre-determined locations in each GS, namely, the register, the fruits and vegetable area, or the storage area. The monitoring campaign took place between November 2021 and February 2022. The MBs were placed in each grocery store at a height of around 1.20 m for a period of 2 to 5 days. The placement and number of monitoring boxes allocated to each store were determined by the size of the GS and the existence of a storage area. Table S2 provides the location of each MB within the studied GSs.

According to the Instituto Português do Mar e Atmosfera (IPMA), November had a mean air temperature of 11.2 ± 1.2 °C (ranging from 5.8 ± 2.1 °C to 16.6 ± 0.3 °C), December had a mean air temperature of 11.7 ± 1.2 °C (ranging from 7.7 ± 1.6 °C to 15.7 ± 1.8 °C), January had a mean air temperature of 9.7 ± 0.8 °C (ranging from 4.0 ± 0.5 °C to 15.3 ± 2.2 °C), and February had a mean air temperature of 11.3 ± 1.3 °C (ranging from 5.3 ± 0.3 °C to 17.4 ± 3.0 °C) [25–28].

2.4. Statistical Analysis

Data treatment was done by using Microsoft Excel. The statistical analysis of data was performed using IBM SPSS Statistics 28 software. Normality testing was done using the Shapiro–Wilk test, where only CO₂ was found not to have a normal distribution. The statistical analysis was done by using ANOVA, except for CO₂, which was done with the Mann–Whitney and Kruskal–Wallis tests (for non-parametric data). All data analysis was done focusing only on the occupied period.

2.5. Exposure to PM and Inhaled Dose by Workers

Worker exposure to particulate matter ($E, \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$) incorporates both the concentration and the duration of the exposure, and it is assessed by multiplying the daily mean concentration monitored (C_j) in the GS by time spent in the GS by the worker (t_j), namely, $E = C_j \cdot t_j$. The potential inhaled dose ($D, \mu\text{g}$), which is the amount of a contaminant that is absorbed in the body of an exposed individual over a specific period (t_j), was calculated by multiplying the exposure by the Inhalation Rate ($IR, \text{m}^3\cdot\text{h}^{-1}$) [6,10,29,30].

IR differs between different age groups and the different activities that individuals are performing. These values can vary from $0.3 \text{ m}^3\cdot\text{h}^{-1}$ (for children and young people resting) to $2 \text{ m}^3\cdot\text{h}^{-1}$ (for adults engaged in sports). Based on our study population, the activity may be characterized as a non-sedentary job and the population is between young adults (19–40 years) and middle adulthood (41–65 years) with an IR of $0.94 \text{ m}^3\cdot\text{h}^{-1}$ and $1.01 \text{ m}^3\cdot\text{h}^{-1}$, respectively [30]. Therefore, to calculate the potential inhaled dose of GS workers, a mean IR of $0.975 \text{ m}^3\cdot\text{h}^{-1}$ was considered.

3. Results and Discussions

Table S1 shows that the total area of the studied GSs ranged from 30 m^2 to 200 m^2 and that the number of employees also varied, with eight GSs (corresponding to 61.5%) having two employees, three GSs (23.1%) having three employees and one GS (7.7%) having seven employees. One GS (7.7%) did not disclose this information. The daily volume of customers of the studied GSs ranged from 10 to 250 customers per day.

The results displayed below only apply to the occupied period in the GSs since it represents the relevant period to assess worker exposure to air pollutants.

3.1. Comfort Parameters

3.1.1. Temperature

Figure 2 represents the mean levels of temperature assessed in the studied GSs during the working period, where the mean temperature level was $20.4 \pm 1.2 \text{ }^\circ\text{C}$, ranging from a maximum value of $23.8 \pm 0.8 \text{ }^\circ\text{C}$ (GS M5, Location A) and a minimum of $18.4 \pm 1.1 \text{ }^\circ\text{C}$ (GS M11, Location B).

