POLITÉCNICO DE LISBOA

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DE LISBOA
INSTITUTO POLITÉCNICO DE LISBOA

Indoor Environmental Quality Assessment in Groceries

Teresa Emília de Freitas Baptista

Dissertation to obtain degree in Masters in Occupational health and Safety

(Mestrado em Segurança e Higiene no trabalho)

Supervisors:

PhD Marina Almeida-Silva

PhD Nuno Henrique Varela Canha

July 2022

POLITÉCNICO DE LISBOA

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DE LISBOA
INSTITUTO POLITÉCNICO DE LISBOA

Instituto Politécnico de Lisboa

Escola Superior de Tecnologia da Saúde de

Lisboa

Indoor Environmental Quality Assessment in Groceries

Supervisors:

PhD Marina Almeida-Silva

PhD Nuno Henrique Varela Canha

Jury:

President: PhD Carla Sofia Costa

Viegas Arguer: MSc Tiago Miguel Ferreira Dias

Masters in Occupational health and Safety

(This version includes changes suggested by the jury)

POLITÉCNICO DE LISBOA

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DE LISBOA
INSTITUTO POLITÉCNICO DE LISBOA

TABLE OF CONTENTS

List of Abbreviations ... i

List of Figures ... ii

List of Tables ... iii

Abstract ... 1

1. Introduction ... 2

1.1. Framework ... 2

1.2. State of theArt ... 7

1.2.1. Indoor Air Quality ... 7

1.2.2. Comfort Parameters ... 12

1.2.3. Legislation ... 15

1.3. Goal of this thesis ... 16

2. Materials and Methods ... 17

2.1. Study Site ... 17

2.2. Groceries Characterization ... 17

2.3. Monitoring equipment ... 18

2.4. Monitoring campaign ... 20

2.5. Statistical analysis ... 21

3. Results and discussion ... 22

3.1. Carbon Dioxide ... 22

3.2. Volatile Organic Compounds ... 26

3.3. Particulate Matter ... 28

3.3.1 Exposure to PM and inhaled dose by workers ... 32

3.4. Temperature ... 35

3.5. Relative Humidity ... 37

3.6. Considerations ... 38

4. Limitations ... 41

5. Conclusions ... 42

6. References ... 43

7. Appendix ... 53

List of Abbreviations

AR - Acceptable range

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers

BRS - Building Related Symptoms

CO_2 - Carbon Dioxide

C_j - Concentration

E - Exposure

EEA - European Environment Agency

D - Dose

DALYs – Disability-adjusted life years

GS - Grocery stores

IAQ - Indoor air quality

IEQ – Indoor Environmental Quality

ILO – International Labour Organization

IPMA – Instituto Português do Mar e Atmosfera

IR – Inhalation Rate

LV – Limit value

MAT – Mean Air Temperature

MB - monitoring boxes

PM - Particulate Matter

$PM_{2.5}$ – Particulate Matter with an aerodynamic diameter lower than 2.5 μm.

PM_{10} - Particulate Matter with an aerodynamic diameter lower than 10 μm.

REF - Reference equipment

RH - Relative Humidity

SBS - Sick Building Syndrome

T- Temperature

tj - Time

VOCs - Volatile Organic Compounds

WHO - World Health Organization

List of Figures

Figure 1- Optimum Relative Humidity range for minimum health effects (33) 14

Figure 2 - Locations of the 13 studied GSs in the Cascais municipality (delimitation defined by dark grey area), within the Lisbon metropolitan area 18

Figure 3- Examples of location of the IAQ monitoring boxes at the grocery stores.................... 20

Figure 4 - CO_2 mean values for occupied moments in all 13 grocery stores. Red line represents the established LV by the Portuguese legislation *(65)* 22

Figure 5 - Variation of CO_2 during 5 days in GS M4... 24

Figure 6 - Levels of CO_2 in the different GSs regarding their number of clients per day 25

Figure 7 - VOCs mean levels for occupied periods in all 13 grocery stores. The red line represents the limit value of 262 ppb established by Portuguese legislation (65).. 26

Figure 8 - VOCs mean values for the two different cleaning procedures, where n is the total number of studied locations in the different GSs... 27

Figure 9 - Variation of VOCs during 5 days in GS M4.. 28

Figure 10 - PM_{10} mean levels for occupied moments in all 13 grocery stores. Red line represents the limit value established by the Portuguese legislation (65) and the yellow line represents the WHO guideline 29

Figure 11 - $PM_{2.5}$ mean levels for occupied moments in all 13 grocery stores. Red line represents the limit value established by the Portuguese legislation (65) and the yellow line represents the WHO guideline 29

Figure 12 - Variation of PM_{10} for 5 days in GS M4. 31

Figure 13 - Variation of $PM_{2.5}$ during 5 days in GS M4. 32

Figure 14 - Worker exposure to $PM_{2.5}$ during working periods of 8 hours 34

Figure 15- Mean temperature assessed in all the studied GSs. Green area represents the acceptable range (AR) of 18 – 25 ºC, defined by the Portuguese legislation (67)... 35

Figure 16 - Variation of temperature during 5 days in GS M4.. 36

Figure 17 - Mean levels of relative humidity in all the studied grocery stores (GSs), where AR stands forAcceptable Range (30-70%) 37

Figure 18 - Variation of RH during 5 days in GS M4. 38

POLITÉCNICO DE LISBOA

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DE LISBOA
INSTITUTO POLITÉCNICO DE LISBOA

List of Tables

Table 1- Provides the summary of the limit values established by the Portuguese legislation (63,65–68) 15

Table 2 - Intercomparison results between MBs and the reference equipment's for all the studied parameters. Range REF stand for the range of the pollutant as measured by the reference equipment (REF) 19

Table 3 - PM_{10} and $PM_{2.5}$ exposure and correspondent potential inhaled dose during working period for the studied GSs 33

Table 4 - Summary of measures to improve indoor air quality in grocery stores............ 40

Table S1 - Survey for characterization of the GSs 53

Table S2 - Summary of the characteristics of the studied GSs, including cleaning procedures 54

Table S3 - Identification of the studied GSs and the monitoring boxes used during the study, including the type of location and monitoring period 55

Table S4 - Description of the independent variables considered in the statistical analysis regarding their influence on the IAQ levels at the GSs............ 56

Table S5 - Results of the statistical analysis to the mean levels of IAQ parameters registered in all the locations of the studied GSs............ 57

Table S6 – Summary of the mean levels of the considered parameters during the occupied period in the studied Grocery Stores, at each studied location. 59

Table S7 - Summary of the mean levels of the studied parameters assessed in each GSs (considering all locations within the GSs for the mean assessed at a specific GS), during the occupied period............ 60

POLITÉCNICO DE LISBOA
ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DE LISBOA
INSTITUTO POLITÉCNICO DE LISBOA

Abstract

Air is among the vital human needs to survive. It is the one thing humans cannot be without longer than a few minutes. Indoor Air Quality (IAQ) is a public and occupational health concern, since we are exposed to air pollutants daily, given that we spend almost 90% of our time in indoor environments. IAQ can be affected by numerous factors, from outdoor pollutants that get indoors through ventilation to building material, furnishing 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 (GS) in the municipality of Cascais in the Lisbon district of Portugal, and, consequently, 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 technologies, focused on several parameters, namely: Carbon dioxide (CO_2), Volatile organic compound (VOCs), Particulate matter (PM_{10} and $PM_{2.5}$), Temperature (T) and Relative Humidity (RH). The results were analyzed using SPSS software. Overall, the IAQ of the studied GSs complied with the Portuguese legislation, except for $PM_{2.5}$, where 23% of GSs presented levels above the established limit value of 25 $\mu g.m^{-3}$. The IAQ assessment allowed to identify the best strategies to improve the workers' experience in the indoor environments at their workplaces.

Keywords: Indoor air Quality; Occupational assessment; Grocery Stores

1. Introduction

1.1. Framework

Air is the most important thing to survive since breathing is one of the most essential human needs. Realistically, an individual can survive a few days without food or even water, but not one person is able tosurvive without air for more than a few minutes. Unlike the other natural resources, the air is not scarce, but its vulnerability lies mainly in its risk of deterioration (1). The indoor air is a complex mixture of non-biological and biological contaminants as well as outdoor and indoor pollutants, Indoor air quality (IAQ) is a public and occupational health concern, the IAQ has significant impact in human health and well-being, the IAQ has been found to be the source of numerous adverse impacts to human health such as respiratory and cardiovascular illnesses, allergic symptoms, cancer and premature mortality (2). The changes in lifestyles have made us more subjected to air pollutants since, nowadays, we spend a great amount of time in indoor environments. In average, a person spends about 90% of their time in indoor environments (public to private environments, namely, home, workplace, leisure, buildings and commuting, for instance), where people are exposed to several pollutants in their daily life that may have negative impact on their health, productivity and welfare (3,4).

The history of indoor environment started centuries ago when humans lived in caves and used campfires to try and keep themselves warm (5). The development of civilization has made our environment dangerously polluted. In the last decades, the building paradigm for workplaces and dwellings have changed, whereas the control over the thermal climate and energy efficiency have been prioritized. Naturally ventilated buildings have been replaced by airtight buildings, which conducts to indoor spaces with lower air flow where dilution of the air pollution becomes more difficult. Simultaneously more complex materials are being used for furniture, clothing, detergents and etc., which promotes an increase in new indoor pollutants, such as organic compounds, resulting in potential health problems to humans (6,7).

Historically, there has been mentions on the effects of the air quality in health, from as early as 1500 BC by the Egyptians, later by Hippocrates, and by the XIII century coal combustion emissions were feared as a source of illnesses (8). The general idea in the XVIII century was that breathing was a way of cooling down the heart, the composition of the air was not important, only its coolness, and it was believed that the concentration of carbon dioxide (CO_2) was a way of measuring if the air was fresh or stale, although they did recognize at the time that the "expired air" was unfit for breathing until it had been refreshed (9). Even with historical database, efforts to improve the air quality only began in relatively recent years.