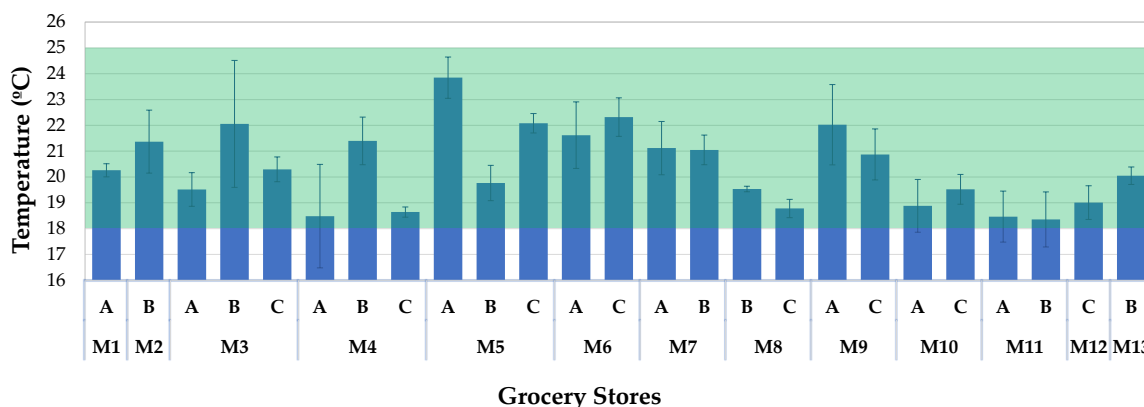


Figure 2. Temperature levels assessed in all locations of the studied GSs. The green area represents the acceptable range (18–25 °C) for workplaces defined by Portuguese Legislation [31].

The guideline ISO 7730 establishes the optimal temperature range for indoor environments and, in winter, this range is between 20 and 24 °C [32]. Considering this range, 62% of the GSs presented mean levels within this acceptable range, while the remaining 38% showed mean temperature levels below the minimum threshold of 20 °C (namely, M4, M10, M11, and M12), which highlights the lack of heating during the cold period when the monitoring occurred.

Considering the Portuguese Decree-Law nr 243/86 of 20 August—Article 11th [31], which states that workplaces, as well as common facilities, must offer good temperature and humidity conditions, with the workplace temperature being between 18 °C and 22 °C (except for specific conditions that may reach 25 °C), all the studied GSs had mean temperature levels within the permitted range.

The type of facilities of the GSs showed to have a significant impact on temperature levels (ANOVA: $F(2,22) = 3.665$, p -value = 0.042), however, when performing the post hoc test to understand the differences between the influence of the different type of facilities on temperature levels, no significant difference was found (p -value for all the cases was above p -value > 0.050).

3.1.2. Relative Humidity

Figure 3 presents the mean RH levels found in each location of all the studied GSs, where a mean overall value of $51 \pm 6\%$ was found, ranging from $39.3 \pm 3.5\%$ (M4, Location C) to $64.7 \pm 5.5\%$ (M10, Location A).

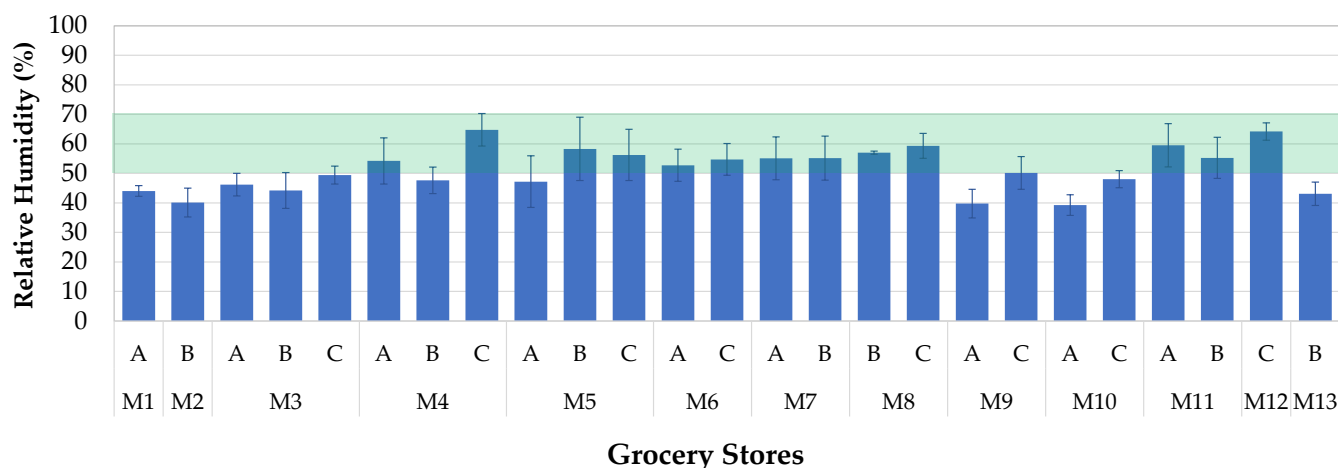


Figure 3. Relative humidity levels assessed in all locations of the studied GSs. The green area represents the acceptable range (50–70%) for workplaces defined by Portuguese Legislation [31].