With the technological advancements and the industrial revolution came numerous new sources of air pollutants, with the modern philosophy of building design being to prevent "leaks" and to minimize electric and thermal energy losses attributable to its insulation. Moreover, due to changes in lifestyle and the building materials used in indoor environments, comes a change in the composition and complexity of indoor air, due to the use of more synthetical materials and chemicals, both for construction and decoration, as well as cleaning agents, along with specific indoor emissions, such as gases from cooking, air fresheners and candle burning or incense, for instance (4,10). All these changes have made the building more energy efficient but are also responsible for indoor environments where airborne pollutants are produced and may reach high concentration levels indoors, due to the lack of proper ventilation. Moreover, if the outdoor air is not properly filtered and cleaned in areas where there are specific outdoor pollution sources (such as traffic), some pollutants, such as particles, may find their way inside indoor environments, where they can react with the pollutants already present in the indoor and become more harmful. Therefore, the concentration of many pollutants can be many times higher in indoor compared to outdoor environment, whilst this does not mean that indoor air will cause more harmful health effects, the presence of these pollutants, even at low concentrations, may have significant biological impact due to its time of exposure (7,10).

According to the World Health Organization (WHO), 1.5 million deaths and 2.7% of the global burden of disease were attributed to the IAQ in 2000 (11). Later, by 2017, IAQ was linked worldwide to 1.8 million deaths and 60.9 million DALYs (Disability-adjusted life years), which represents the years lost due to a disability (12). According to the United Nations Environment Programme, IAQ was responsible for around nearly 3.2 million premature deaths in 2020, and around 4 million in 2021 (13,14).

Although air pollution affects the entire population, some are more exposed to it than others and some are more susceptible to it than others. Moreover, the type, levels and sources of indoor pollutants and their exposure profiles are considerably different between the developed and developing world. For instance, lower socio-economic groups, that are more likely to live in industrial areas and busy roads, are more exposed to air pollutants. Regarding the susceptibility to air pollution, the main population groups are children, older people and people with pre-existing health conditions, due to lower capability of their body to deal to the exposure to air pollutants. Another relevant impact of exposure of citizens to air pollution is its significant impact into the countries' economy since it promotes an increase of medical costs, reduction of life expectancy and decrease of productivity (15).

Research efforts have been done towards better understand the complexity and effects of the IAQ in human health in different environments such as dwellings, schools, restaurants, retails and others (16). However, there is a gap in knowledge related to characterization of air quality in groceries and markets, not only in Portugal but also internationally. Therefore, it is important to study these specific types of indoor environments to understand how IAQ is characterized, which allows us to assess the occupational exposure of workers. This information is crucial to design and promote targeted mitigation measures to minimize workers' exposure.

An adult human generally spends about 8 hours at work during 5 days per week. In average, we spend about around 90 000 hours (considering 50 working weeks per year), some even more than that depending on the profession and type of work. The Eurostat statistical atlas in 2020 estimated that the average duration of working life of a regular person in the European Union was 35.2 years. Regarding Portugal, the estimative is slightly higher, namely 38.2 years, which is equivalent to about of a 1/3 of our lifetime (17). Therefore, the job workplace and its conditions may have a huge impact in your life.

When thinking of a healthy workplace, the first instinct is to think about the social environment, and most of the time we tend to neglect the indoor environmental quality (IEQ) which refers to the quality of the environment of buildings, regarding comfort parameters, air pollutants and other parameters (such as noise and lighting), that may have a significant impact on the health and welfare of their occupants. One of those factors is the IAQ. Several studies have already shown that these environmental parameters may have a great impact on the quality of people's lives and the productivity of workers (18).

The importance of health and safety at the workplace cannot be underestimated. Even though workplace health and safety are an obligation of the employer, it is many times neglected.

It has great advantages for the employers, as it is beneficial for the wellbeing and productivity and loyalty of the employees.

For a long time, the link between the work conditions and productivity has been imperceptible, including how it affected the companies. However, it was recognized the burden of economic costs of work-related accidents to the companies, regarding both medical costs and the worker compensation, along with equipment and material costs depending on the job, and absenteeism. Moreover, typically, only after those issues, professional diseases would be considered (19).

Nowadays, it is known that the success of a company is directly linked to the conditions of the workplace.

According to the International Labour Organization (ILO) (20), it is estimated that around 2.3 million people succumb work-related accidents and diseases every year, with around 160 million annually are thought to be victims of work-related illnesses. It is important to highlight that work-related diseases cause the most deaths among workers.

Moreover, work-related diseases and accidents result on various work days missed by the employees, which has a direct impact on the company and, consequently, in the economy of the country (21).

1.2. State of the Art

1.2.1. Indoor Air Quality

According to World Health Organization (WHO), health is defined as "state of complete physical, mental, and social well-being and not merely the absence of disease and infirmity" (22). In the same way, a healthy indoor air is one that does not have a risk of disease or adverse health effects and insures the comfort and well-being of the occupants (23). Due to its recognized impact of IAQ on our daily life, WHO has acknowledged it by establishing that everyone has the right to breathe healthy indoor air, under the principle of the human right to health, stated in its Constitution in 1946 (24).

Respiration is the first route of entry into our organisms, therefore should be taken with the most significance. In average, an adult person has a ventilation rate of about 6 liters of air per minute, where is also influenced by individual variations due to biological characteristics (such as age, gender, health-state and size) and also due to the type of activity that the individual is doing. However, during a full day, an individual may breathe a total of around 12000 to 15000 l/day (25). Pollution is when a specific pollutant (that can be in the form of gas, liquid or solid) is in higher concentration than usual, which reduces the quality of the environment (26). As already highlighted, several studies have already shown that indoor levels of pollutants may be 2 to 5 and sometimes as high as 100 times higher than outdoor levels (27,28).

As a result of the energy crisis in the 1970s and with the amount of fresh air supplied minimized to 2 l/s per person, there was an increase in indoor environments problems, mainly in office buildings, since the concern with energy conservation led to the constructions of airtight buildings with a major decrease of fresh air intake (5).

The term sick building syndrome (SBS) was first used in 1982 by the WHO. SBS, also sometimes called as Building Related symptoms (BRS), is used to describe a number of symptoms with no specific etiology reported by the occupants, including upper-respiratory irritative symptoms, fatigue, headaches, irritation of the skin, difficulty concentrating, that is related to working in particular non-industrial indoor environment, such as modern office buildings. The sort and severity of the symptoms are reliant of the environment and also of the individuals' vulnerability and exposure (29–32). In some cases, individuals suffering from SBS symptoms have reported that the symptoms tend to decrease away once out of those environments (32).

The indoor air is a complex system of pollutants, contaminants and physical parameters that interact with each other. Indoor air pollutants include, for instance, carbon monoxide, carbon dioxide, volatile organic compounds, and particulate matter (33).

The indoor air is mostly affected by four different factors: i) indoor sources, such as pollutants emitted from building materials and furnishing, electronic equipment's, cleaning and consumer products, including the ones promoted by activities of the occupants; ii) outdoor sources associated with industrial activities and vehicular traffic, that gets indoor by infiltration through mechanical and/or natural ventilation systems; iii) physical parameters, such as relative humidity and temperature, that can promote the emission of air pollutants from building material and; iv) ventilation that help to promote the dilution of the concentration of air pollutants in order to keep a good IAQ (2,34). Based in these factors, a set of four principles were identified to achieve a good indoor air quality: i) minimize indoor emissions; ii) keep it dry; iii) ventilate well; and iv) protect against outdoor pollution (35).

1.2.1.1. Carbon Dioxide (CO_2)

Carbon Dioxide (CO_2) is a chemical compound colorless and non-flammable gas at normal temperature and pressure. With energy saving measures, the building ventilation was typically reduced, which can lead to higher indoor levels of CO_2. This happens because the major source of indoor CO_2 is the human respiration and, when there is not adequate ventilation (which promotes the dilution of indoor pollutants), the levels of CO_2 continue rising. Therefore, CO_2 concentrations are often used as an indicator of adequate ventilation in buildings(36).

Exposure to high levels CO_2 can cause tiredness, somnolence, dizziness, headaches and decrease in mental acuteness, which promotes a lower performance of the individuals (37). Carbon dioxide is, in fact, considered a contaminant as an alternative of pollutant since it doesn't have major adverse effects to health and it is naturally emitted by people.

1.2.1.2. Volatile Organic Compound

Volatile organic compounds (VOCs) are chemicals that evaporate very easily at room temperature due to its high vapor pressure. These pollutants are emitted from natural and anthropogenic sources, such as construction materials, office equipment, combustion by-products, consumer products and cooking (38). They include a variety of compounds, with different VOCs having different health effects, ranging from highly toxic to those with no known health effect, and some that can have short- and long-term health effects. Due to their high variable lipophilicity and volatility, the major route of exposure of VOCs is the inhalation. VOCs are widely used as an ingredient in household products, such as cleaning products, paints, disinfectants, cosmetics, air fresheners, etc. Office supplies also contain VOCs, like printers, glues, and adhesive, etc. Studies have shown that the levels of VOCs are 2 to 5 times sometimes up to 10 higher in indoor environments in contrast with outdoor environments, regardless if it is a rural area or highly industrial areas (39–41). Even small low concentration of these compounds have been associated with a series of discomfort and respiratory illness (2). Numerous studies have shown that building materials can be sources of VOCs, which affect greatly the IAQ. Some studies also highlighted the correlation between VOCs and SBD symptoms (2,39).

Some VOCs are considered toxic, carcinogenic, mutagenic and teratogenic (38), whereas some of the health effects may be skin, eye, nose and throat irritation, headaches and nausea, damage to liver, kidney and central nervous system, allergic skin reaction. Naturally, as it happens with other pollutants, the nature and extent of the health effects will depend on level and time of exposure of the individual (40).

1.2.1.3. Particulate Matter

Particulate matter (PM) has been recognized as a priority pollutant and, since 2013, it was considered as carcinogenic (42) due to its association with adverse health effects, confirmed by innumerous studies (43,44).

PM is a mixture of solid, liquid, and gaseous matter in the air, includes inorganic and organic particles such as dust, dirt, smoke, and liquid droplets. Generally, PM originates from natural processes like sea sprays, volcanoes, dust storms etc., as well as anthropogenic sources like human activities such as industrial processes, fossil fuel in traffic, among others. The deposition of PM on the respiratory tract depend on particle size, with smaller particles resulting in larger lung deposition and farther airway penetration (45). PM enters the organism mostly through inhalation and the large particles are filtered by the nose, however smaller particles can get through and deposit in the lungs, some of which find their way into the heart and other organs through the bloodstreams causing damage to multiple physiological systems, especially the respiratory, cardiovascular and nervous systems (46–49).

The particle varies widely in size, chemical composition, and shape. Regarding size, PM are defined by their aerodynamic diameter with the main type being PM_{10} and $PM_{2.5}$. PM_{10} corresponds to the particulate matter with an aerodynamic diameter lower than 10µm, which are considered inhalable particles. The size of the particles generally determines where the particles deposit in the respiratory tract when inhaled. Larger particles are filtered by the nose and throat, but smaller particles can get through. Particulate matter smaller than 10 micrometers can penetrate the trachea and bronchial regions and deposition in the lungs which can cause adverse health effects. $PM_{2.5}$ is the particulate matter with an aerodynamic diameter lower than 2.5µm, which can easily enter the alveolar region of the lung, giving rise to deep deposition within the lung. These particles often derive from different sources and have different compositions and, when deposited in the lungs, can cause inflammation and tissue damage (46,50).

PM is found to be the cause of a broad range of health effects, and it has been linked to the aggravation of respiratory illness like asthma and allergies. Moreover, short term exposure has been linked with acute cardiovascular risks like, myocardial infarction, hypertension, among others (49). In fact, WHO already pronounced fine particles (2.5 µm or less) to be responsible for more premature deaths than any other pollutant (51).

Both $PM_{2.5}$ and PM_{10} have been linked to heart failure, hospitalization and mortality (52). It is important to keep in mind that there are many factors influencing the infiltration of particles in indoor environments, including building material, quality of windows and doors as well as difference in ventilation habits, which can be implicated by climate conditions.

1.2.2. Comfort Parameters

Thermal comfort is essential for building occupants' health and comfort (53). Temperature and relative humidity are usually used as parameters of indoor environmental quality since their levels affect individuals' perception of comfort in indoor environments (54).

The human body is homoeothermic, which is the ability of the human body to regulate internal body temperature regardless of external influence (55). The internal body temperature is normally higher than the environment (varies from 36.5ºC – 37.5ºC)., there is no flow of heat in or out of the body, that is what is called Thermal Equilibrium (56).

Thermal comfort is difficult to define as it is a condition of the mind that expresses satisfaction or dissatisfaction with the thermal environment (57). It can be influenced by personal, work-related and environmental factors (58).

The thermal comfort is an important parameter in the workplace risk assessment, since a deficiency in this aspect may result in dissatisfaction of the workers and a reduction on productivity and performance, along with a direct impact in the individual's health and well-being (59).

The thermal comfort is not measured by room temperature, but by the occupant's satisfaction. The Health and Safety Executive (HSE) states that realistically we must hope to achieve an environment that satisfies the majority of the people in the workplace (60). Even at a considered moderate temperature where the majority would be satisfied, about 5% of the occupants are still going to be dissatisfied (61).

1.2.2.1. Temperature

The interaction between the workers and their environment is a key issue in all work setting. The relation between work and setting can cause physiological and psychological responses in workers, and therefore their comfort, productivity, health and safety (62). The thermal sensation of a human being is related to thethermal balance of the body as a whole, this balance is influenced by environmental parameters but also by activities as well as the clothing (63).

Exposure to different air temperatures, different times of exposure, along with the individual characteristics of the occupants, are some of the factors that might influence human performance (62). According to ISO 7730 from 2005, the optimal temperature for indoor environments are 23-26ºC during summer and 20-24ºC during the winter (63).

1.2.2.2. Relative Humidity

Relative humidity (RH) is the water vapor, or the percentage of water vapor held by the air in comparison with the saturation level. Some level of humidity is necessary for comfort, both low and high RH cause discomfort since they affect the thermal perception.

RH have both direct and indirect effects on comfort and health. The direct effects are the effects on physiological processes – for instance, 20% or below, which is considered extremely low RH, may cause eye irritation, with some physicians have reported that in environments with low RH some patients have complains of dryness of the throat and nose. Another important direct adverse effect of RH on health is when high RH is paired with high temperatures, which are detrimental to the perceived IAQ. This combination reduces the rate of evaporate/cooling of the body which can cause significant discomfort or cause exhaustion, lead to heat stroke and possibly death (33,64). Furthermore, RH have also indirect effects on health, namely, RH affects the concentration of noxious chemicals in the air by altering the rate of off-gassing from building, materials and the reaction of water vapor with chemical in the air (33).

RH in buildings is influenced by occupancy, the construction and building design, ambient climate, and operation. The optimum relative humidity recommended is 40-60%, which is the optimum zone to promote the proliferation of bacteria, viruses, fungi and mites, to minimize health impacts and also to minimize the chemical interactions in the indoor air, as showed by Figure 1 (33).

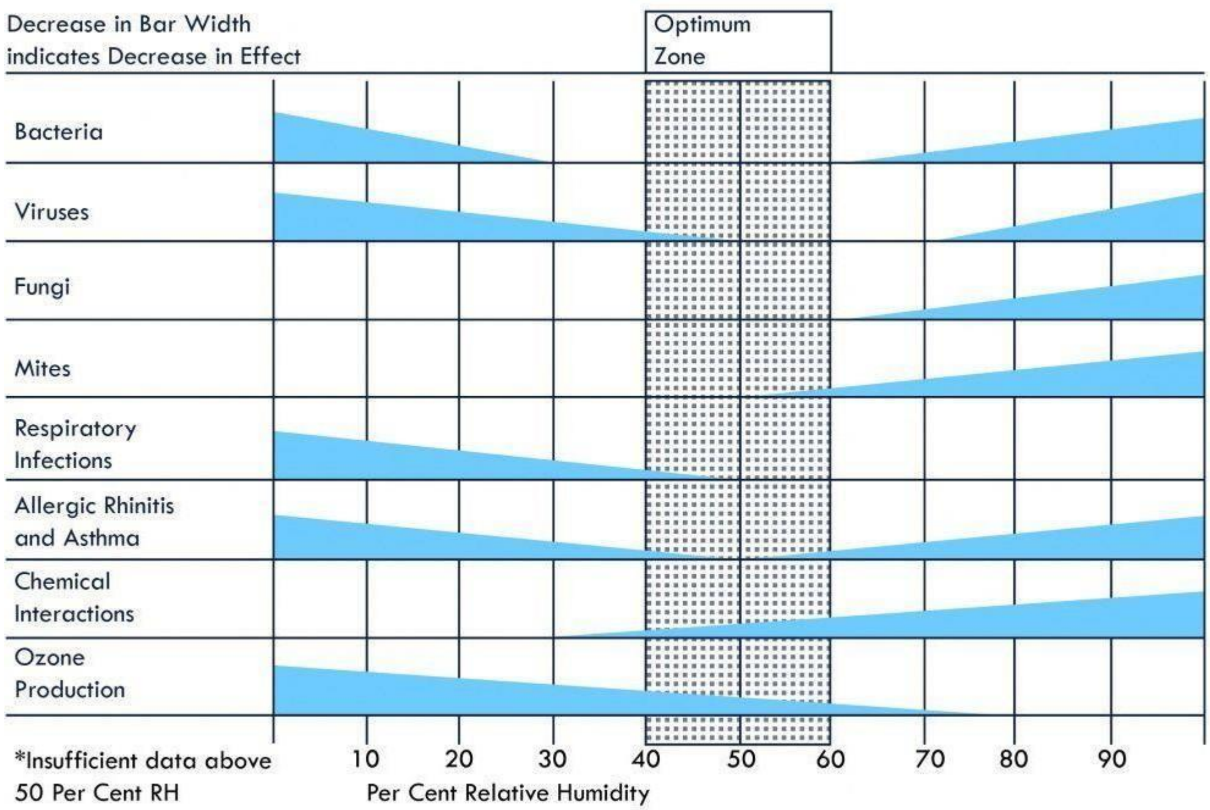

Figure 1- *Optimum Relative Humidity range for minimum health effects* (33).

1.2.3. Legislation

The Portuguese legislation (65) provides a set of limit values to different IAQ parameters to promote healthy indoor environments, focusing on the parameters described above (VOCs, CO_2, $PM_{2.5}$, PM_{10} and comfort parameters), and also on radon, carbon monoxide (CO), and bioaerosol levels (namely, fungi and bacteria). There are other relevant guidelines for IAQ, such as the WHO guideline for indoor air pollution (66). It is important to highlight that between organizations and countries, the established threshold limit values may vary.

Table 1- Provides the summary of the limit values established by the Portuguese legislation (63,65–68).

Legislation/guidelines		
Parameters	**Values**	**References**
$PM_{2.5}$	25 ($\mu g.m^{-3}$)	Portaria n.º 138-G/2021, de 1 de julho
	5 ($\mu g.m^{-3}$)	WHO (2021)
PM_{10}	50 ($\mu g.m^{-3}$)	Portaria n.º 138-G/2021, de 1 de julho
	15 ($\mu g.m^{-3}$)	WHO (2021)
Carbon Dioxide (CO_2)	2250 ($mg.m^{-3}$) ≅ 1250 (ppm)	Portaria n.º 138-G/2021, de 1 de julho
Volatile Organic Compound (VOCs)	600 ($\mu g.m^{-3}$) ≅ 262 (ppb)	Portaria n.º 138-G/2021, de 1 de julho
Temperature (T)	18ºC - 22ºC, 25ºC depending on meteorological conditions	Decreto-Lei n.º 243/86, de 20 de agosto
	20ºC - 27ºC	ASHRAE
	23ºC-26ºC (Summer); 20ºC-24ºC (Winter)	ISO 7730
Relative Humidity (RH)	50% - 70%	Decreto-Lei n.º 243/86, de 20 de agosto
	40% - 60%	Arundel et al, 1986
	30% - 70%	ISO 7730

1.3. Goal of this thesis

The main objective of this work was to understand the IAQ that workers in grocery stores are exposed while working, check the compliance of those IAQ levels regarding the Portuguese legislation and international guidelines (when appropriate) and to define the best practices to minimize the workers' exposure in those workplaces. The chosen grocery stores were all small and of the "family owned" type. The specific goals of this work were:

1) Characterize the grocery stores;
2) Perform real-time monitoring of IAQ using low cost technology, focusing on comfort parameters (T and RH) and chemical pollutants ($PM_{2.5}$, PM_{10}, CO_2, VOCs);
3) Based on evaluation of temporal patterns and compliance of IAQ levels with legislation/guidelines, to define best practices to minimize the workers' exposure to air pollutants.

This work is relevant since there is not many studies in grocery stores in Portugal and worldwide, and, therefore, it also brings more knowledge to the field of health and safety in the workplace in this type of environment.