ISO 7730 establishes the optimal RH range to be between 30% and 70% [32]. Considering this range, all the studied GSs presented mean RH levels within the acceptable range. However, the Portuguese Decree-Law nr 243/86 of 20 August—Article 11th [31] establishes that the relative humidity range in workplaces, as well as common facilities, should be between 50 and 70% (green area of Figure 3). Considering this range, 7 out of 13 GSs (53%) presented mean values within this range, while the remaining GSs were always below the lower recommended limit value of 50% (M1, M2, M3, M9, M10, and M13).

3.2. Carbon Dioxide

Figure 4 presents the CO₂ levels measured in all the studied locations of the GSs, where the mean CO₂ level assessed was 486 ± 90 ppm, ranging from 365 ± 16 (GS 11, Location B) to 864 ± 178 (GS 4, Location B). It is important to highlight that since CO₂ is only produced by occupants, this parameter is often used as an indicator of ventilation and occupancy [33]. Moreover, all the 13 studied GSs had only natural ventilation.

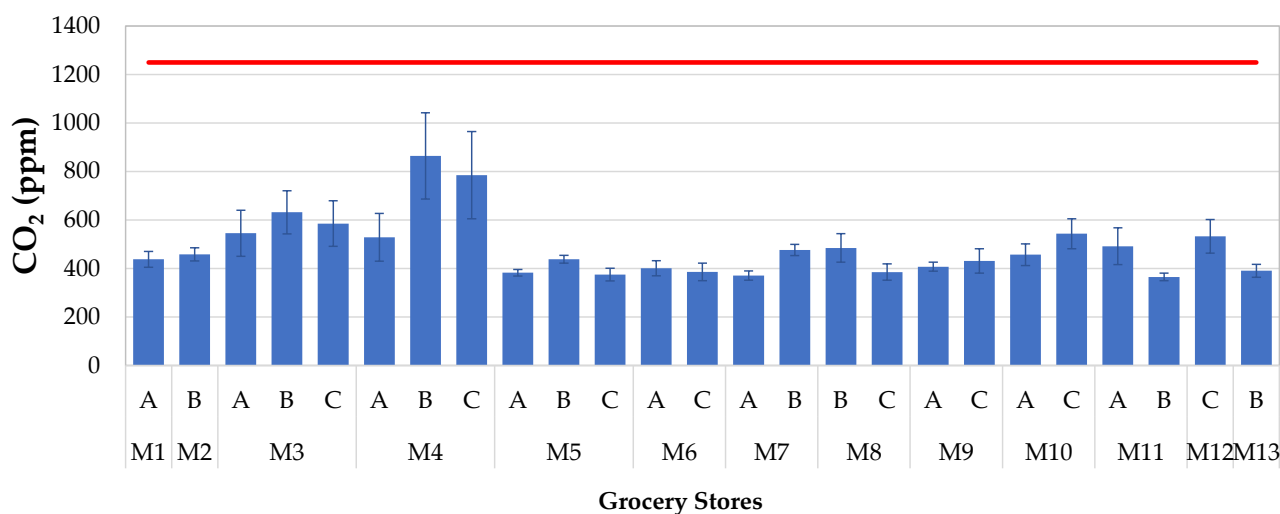


Figure 4. CO₂ levels assessed in all locations of the studied GSs. The red line represents the limit value of 1250 ppm established by Portuguese legislation [34].

Portuguese legislation (Portaria n.º 138-G/2021, de 1 de julho) [34] establishes a limit value of 1250 ppm and all GSs presented mean levels below that threshold, which was expected since the doors are mostly open during working hours, promoting good circulation of air. Studies focusing on working environments also found similar results. For instance, a study in a copy center in Aveiro, Portugal, found similar values to the present study, with CO₂ levels also below the LV, with a mean level of 552 ± 65 ppm [35]. A study performed in 14 retail stores from Texas and Pennsylvania in the US also found that the average CO₂ levels varied between 381 ppm and 716 ppm in all retail stores [36]. Conversely, studies conducted in residential settings showed higher levels of CO₂, mainly due to the poor ventilation conditions of such spaces. For instance, a study carried out during the sleeping period of couples found levels of 1911 ± 894 ppm, which are considered very high (and above the LV), and those values were due to the type of ventilation used in bedrooms [9]. Similarly, a study carried out in Elderly Care Centers in Lisbon also found higher values of CO₂ in bedrooms, with all of them exceeding the LV, with an average value of 1755 ppm [37].