2. Materials and Methods

2.1. Study Site

The study area was in the municipality of Cascais, which is a municipality of the Lisbon District (Portugal). Cascais has a total area of 97,4 km^2 and a population of about 200 000 inhabitants. The municipality is divided in 4 parishes: Alcabideche, Carcavelos e Parede, Cascais e Estoril and São Domingos de Rana. Cascais has a moderate Mediterranean climate moderated by the Atlantic Ocean.

2.2. Groceries Characterization

For the present study, a total of 13 small "family" Grocery stores (GS) were randomly selected from different parishes of Cascais municipality. Figure 2 provides the location of the studied grocery stores in the Cascais Municipality.

A survey (Table S1, available in the Appendix section) was applied for the characterization of each store in terms of dimension of the store,ventilation methods, cleaning products as well as the routine of the cleaning, number of employees, and other relevant information. Table S2 (available in the Appendix section) provides a summary of the characteristics of the studied grocery stores.

The total area of the grocery stores varied from $30m^2$ to $200m^2$. The number of employees varied between them, with 61.5% (8) having 2 employees, 23.1% (3) having 3 employees, 7.7% (1) having 7 employees (one grocery did not disclosure this information, which accounts to 7.7%). and thedaily costumer volume of the studied groceries ranged from 10 to 250 people per day. Since there is a high flow of customers going in and out, many of the GS kept their doors open and, the ones that do not kept the door always open, the door are always opening.

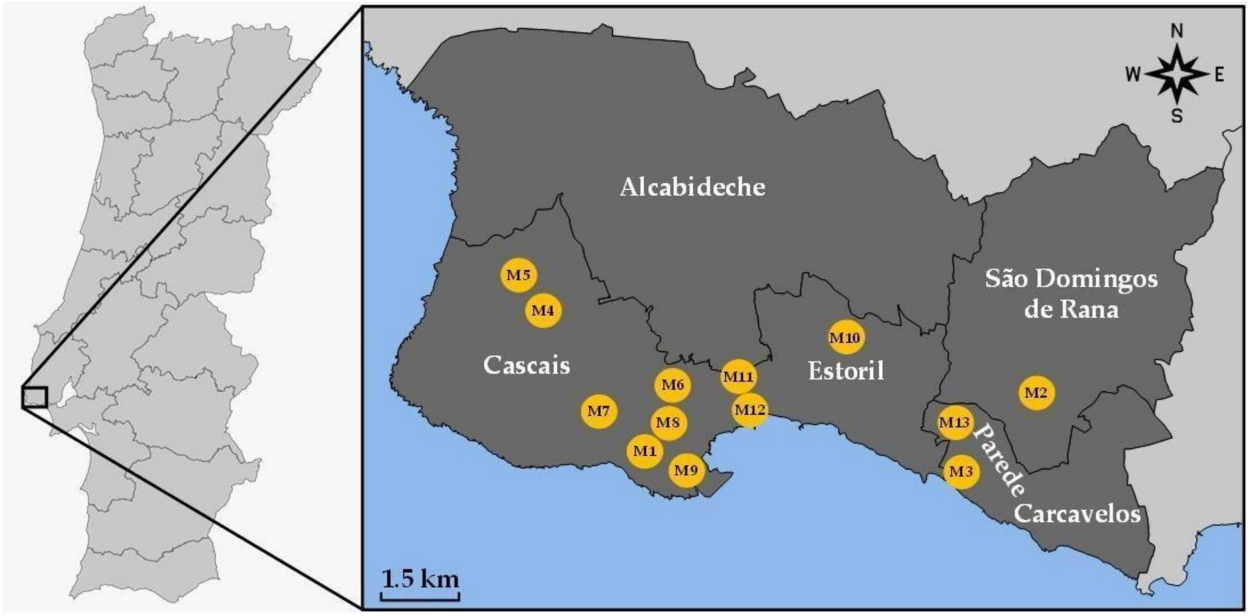

Figure 2 - Locations of the 13 studied GSs in the Cascais municipality (delimitation defined by dark grey area), within the Lisbon metropolitan area.

2.3. Monitoring equipment

Monitoring campaigns were conducted to characterize IAQ of the groceries stores by using air quality monitoring units (MB), based in low-cost sensors. The monitoring units collected real-time data of CO_2, $PM_{2.5}$, PM_{10}, VOCs, RH, and T, with a 5-minute monitoring frequency. These MB were developed by a team of investigators of the Instituto Superior Técnico of University of Lisboa and were already employed in IAQ survey studies (69). The low-cost sensors used in the MBs were i) SCD30 for CO_2 (with a measuring range of 380 to 10 000 ppm), ii) MiCS-VZ-89TE for VOCs (with a measuring range of 0 – 1000 ppb in isobutylene), iii) HPMA115s0 for $PM_{2.5}$ and PM_{10} (with a measuring range of 0 – 1000 $\mu g.m^{-3}$), and iv) SHT31 for T and RH. After being plugged, the MBs sent the data to an online platform instantaneously via wireless, which stored the data in a cloud developed by the investigators. Simultaneously, the data was available visually online in real-time. A total of three MBs were used in this study, with the following ID: AirQ1, AirQ2 and AirQ3.

The performance and data reliability of the MBs was assessed by comparing its monitoring data with the one obtained by reference real-time instruments and, afterwards, by defining correction factors to apply to the raw data assessed by the MBs. The used reference instruments were DustTrak DRX monitor (8533 model, TSI, USA) to assess $PM_{2.5}$ and PM_{10} levels, and Graywolf (IQ-610 probe, WolfSense Solutions, USA) to assess CO_2, VOCs, T and RH.

This inter-comparison study was done in an office, with a 5 minutes monitoring frequency, where the several target IAQ parameters were made to vary by the use of local sources.

Table 2 provides the correlations between the MBs and the reference equipment for all studied parameters. Very strong correlations were obtained (R^2 ranging from 0.80 - 1.00) for all the parameters, except for VOCs that was considered moderate for AirQ1 (0.43) and strong for AirQ2 and AirQ3 (0.64 and 0.68, respectively).

Table 2 - Intercomparison results between MBs and the reference equipment's for all the studied parameters. Range REF stand for the range of the pollutant as measured by the reference equipment (REF).

Monitoring unit	Parameter	Unit	m	b	R^2	Frequency	Range REF	n points	Ratio MB/REF
Air Q1	$PM_{2.5}$	$\mu g.m^{-3}$	3.5262	3.5003	0.977	5min	4.2 - 382.2	763	**0.26**
	PM_{10}	$\mu g.m^{-3}$	3.4709	1.6958	0.973	5min	4.2 - 383.0	884	**0.28**
	CO_2	ppm	1.0389	-12.427	0.986	5 min	369.4 - 2548.5	1336	**0.98**
	VOCs	ppb	0.4529	-191.69	0.426	5min	60.0 - 139.3	278	**6.77**
	T	ºC	1.1421	-4.4108	0.936	5 min	15.0 - 31.7	1418	**1.07**
	RH	%	1.2837	-9.03	0.927	5 min	36.1 - 69.6	1430	**1.09**
Air Q2	$PM_{2.5}$	$\mu g.m^{-3}$	2.0717	1.3919	0.993	5min	3.0 - 198.1	1206	**0.46**
	PM_{10}	$\mu g.m^{-3}$	2.0024	0.9004	0.992	5min	3.0 - 190.3	1289	**0.48**
	CO_2	ppm	1.0259	-78.503	0.987	5 min	369.4 - 2548.5	1461	**1.11**
	VOCs	ppb	0.3484	-63.02	0.635	5min	60.0 - 122.0	281	**4.82**
	T	ºC	1.144	-3.9528	0.931	5 min	15.0 - 31.7	1470	**1.04**
	RH	%	1.2346	-8.2152	0.931	5 min	36.1 - 69.6	1470	**1.06**
Air Q3	$PM_{2.5}$	$\mu g.m^{-3}$	1.8409	1.7687	0.992	5min	3.0 - 176.2	1246	**0.50**
	PM_{10}	$\mu g.m^{-3}$	1.7658	1.2891	0.992	5min	3.0 - 164.7	1267	**0.53**
	CO_2	ppm	0.9917	-128.65	0.982	5 min	369.4 - 2548.5	1471	**1.24**
	VOCs	ppb	0.3138	-134.26	0.677	5 min	60.0 - 110.0	238	**7.87**
	T	ºC	1.0334	-1.3159	0.949	5 min	15.0 - 31.7	1467	**1.03**
	RH	%	1.1233	-3.2509	0.938	5 min	36.1 - 69.6	1473	**1.06**

2.4. Monitoring campaign

The MB were placed in pre-determined spots inside the selected grocery stores (Table S3, available in the Appendix section), namely, the register, the fruits and vegetable area and in some cases the storage area (AirQ1, AirQ2 and AirQ3, respectively, though not exclusively). Figure 3 presents examples of locations of the IAQ monitoring boxes at the grocery stores. The Monitoring campaign took place between November 2021 and February 2022, during which the MBs were placed in each grocery store, at around 1.20m of height for a time period between 2 and 5 days. In each grocery, the number of monitored locations varied between 1 and 3. The placement and the number of monitoring boxes allocated to each store were determined by the size of the grocery store, the existence or not of a storage space in the store, and the proximity of the selected points of monitoring from each other. The data provided by the MB went directly to the cloud with continuous surveillance.

Figure 3- Examples of location of the IAQ monitoring boxes at the grocery stores.

According to the Instituto Português do Mar e Atmosfera (IPMA), November was considered as very cold and very dry with a mean air temperature (MAT) of 11.2 ± 1.2 ºC (ranging from 5.8 ± 2.1 ºC min to 16.6 ± 0.3 ºC) (70), while December and January were considered very hot and dry months with a MAT of 11.7 ± 1.2 ºC (ranging from 7.7 ± 1.6 ºC to 15.7 ± 1.8 ºC) (71) and of 9.7

± 0.8 ºC (ranging from 4.0 ± 0.5 ºC to 15.3 ± 2.2 ºC) (72), respectively, and February was considered very hot and extremely dry with a MAT of 11.3 ± 1.3ºC (ranging from 5.3 ± 0.3 ºC to 17.4 ± 3.0 ºC max)(73).

2.5. Statistical analysis

The data treatment was done by using Microsoft Excel. The statistical analysis of data was performed using IBM SPSS Statistics 28 software, considering the mean values of the different IAQ parameters assessed for the occupied periods by each monitoring unit (n = 25). The evaluation of the normality of data was done using a Shapiro-Wilk test and only CO_2 data was found not to have a normal distribution (p-value < 0.010). Therefore, for all parameters (except CO_2), the statistical analysis was done by using ANOVA to evaluate the existence of statistically significant differences between two or more groups of an independent variable (the post-hoc test Bonferroni was used to understand the significant different between groups). For CO_2, the analysis of variance was studied using non-parametric statistics, namely Mann-Whitney test and Kruskal-Wallis test, for independent groups to see if there were statistically significant difference between two or more groups of an independent variable, respectively. In the case of Kruskal-Wallis test, if a significant difference was found, the significant pairs were found by pairwise comparisons (with significance values being adjusted by the Bonferroni correction for multiple tests).

A total of 8 GSs characteristics (independent variables) were evaluated regarding their impact on the assessed IAQ parameters (dependent variables), namely: 1) type of facilities, 2) type of products, 3) selling area, 4) storage area, 5) cleaning procedure, 6) type of cleaning products, 7) number of clients per day, and 8) closing days. Tables S4 and S5 in the Appendix section provide the description of the variables and the results of the statistical analysis, respectively.

3. Results and discussion

This chapter displays all the obtained results from the monitoring campaign and provides a discussion of the data. Table S6 (available in the Appendix section) provides the results of all the monitored locations at the GSs for all parameters, and Table S7 (available also in the Appendix section) provides the mean levels for all parameters per GSs. The results ahead only apply to occupied periods of the GSs since it is the time period that is relevant to assess the workers' exposure to air pollutants, which is the goal of this work (74).

3.1. Carbon Dioxide

None of the GS exceeded the mean CO_2 limit value of 1250 ppm established by Portaria n.º 138-G/2021, de 1 de julho (Figure 4). The mean concentration of CO_2 found in all the studied sites of the GSs was 486 ± 90 ppm, ranging from 365 ± 16 (GS 11, location B) to 864 ± 178 (GS 4, location B), as fully described in the Appendix section (Table S6).

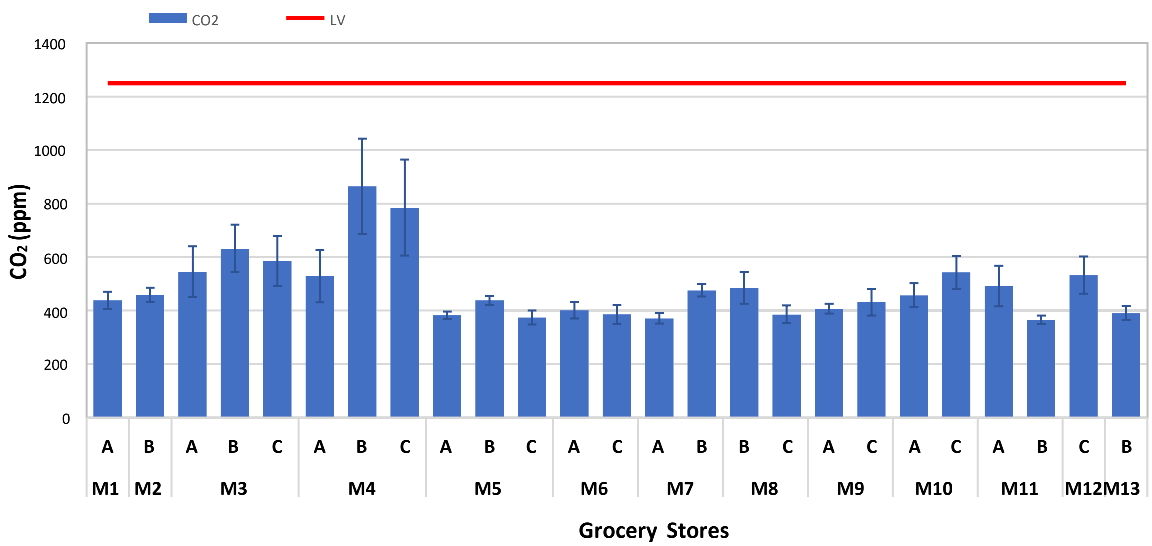

Figure 4 - CO_2 mean values for occupied moments in all 13 grocery stores. Red line represents the established LV by the Portuguese legislation *(65)*.

Since CO_2 is only produced by occupants, this parameter is often used as indicator of ventilation and occupancy (75). All of the 13 studied GS had only natural ventilation.

The levels of CO_2 in the GSs are not worrisome since all of them are under the LV. For instance, a study carried during the sleeping period of couples found levels of 1911 ± 894 ppm which are considered very high (and above the LV), and those values are due to the type of used ventilation in the bedrooms (76). In that study, the bedroom that had mechanical ventilation had lower levels, and those that slept with closed door and windows (which typically provides very low ventilation conditions) had higher values (76). In the same way, the levels found in the studied GSs may be low, since the doors are mostly open during working hours, which contributes to a good circulation of air. Similarly, a study carried out in Elderly Care Centers in Lisbon found higher values of CO_2 in the bedrooms compared with the living-rooms, with all of them exceeded the LV with an average value of 1755 ppm (77). However, commercial buildings have typically better ventilation conditions, with doors often open or with a very high rate of entrance/exit of costumers, which will promote higher dilution of indoor pollutants. For instance, a study in a copy center in Aveiro, Portugal, also found similar values to the present study, with CO_2 levels being also below the LV, namely with a mean level of 552 ± 65 ppm. Even when the area had more affluence of students, the maximum levels found indoors were > 600 ppm but always lower than the LV (78).

As an example, in Figure 5, it is possible to observe the hourly variability of CO_2 levels throughout 5 days in one of the GS.

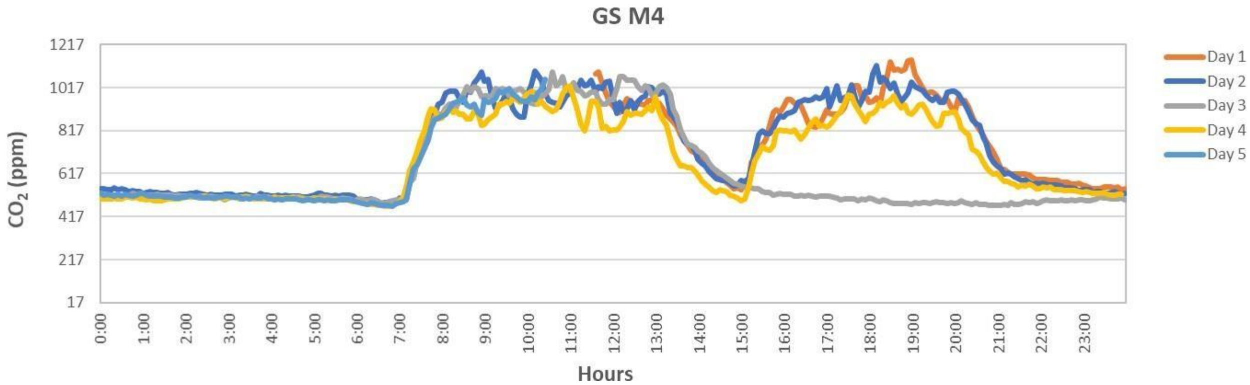

Figure 5 - Variation of CO_2 during 5 days in GS M4.

In this case, the CO_2 levels from 00:00 to 7:00 are stable (which is the non-occupied period of the GS) and then it is possible to observe an increase in its concentration, consistent with the opening hour and occupied period till around 13:00, where a decrease in CO_2 levels is observed, which is consistent with "lunch period". Afterwards, CO_2 levels increase again from 15:00 until 20:00, that is the closing period of the GS. It is relevant to mention that day 3 in this case is during the 1st of December, which is a national holiday in Portugal, and this particular GS closed at 13:00 during that day. Therefore, it is possible to observe that the CO_2 levels start to decrease at that time, and it stays stable after it, as it has no occupants.

The number of clients per day in each GS was found to have a significant impact on the mean CO_2 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 less 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), as shown Figure 6. The area of the GSs also was found to significantly influence the indoor levels of CO_2, with GSs with selling areas below 110 m^2 having lower levels (421 ± 14 ppm) than GSs with selling areas higher than 110 m^2 (546 ± 40) (Mann-Whitney U Test: U = 127.000, p-value = 0.007). Since CO_2 is mainly produced by human breathing, it is expected that indoor environments with higher number of occupants may have higher CO_2

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 CO_2 levels. Despite the CO_2 levels are below the LV in all cases, this fact also highlights that workers may be exposed to higher levels of CO_2 in GSs with larger selling areas and with higher number of clients.

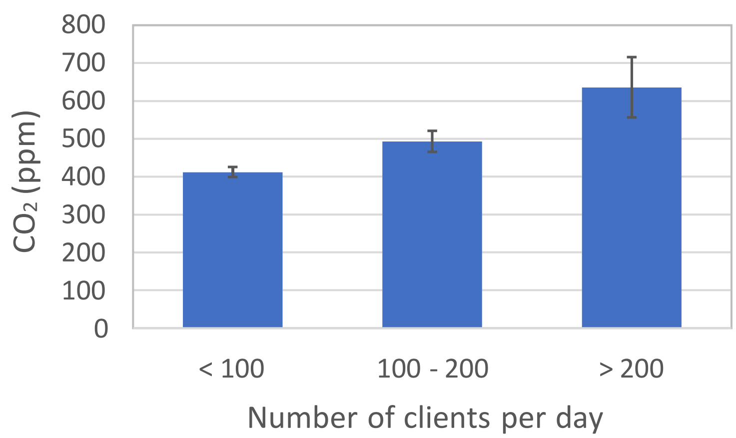

Figure 6 - Levels of CO_2 in the different GSs regarding their number of clients per day.

The statistical analysis also revealed that the cleaning procedure also had an influence on the CO_2 levels, with GSs that did the cleaning daily at closing having lower mean levels of CO_2 (422 ± 13 ppm) than the 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 showed to have a significant impact on CO_2 levels (Kruskal-Wallis Test: $\chi^2(2)$ = 6.846, p-value = 0.033), with the levels of CO_2 in GSs that used products of domestic used being significantly lower (425 ± 16 ppm) than GSs that used products of domestic use but designated as environment friendly (587 ± 25 ppm). However, interpretation of these results is not direct and probably these influences may have the contribution of the size of the selling area and number of clients per day (since bigger spaces implemented the cleaning more frequently and used specific type of products).