The number of clients per day in each GS was found to have a significant impact on the mean CO₂ levels registered in the GSs (Kruskal–Wallis Test: $\chi^2(2) = 9.902$, p -value = 0.007), with the levels found in the GSs with fewer than 100 clients per day (412 ± 13 ppm) being significantly lower than the levels found in GSs with more than 200 clients per day (636 ± 80 ppm) (p -value = 0.009, by pair-wise comparison). The size of the GSs was also found to significantly influence the indoor levels of CO₂, with GSs with selling areas of below 110 m² having lower levels (421 ± 14 ppm) than GSs with selling areas of more than 110 m² (546 ± 40) (Mann–Whitney U Test: $U = 127.000$, p -value = 0.007). Since CO₂ is mainly produced by human breathing, it is expected that indoor environments with higher numbers of occupants may have higher CO₂ levels. Moreover, the size of the selling area of the GSs may also be an indicator of the number of clients (bigger areas may have more clients), which explains the impact of the selling area on CO₂ levels. Despite the CO₂ levels being below the LV in all cases, this fact also highlights that workers may be exposed to higher levels of CO₂ in GSs with larger selling areas and with higher numbers of clients.

The statistical analysis also revealed that the cleaning procedure also influenced the CO₂ levels, GSs that did the cleaning daily at closing having lower mean levels of CO₂ (422 ± 13 ppm) than GSs that did the cleaning daily at opening or more times per day (537 ± 39 ppm) (Mann–Whitney U Test: $U = 116.000$, p -value = 0.033). The type of products used for cleaning also proved to have a significant impact on CO₂ levels (Kruskal–Wallis Test: $\chi^2(2) = 6.846$, p -value = 0.033), with the levels of CO₂ in GSs that used products of

domestic use being significantly lower (425 ± 16 ppm) than GSs that used products of domestic use but designated as environmentally friendly (587 ± 25 ppm).

However, the interpretation of these results is not direct and these influences may incorporate the contribution of the size of the selling area and the number of clients per day (since bigger spaces implemented cleaning more frequently and used specific types of products).

3.3. Volatile Organic Compounds

All assessed mean levels of VOCs at all GSs were below the limit value of 262 ppb (corresponding to $600 \mu\text{g}\cdot\text{m}^{-3}$) established by Portuguese legislation [34], as shown in Figure 5. The overall mean of VOCs at all GSs was 51.2 ± 20.6 ppb, ranging from 11.1 ± 12.7 ppb (at GS2, Location B) to 109.5 ± 18.6 ppb (at GS10, Location C).

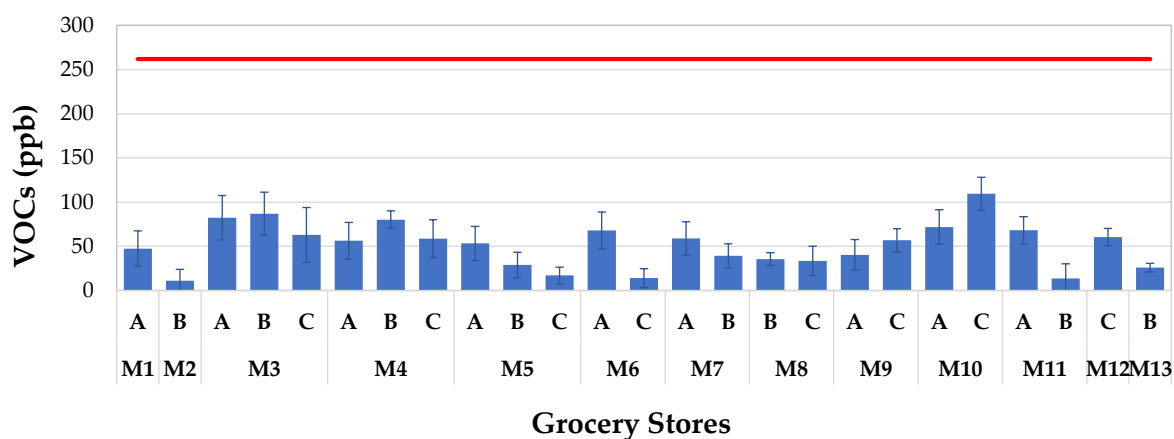


Figure 5. VOC levels assessed in all locations of the studied GSs. The red line represents the limit value of 262 ppb established by Portuguese legislation [34].

The cleaning procedure was revealed to have a significant impact on the mean VOC levels found in the GSs, with GSs that did the cleaning daily at closing having significantly lower mean VOCs levels (37.6 ± 20.8 ppb) than GSs that did the cleaning daily at opening or more times per day (61.8 ± 24.0 ppb) (ANOVA: $F(1,23) = 7.003$, p -value = 0.014). The type of products used for cleaning also showed to have a significant impact on VOC levels (ANOVA: $F(2,22) = 3.497$, p -value = 0.048). However, when performing the post hoc test to understand the differences between the influence of the different types of used products on VOC levels, no significant difference was found (the p -value for all the cases was above 0.050). The biggest difference was found for GSs that used products of domestic use (38.9 ± 21.7 ppb) and GSs that used products of domestic use but designated as environmentally friendly (77.3 ± 12.7 ppb) (p -value = 0.057).

Similarly to with CO_2 , it was also found that the number of clients had an impact on the VOCs levels found in the GSs (ANOVA: $F(2,22) = 5.800$, p -value = 0.009), with GSs that had fewer than 100 clients per day being significantly lower (36.8 ± 20.0 ppb) than GSs that had more than 200 clients per day (75.2 ± 21.5 ppb) (p -value = 0.009). GSs with selling areas equal or below to 110 m^2 were also found to have significantly lower levels (36.0 ± 18.2 ppb) than GSs that had selling areas of higher than 110 m^2 (51.2 ± 25.3 ppb) (ANOVA: $F(1,23) = 12.109$, p -value = 0.002).

3.4. Particulate Matter

Figures 6 and 7 present the mean $\text{PM}_{2.5}$ and PM_{10} levels assessed in each studied location of all the GSs, respectively. Regarding $\text{PM}_{2.5}$, 23.1% of the 13 GSs presented mean $\text{PM}_{2.5}$ levels above the limit value of $25 \mu\text{g}\cdot\text{m}^{-3}$ established by Portuguese legislation [34], namely, M3, M9, and M10. Considering PM_{10} , all GSs presented mean values below the limit value of $50 \mu\text{g}\cdot\text{m}^{-3}$ established by Portuguese legislation [34].

Considering World Health Organization (WHO) air quality guidelines, which establish guideline values of $5 \mu\text{g}\cdot\text{m}^{-3}$ and $15 \mu\text{g}\cdot\text{m}^{-3}$ for $\text{PM}_{2.5}$ and PM_{10} , respectively, all the GSs presented $\text{PM}_{2.5}$ levels above the guideline value and only four GSs presented PM_{10} levels below the PM_{10} guideline value (M2, M4, M5, and M12).

The variability of indoor particle levels was found to be high among the studied GSs, with mean levels of $20.2 \pm 7.3 \mu\text{g}\cdot\text{m}^{-3}$ (ranging from $1.4 \mu\text{g}\cdot\text{m}^{-3}$ to $278.5 \mu\text{g}\cdot\text{m}^{-3}$) for $\text{PM}_{2.5}$ and $21.3 \pm 7.2 \mu\text{g}\cdot\text{m}^{-3}$ (ranging from $2.9 \mu\text{g}\cdot\text{m}^{-3}$ to $279.0 \mu\text{g}\cdot\text{m}^{-3}$) for PM_{10} . It is important to highlight that these levels were obtained with the monitoring instruments in different locations and GSs. Sudden increases in PM concentrations indoors are typically due to indoor activities [38]. Additionally, the movement of people in these environments is high since there are always clients coming in and out of the store and, therefore, the possibility of resuspension of dust is elevated [33]. GS stores with selling areas of more than 100 m^2 proved to have significantly higher levels of $\text{PM}_{2.5}$ ($24.0 \pm 10.8 \mu\text{g}\cdot\text{m}^{-3}$) and PM_{10} ($24.9 \pm 10.7 \mu\text{g}\cdot\text{m}^{-3}$) when compared with GSs with lower selling areas ($\text{PM}_{2.5}$: $16.5 \pm 4.8 \mu\text{g}\cdot\text{m}^{-3}$, ANOVA: $F(1,23) = 4.816$, p -value = 0.039; PM_{10} : $24.0 \pm 10.8 \mu\text{g}\cdot\text{m}^{-3}$, ANOVA: $F(1,23) = 4.760$, p -value = 0.040).