3.2. Volatile Organic Compounds

The mean levels of VOCs at all GSs are all below the limit value of 262 ppb (corresponding to 600 µg.m^{-3}) established by the Portuguese legislation, as shown by Figure 7. 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), which is almost 5 times smaller than the legislation LV. These pollutants are emitted by building materials and common household products, like paints, as well as cleaning, consumer products.

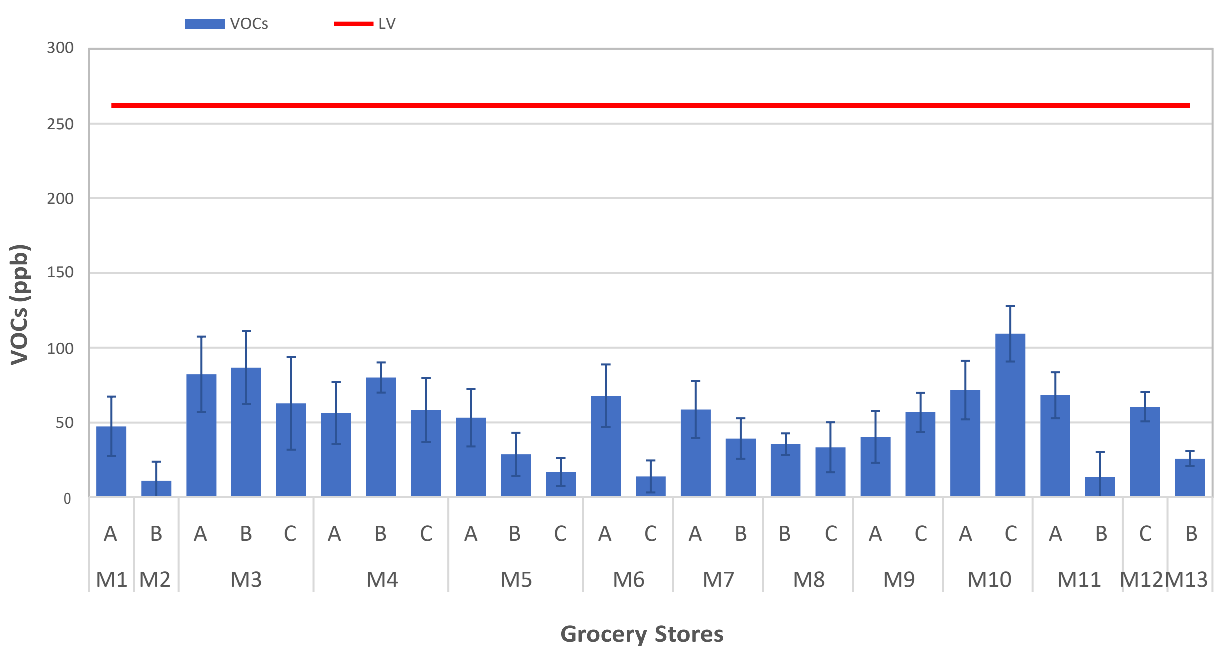

Figure 7 - VOCs mean levels for occupied periods in all 13 grocery stores. The red line represents the limit value of 262 ppb established by Portuguese legislation (65).

Figure 8 shows the levels of VOCs promoted by the two different strategies of cleaning used in the GSs: "Daily at closing" and "Daily at opening/more times" (GSs performed the cleaning 2 to 3 times during the working period). The cleaning procedure 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 the 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 VOCs 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 type of used products on the VOCs levels, no significant difference was found (p-value for all the cases was above p-value > 0.050). However, 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 environment friendly (77.3 ± 12.7 ppb) (p-value = 0.057).

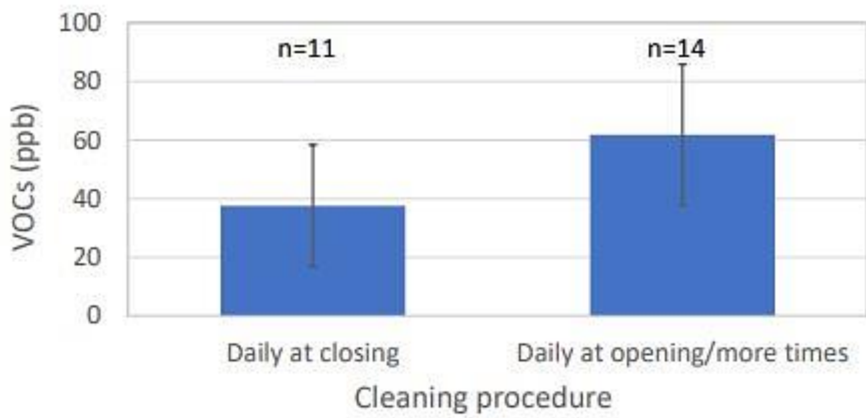

Figure 8 - VOCs mean values for the two different cleaning procedures, where n is the total number of studied locations in the different GSs.

As an example, Figure 9 shows the temporal variability during 5 days, where it is possible to observe 3 peaks during the daytime, that could be attributed to the cleaning periods. This specific GS has a cleaning time of 3 times a day, which promotes the VOCs peak levels observed during the daytime since these pollutants are emitted by the cleaning products.

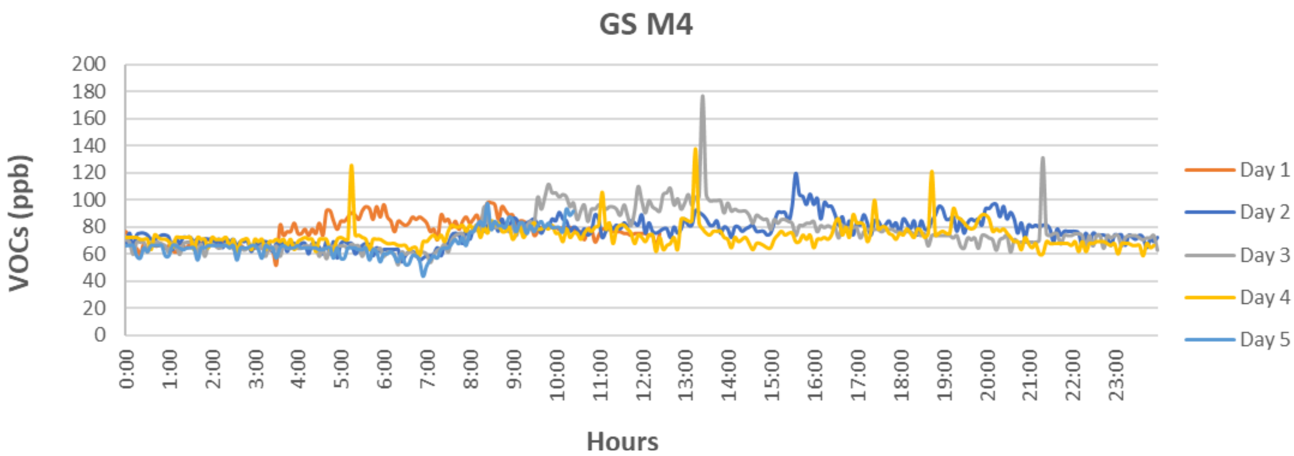

Figure 9 - Variation of VOCs during 5 days in GS M4.

Similarly to 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 less than 100 clients per day being significantly lower (36.8 ± 20.0 ppb) that 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 higher than 110 m^2 (51.2 ± 25.3 ppb) (ANOVA: $F(1,23) = 12.109$, p-value = 0.002).

3.3. Particulate Matter

Figures 10 and 11 present the mean levels of PM_{10} and $PM_{2.5}$, respectively, for all the locations monitored in the studied GSs, along with the established limit values (LV) values and the WHO guidelines. The established LV by the Portuguese legislation are 25 $\mu g.m^{-3}$ and 50 $\mu g.m^{-3}$ for $PM_{2.5}$ and PM_{10}, respectively.

For $PM_{2.5}$, 23.1% of the GS had mean $PM_{2.5}$ levels above the established LV namely the GSs M3, M9 and M10, while 76.9% presented mean levels below LV, namely, GSs M1, M2, M4, M5, M6, M7, M8, M11 M12 and M13. Regarding PM_{10}, all the GSs had mean values below the LV established by the Portuguese legislation of 50 µg.m^{-3}.

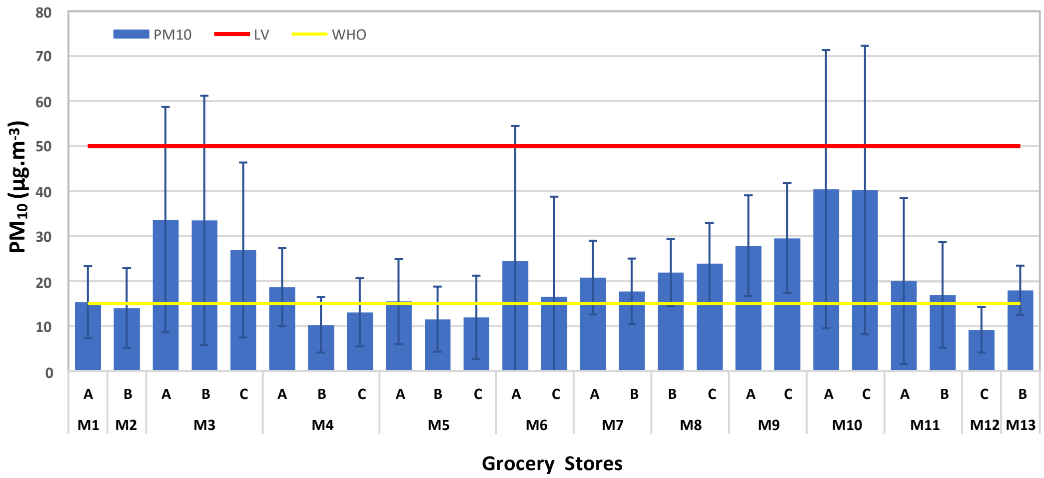

Figure 10 - PM_{10} mean levels for occupied moments in all 13 grocery stores. Red line represents the limit value established by the Portuguese legislation (65) and the yellow line represents the WHO guideline.