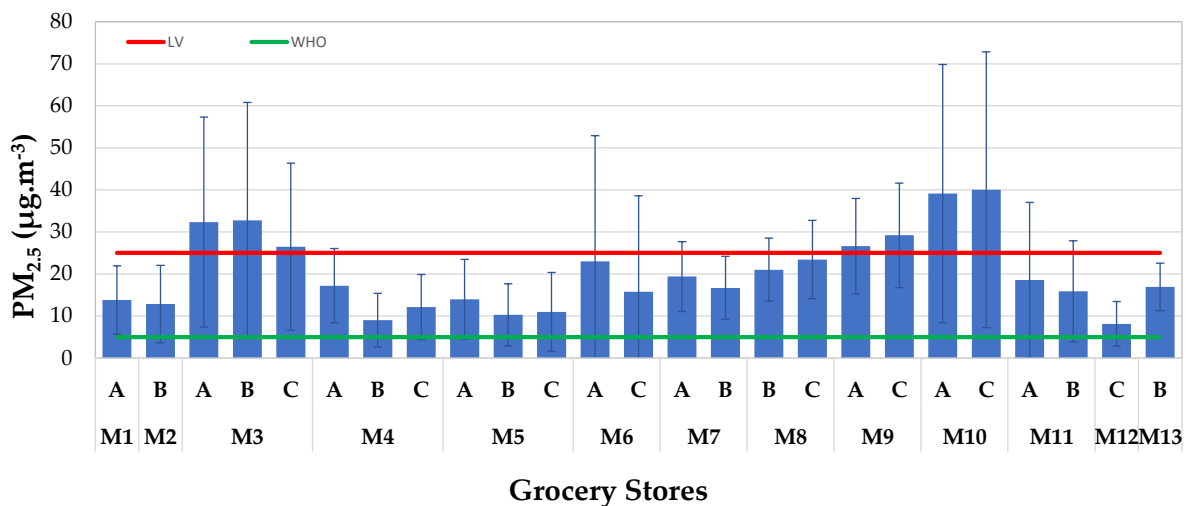


Figure 6. $\text{PM}_{2.5}$ levels assessed in all locations of the studied GSs. The red line represents the limit value (LV) of $25 \mu\text{g}\cdot\text{m}^{-3}$ established by Portuguese legislation [34] and the green line represents the air quality guideline of $5 \mu\text{g}\cdot\text{m}^{-3}$ established by the WHO [39].

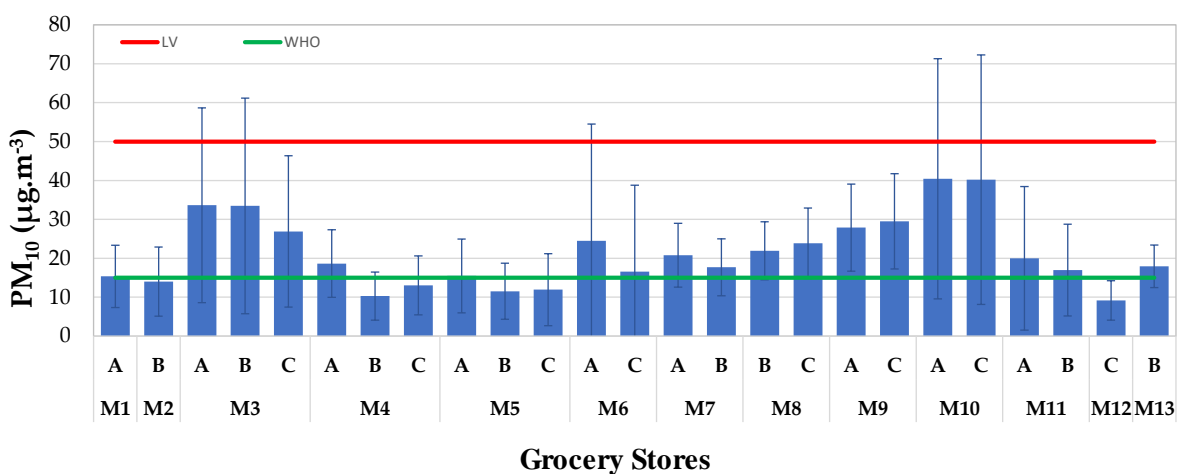


Figure 7. PM_{10} levels assessed in all locations of the studied GSs. The red line represents the limit value (LV) of $50 \mu\text{g}\cdot\text{m}^{-3}$ established by Portuguese legislation [34] and the green line represents the air quality guideline of $15 \mu\text{g}\cdot\text{m}^{-3}$ established by the WHO [39].

Similar results were found in a study in classrooms in France, with mean $PM_{2.5}$ levels of $22 \pm 8 \mu\text{g}\cdot\text{m}^{-3}$, ranging from 10 to $47 \mu\text{g}\cdot\text{m}^{-3}$ [40]. In contrast, less-crowded environments have a lower possibility of resuspension of particles. Therefore, for example, a study in elderly care centers in Lisbon assessed lower PM_{10} levels, ranging from $11 \mu\text{g}\cdot\text{m}^{-3}$ to $19 \mu\text{g}\cdot\text{m}^{-3}$ [33].

In relation to the influence of other GS characteristics, no other significant impacts were found on either $PM_{2.5}$ or PM_{10} . However, some studies showed that some activities in houses had peak concentrations of PM, such as during the preparation of breakfast, tea, and toast, and natural-gas burning, as well as other types of cooking [41–43]. Some retail environments have different indoor spaces within and with different associated activities, which can promote different emissions of pollutants (including particulate matter, from fine to ultrafine particles) [44]. This is the case for some of the studied GSs, which have different areas within, such as a bakery or coffee shop, that may promote higher levels of PM when compared with GSs without those types of facilities.

Exposure to PM and Inhaled Dose by Workers

The exposure to and the associated potential inhaled dose of PM in the GSs during working hours (8 h) are described in Table 2. Exposure to PM_{10} and $PM_{2.5}$ were estimated to be $170.0 \pm 57.4 \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$ and $161.7 \pm 58.7 \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$, respectively. Figure 8 presents $PM_{2.5}$ exposure levels of workers at all studied locations of the GSs, considering a working period of 8 h.

Table 2. PM_{10} and $PM_{2.5}$ exposure and correspondent potential inhaled dose during the working period at the studied GSs.

ID	MB	PM Concentration, C_j ($\mu\text{g}\cdot\text{m}^{-3}$)		Time, t_j (h)	Exposure to PM ($\mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}^1$)		Potential Inhaled Dose (μg)	
		PM_{10}	$PM_{2.5}$		PM_{10}	$PM_{2.5}$	$PM_{2.5}$	PM_{10}
M1	A	15.3	13.8	8.0	122.7	110.6	107.9	119.6
M2	B	14.0	12.8	8.0	111.7	102.7	100.1	108.9
M3	A	33.6	32.3	8.0	269.1	258.8	252.3	262.4
	B	33.5	32.7	8.0	267.8	261.8	252.2	261.1
	C	26.9	26.5	8.0	215.1	211.6	206.3	209.7
M4	A	18.6	17.2	8.0	149.0	137.7	134.2	145.3
	B	10.3	9.0	8.0	82.1	72.0	70.2	80.0
	C	13.0	12.1	8.0	104.2	97.0	94.6	101.6
M5	A	15.5	14.0	8.0	123.7	111.9	109.1	120.6
	B	11.5	10.3	8.0	92.0	82.3	80.2	89.7
	C	11.9	11.0	8.0	95.3	87.7	85.5	93.0
M6	A	24.4	23.0	8.0	195.6	184.0	179.4	190.7
	C	16.5	15.8	8.0	132.4	126.0	122.9	129.1
M7	A	20.8	19.4	8.0	166.0	155.0	151.1	161.9
	B	17.7	16.7	8.0	141.4	133.3	130.0	137.8
M8	B	21.9	21.0	8.0	175.2	168.1	163.9	170.9
	C	23.9	23.4	8.0	190.9	187.4	182.8	186.1
M9	A	27.9	26.6	8.0	223.0	212.8	207.5	217.4
	C	29.5	29.2	8.0	235.9	233.5	227.7	230.0

Table 2. Cont.

ID	MB	PM Concentration, Cj ($\mu\text{g}\cdot\text{m}^{-3}$)		Time, tj (h)	Exposure to PM ($\mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}^1$)		Potential Inhaled Dose (μg)	
		PM10	PM2.5		PM10	PM2.5	PM2.5	PM10
M10	A	40.4	39.1	8.0	323.3	312.9	305.1	315.3
	C	40.2	40.0	8.0	321.7	320.3	312.3	313.7
M11	A	20.0	18.5	8.0	159.8	148.3	144.6	155.8
	B	16.9	15.9	8.0	135.5	127.0	123.8	132.1
M12	C	9.2	8.1	8.0	73.2	65.0	63.4	71.4
M13	B	17.9	16.9	8.0	143.4	135.4	132.1	139.8
Mean \pm SD		21.3 \pm 7.2	20.2 \pm 7.3		170.0 \pm 57.4	161.7 \pm 58.7	157.7 \pm 57.2	165.8 \pm 56.0



Figure 8. PM_{2.5} exposure levels of workers at all studied locations of the GSs, considering a working period of 8 h.

The exposure levels found were higher than those found in the bedrooms of university student residences, which were $62.9 \pm 24.3 \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$ and $76.3 \pm 26.3 \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$ for PM_{2.5} and PM₁₀, respectively [10]. Another study carried out in the bedrooms of couples in Lisbon dwellings during sleeping periods estimated exposures to PM_{2.5} and PM₁₀ of $113.6 \pm 64.8 \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$ and $148.1 \pm 84.8 \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$, respectively [9]. In a study on children’s exposure and dose assessment to PM in Lisbon (which accounted for the period spent in school as well), higher values were found, namely, $218 \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$ and $404 \mu\text{g}\cdot\text{m}^{-3}\cdot\text{h}$ for PM_{2.5} and PM₁₀, during weekdays, respectively [6].