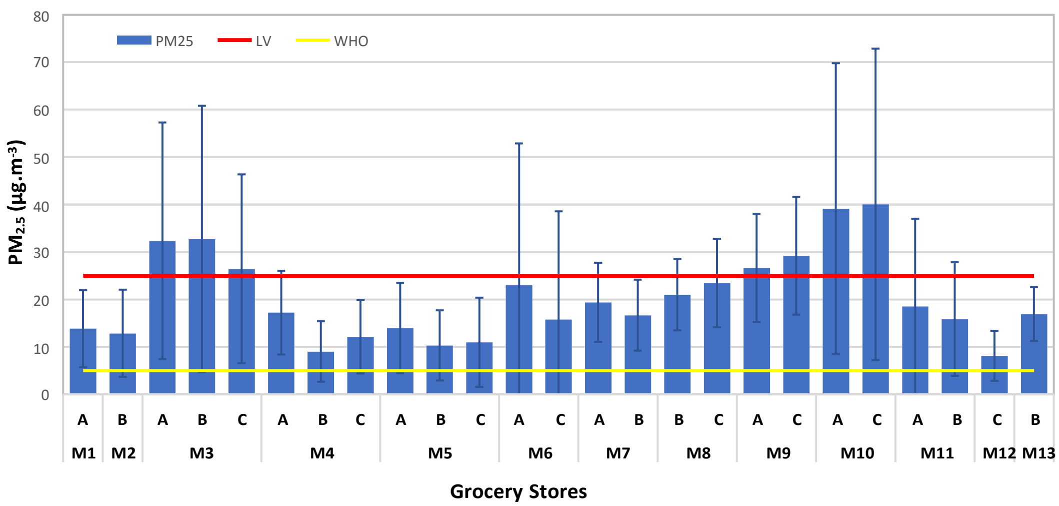

Figure 11 - $PM_{2.5}$ mean levels for occupied moments in all 13 grocery stores. Red line represents the limit value established by the Portuguese legislation (65) and the yellow line represents the WHO guideline.

Considering the WHO guidelines, which establishes values of 5 µg.m^{-3} and 15 µg.m^{-3} for $PM_{2.5}$ and PM_{10}, respectively, all the GSs were above the guideline for $PM_{2.5}$. Regarding PM_{10}, 69.3% of the GS had mean PM_{10} levels above the guideline value (M1, M3, M7, M8, M9, M10, M11 and M13) except for 30.7% (M2, M4, M5 and M12) that had mean values below that guideline value of 15 μg.m^{-3}.

The indoor particle concentration varies to a great degree in the studied GSs, as shown by Figures 10 and 11, where the mean level was 20.2 ± 7.3 μg.m^{-3} (ranging from 1.4 μg.m^{-3} to 278.5 μg.m^{-3}) for $PM_{2.5}$ and 21.3 ± 7.2 μg.m^{-3} (ranging from 2.9 μg.m^{-3} to 279.0 μg.m^{-3}) for PM_{10}. It is important to note that these levels were obtained with the instruments in different locations and GSs. Sudden increases in PM concentrations indoors are typically due to indoor activities (79). Additionally, the movement of people in these environments is large since they are always clients coming in and out of the store and, therefore, the possibility of resuspension of dust is elevated (75). In fact, GSs stores with selling areas larger than 110 m^2 showed to have significantly higher levels of $PM_{2.5}$ (24.0 ± 10.8 μg.m^{-3}) and PM_{10} (24.9 ± 10.7 μg.m^{-3}) when comparing with GSs with lower selling areas ($PM_{2.5}$: 16.5 ± 4.8 μg.m^{-3} , ANOVA: $F(1,23) = 4.816$, p-value = 0.039; PM_{10} : 17.6 ± 4.7 μg.m^{-3}, ANOVA: $F(1,23) = 4.760$, p-value = 0.040).

Similar results were found in a study in schools in France with $PM_{2.5}$ of 22 ± 8 μg.m^{-3}, with values ranging from 10 to 47 μg.m^{-3} (80). Another study in Portuguese schools presented higher values of 10 μg.m^{-3} and 73 μg.m^{-3} and 30 μg.m^{-3} and 146 μg.m^{-3} for $PM_{2.5}$ and PM_{10} respectively (81). In contrast, less crowded environments have lower possibility of re -suspension of particle. Therefore, lower concentrations of PM, for instance a study in Elderly care centers in Lisbon showed PM_{10} variations ranging from 11 μg.m^{-3} to 19 μg.m^{-3} (75).

In relation to the influence of other GS characteristics, no other significant impacts were found neither regarding $PM_{2.5}$ nor PM_{10}. However, for instance, 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 use, as well as other types of cooking (74,82). Certain retail environments have different indoor spaces with different activities within that can promote different emissions of pollutants (including particulate matter, from fine to ultrafine particles) (83), which is the case of some studied GSs, that have different areas within, such as, bakery and coffee shop, that may promote higher levels of PM when compared with GSs without those type of facilities.

Figures 12 and 13 shows the GS there is an increase in PM values, both PM_{10} and $PM_{2.5}$, between 08:00 and 12:00 and again from 15:00 to 21:00 in most days, which corresponds to the opening time. Normally the grocery store is cleaned during opening time which promotes the resuspension of particles. The increase in concentration of particles during these periods can also be attributed to the presence and movement of customers. As expected, the concentrations tend to decrease after closing time.

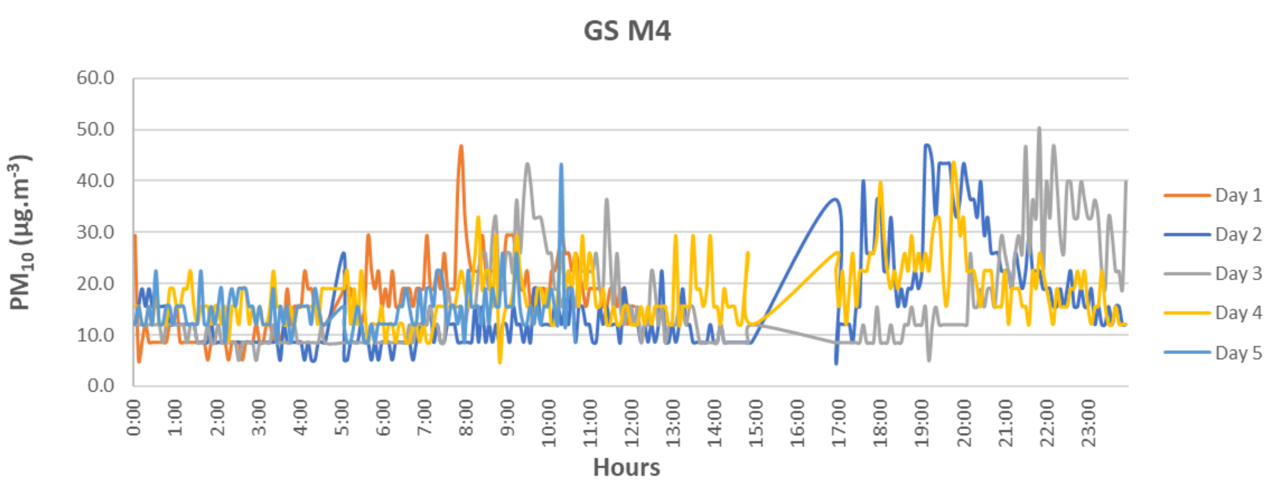

Figure 12 - Variation of PM_{10} for 5 days in GS M4.

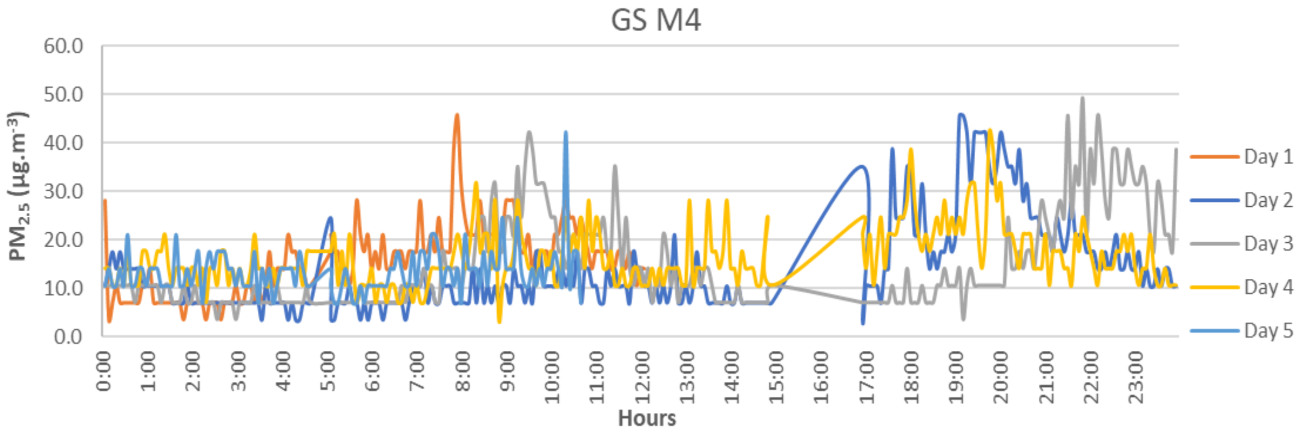

Figure 13 - Variation of $PM_{2.5}$ during 5 days in GS M4.

3.3.1 Exposure to PM and inhaled dose by workers

Exposure (E, µg.m^{-3}.h) can sometimes be confused with concentration (C*j*). Concentration is the level "quantity" of a contaminant present in the air, which can potentially be inhaled, while Dose is the amount of a contaminant that is absorbed in the body of an exposed individual over a specific period (*tj*), and exposure incorporates both the concentration and the duration of the contact E = Cj.tj. The potential Inhaled Dose (D, µg) can be calculated by the multiplication of the exposure by the Inhalation rate (IR, m^3.h^{-1}) (69,84–86).

IR differ between different age groups and the different activities that individuals are performing. These values can vary between 0.3 m^3.h^{-1} to 2 m^3.h^{-1} for children and young people resting to adults in sport activities, respectively. Based on our population, the activity may be characterized as non-sedentary job and our population is between young adults (19 - 40 years) and middle adulthood (41 - 65 years) with an IR of 0.94 and 1.01, respectively, with a mean IR of 0.975 m^3. h^{-1} (86).

The exposure and the associated potential inhaled dose to PM in the GS during working hours (8 hours) are described in Table 3. Exposure to PM_{10} and $PM_{2.5}$ (Figure 14) were estimated to be 170.0 ± 57.4 $\mu g.m^{-3}.h$ and 161.7 ± 58.7 $\mu g.m^{-3}.h$, respectively.

Table 3- PM_{10} and $PM_{2.5}$ exposure and correspondent potential inhaled dose during working period for the studied GSs.