The inhaled dose depends on the activity performed and the inhalation rate of the person. For the present study, the individual’s inhalation rate was considered to be $0.975 \text{ m}^3\cdot\text{h}^{-1}$ (active person) and the mean inhalation dose of the workers of the studied GSs was $157.7 \pm 57.2 \mu\text{g}$ for PM_{2.5} (ranging from $63.4 \mu\text{g}$ at M12 to $312.3 \mu\text{g}$ at M10, location C) and $165.8 \pm 56.0 \mu\text{g}$ for PM₁₀ (ranging from $71.4 \mu\text{g}$ at M12 to $315.3 \mu\text{g}$ at M10, location A). The study focusing on children found that the average daily amount inhaled was $243.5 \mu\text{g}$ and $382.2 \mu\text{g}$ for PM_{2.5} and PM₁₀, respectively, which may be explained because schools typically have more sources of PM [6], such as chalk [45].

3.5. Discussion

The present study presents some limitations such as: (i) the impossibility of performing measurements near the breathing zone, which would be the best approach, in order to assess human exposure; (ii) the location of the MBs, since MB had to be connected to power lines and, therefore, occasionally, had to stay lower or above the breathing zone; and

(iii) the lack of studies available in grocery stores did not allow a comparison of the present results with similar micro-environments.

It is also important to highlight that the use of low-cost sensors in such studies relies on the performance of the sensors, their specifications, and the environmental conditions under which they are used. Despite the inter-comparison with reference real-time instruments allowing us to obtain calibration factors with R^2 above 0.90 (except for VOCs), which were applied afterward to the raw data, the inter-comparison procedure was done only before the monitoring campaign. However, during the monitoring campaign (which took three months), the sensors may have changed slightly in performance. Therefore, in future studies, it is important to evaluate the performance of the sensors during several moments of the monitoring campaign to understand if the calibrations should be updated from time to time.

Regarding the hourly variability of IAQ parameters, this was found mainly with T and CO₂, as shown by Figure S2 (in the supplementary section), which provides the hourly variability of all studied parameters for the GS M4, at location B.

Overall, the only air pollutant that showed levels above the limit value established by the IAQ Portuguese legislation was PM_{2.5}. Regarding comfort parameters, around half of the studied grocery stores showed relative humidity levels below the lower limit value (50%) established by Portuguese legislation.

A large proportion of the indoor particles may come from indoor sources, such as cooking, cleaning, and resuspension of particles, due to the movement of the occupants. As it was possible to observe in the results, an association between the levels of particulate matter and the selling area (which may indicate a higher movement of clients) was found, which can indicate higher levels of resuspension of particles in GSs with bigger selling areas. Since some human activities may influence PM levels, for GSs with a bakery or coffee shop, along with facilities related to the consumption of food, some suggestions to reduce the PM levels may be: (1) change from fuel-based combustion stoves (such as gas) to electric ones; and (2) the installation of exhaust fans vented to the outside when preparing the foods. Moreover, the installation of local air purifiers can help to filter PM in the air and to reduce the levels of this pollutant. However, it is crucial to maintain the equipment, namely, to replace the filter regularly to achieve good results. These strategies may promote the reduction of PM levels due to specific facilities of the GSs.

4. Conclusions

This study aimed to assess indoor air quality in small grocery stores in the Lisbon metropolitan area. This information focused on indoor air pollutants and thermal comfort parameters, allowing an assessment of worker exposure to the air pollutants in their work environment to be performed.

Overall, all the studied GSs complied with Portuguese legislation regarding IAQ, except for fine particulate matter (PM_{2.5}), where 3 out of the 13 GSs exceeded the limit value established by the Portuguese legislation. Regarding comfort parameters, around half of the studied grocery stores showed relative humidity levels below the lower limit value (50%) established by Portuguese legislation.

Based on the characterization of IAQ at these specific micro-environments, some control measures could be identified to reduce the levels of PM. The results of this study are a valuable contribution to the provision of IAQ characterization in grocery stores, a micro-environment that has been neglected in the literature. Further work should focus on the workers' perception of IAQ and comfort parameters and potentially evaluate how they influence their performance and welfare.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app122412940/s1>, Figure S1: Layout of the different low-cost sensors and components within the MB, where uP stands for microcontroller; Figure S2: Example of the hourly variability of the GS M4, at location B; Table S1: Summary of the characteristics of the studied GSs, including cleaning procedures and opening periods. N/A—not available information;

TS/SS—technical sheet/safety sheet; Table S2: Details of the performed monitoring campaign, including monitoring period and locations of the MBs within the GSs.

Author Contributions: T.B., M.A.-S. and N.C. were responsible for the study design; D.S. and C.D. were responsible for the creation of the IAQ monitoring units based in low-cost sensors; T.B. and N.C. performed the data and results' analysis, including statistical analysis and creation of figures; T.B. wrote the original draft; M.A.-S. and N.C. contributed to the review and editing of the original draft. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data that support the findings of this study are available upon request to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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