ID	BOX	Exposure to PM_{10} and $PM_{2.5}$					Potential inhaled dose to PM levels (μg)	
		Mean concentration *Cj* PM_{10} ($\mu g.m^{-3}$)	Mean concentration *Cj* $PM_{2.5}$ ($\mu g.m^{-3}$)	Time (hours) *tj*	Expo. PM_{10} ($\mu g.m^{-3}.h$)	Expo. $PM_{2.5}$ ($\mu g.m^{-3}.h$)	Inhalation dose $PM_{2.5}$	Inhalation dose PM_{10}
M1	A	15.3	13.8	8.0	122.7	110.6	0.0	119.6
M2	B	14.0	12.8	8.0	111.7	102.7	0.0	108.9
M3	A	33.6	32.3	8.0	269.1	258.8	0.0	262.4
	B	33.5	32.7	8.0	267.8	261.8	0.0	261.1
	C	26.9	26.5	8.0	215.1	211.6	0.0	209.7
M4	A	18.6	17.2	8.0	149.0	137.7	0.0	145.3
	B	10.3	9.0	8.0	82.1	72.0	0.0	80.0
	C	13.0	12.1	8.0	104.2	97.0	0.0	101.6
M5	A	15.5	14.0	8.0	123.7	111.9	0.0	120.6
	B	11.5	10.3	8.0	92.0	82.3	0.0	89.7
	C	11.9	11.0	8.0	95.3	87.7	0.0	93.0
M6	A	24.4	23.0	8.0	195.6	184.0	0.0	190.7
	C	16.5	15.8	8.0	132.4	126.0	0.0	129.1
M7	A	20.8	19.4	8.0	166.0	155.0	0.0	161.9
	B	17.7	16.7	8.0	141.4	133.3	0.0	137.8
M8	B	21.9	21.0	8.0	175.2	168.1	0.0	170.9
	C	23.9	23.4	8.0	190.9	187.4	0.0	186.1
M9	A	27.9	26.6	8.0	223.0	212.8	0.0	217.4
	C	29.5	29.2	8.0	235.9	233.5	0.0	230.0
M10	A	40.4	39.1	8.0	323.3	312.9	0.0	315.3
	C	40.2	40.0	8.0	321.7	320.3	0.0	313.7
M11	A	20.0	18.5	8.0	159.8	148.3	0.0	155.8
	B	16.9	15.9	8.0	135.5	127.0	0.0	132.1
M12	C	9.2	8.1	8.0	73.2	65.0	0.0	71.4
M13	B	17.9	16.9	8.0	143.4	135.4	0.0	139.8
Mean ± SD		21.3 ± 7.2	20.2 ± 7.3		170 ± 57.4	161.7 ± 58.7	157.7 ± 57.2	165.8 ± 56.0
Mean inhalation rate for active people ($m3.h^{-1}$)					0.975			

The exposure levels found were higher than the ones found in the bedrooms of university students residencies, which were 62.9 ± 24.3 $\mu g{\cdot}m^{-3}.h$ and 76.3 ± 26.3 $\mu g{\cdot}m^{-3}.h$ for $PM_{2.5}$ and PM_{10}, respectively (69). And on another study carried out in bedrooms of couples in Lisbon dwellings during sleeping periods, exposures to $PM_{2.5}$ and PM_{10} were estimated to be 113.6 ± 64.8 $\mu g{\cdot}m^{-3}.h$ and 148.1 ± 84.8 $\mu g{\cdot}m^{-3}.h$, respectively (76). In a study on children's exposure and dose assessment to PM in Lisbon, higher values were found, namely, 218 μg·m^{-3}.h and 404 μg·m^{-3}.h for $PM_{2.5}$ and PM_{10} during weekdays in schools, respectively. For the sleeping period during weekdays, lower levels were found, namely, 141.4 μg·m^{-3}.h and 177.4 μg·m^{-3}.h for $PM_{2.5}$ and PM_{10}, respectively (84).

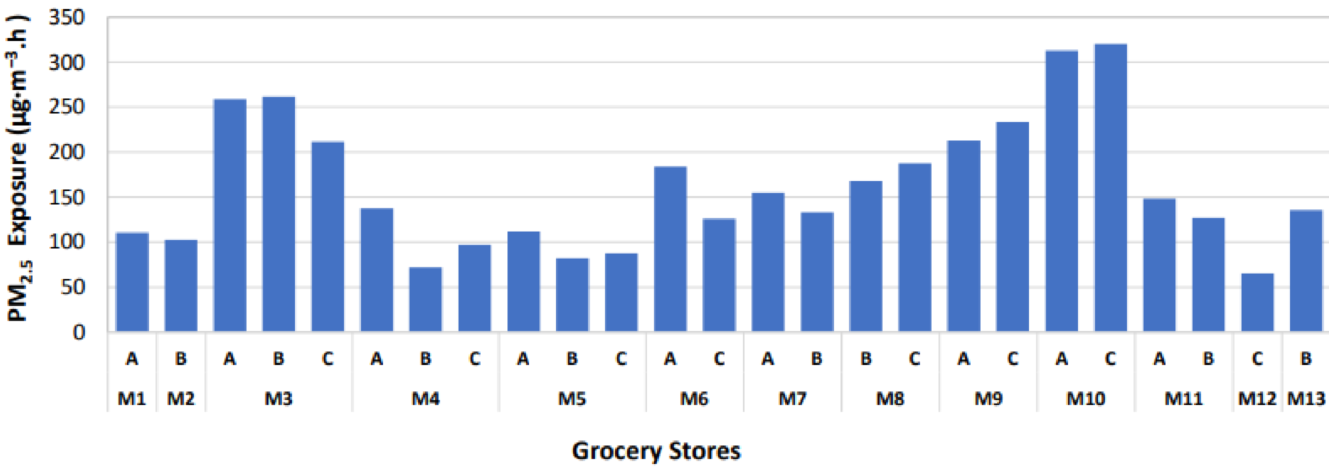

Figure 14 - Worker exposure to $PM_{2.5}$ during working periods of 8 hours.

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 m^3/h (active person) and the mean inhalation dose of the workers of the studied GSs was 157.7 ± 57.2 μg for $PM_{2.5}$ (ranging from 63.4 μg at GS M12 to 312.3 μg at GS M10, location C) and 165.8 ± 56.0 μg for PM_{10} (ranging from 71.4 μg at GS M12 to 315.3 μg at GS M10, location A). The children had higher values, in the study, the average daily inhaled those found was 243.5 μg and 382.2 μg for $PM_{2.5}$ and PM_{10}, this may be explained because schools have more sources of PM (84).

3.4. Temperature

Figure 15 presents the temperature levels registered in the different GS, where the mean overall level was 20.4 ± 1.2ºC, with a maximum of 23.8 ± 0.8ºC (GS M5, Location A) and minimum of 18.4 ± 1.1 ºC (GS M11, Location B) (Table S6).

Considering the guideline ISO 7730, that stablishes the optimal temperature range for indoor environments in the winter between 20 to 24ºC (63), most GSs (61.5%) provided values within the AR (acceptable range), with only 38.5% of GSs presenting colder temperatures than the recommended range (namely, GSs M4, M8, M10, M11 and M12) which highlights the lack of heating during the monitoring period.

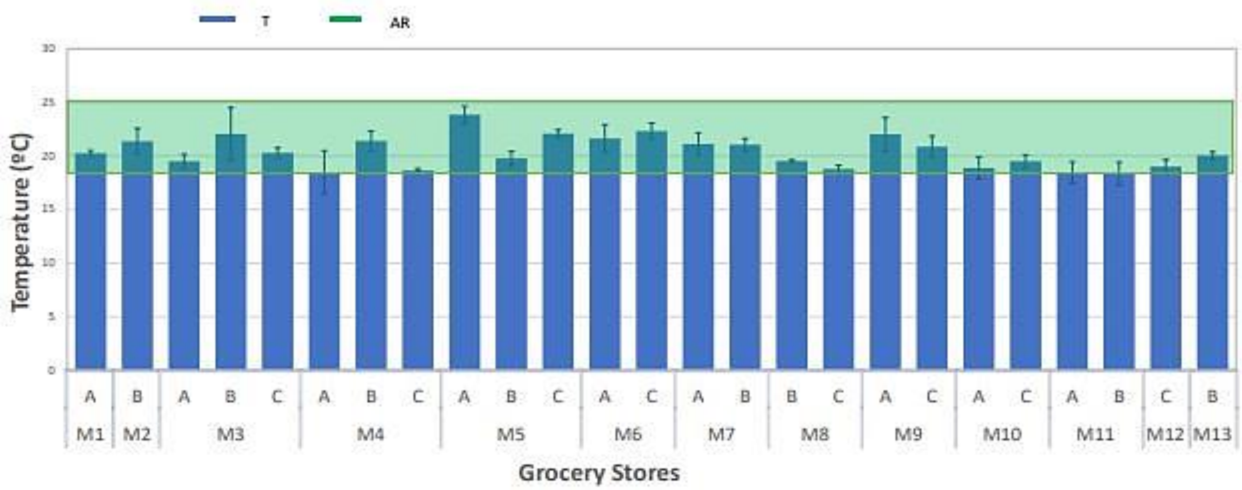

Figure 15- Mean temperature assessed in all the studied GSs. Green area represents the acceptable range (AR) of 18 – 25 ºC, defined by the Portuguese legislation (67).

Considering the Decreto-Lei n.º 243/86 de 20 de Agosto - Artigo 11º (67) which states that work places as well as common facilities must offer good temperature and humidity conditions, with the work place temperature being between 18ºC and 22ºC (except for specific conditions that may reach 25ºC), all the GSs are within the AR. Regarding the comfort range recommended by ASHRAE (namely, 20-27ºC) (68), the majority of the GSs (61.5%) provided values within the recommended range, except 38.5% of the GSs that presented mean temperature levels below the minimum recommended value (namely, GSs M4, M8, M10, M11 and M12).

Figure 16 represents the variation of temperature during 5 days in one of the GS, there is an increase of temperature at the beginning of the day, at around 07:00 till 10:00, consisted with opening time and the temperature keeps stable throughout the day till around 19:00/20:00 where we can see a decrease, consistent with occupancy. It is also possible to observe that during the 3rd day, the temperature start rising at 07:00 consistent with occupancy, but differently from the pattern of the others, the temperature starts descending at around 12:00. In this case, the temperature descends because in this particular case the 3rd day was December 1st which is a national holiday in Portugal, so the GSs closed at 12:00 on this particular date.

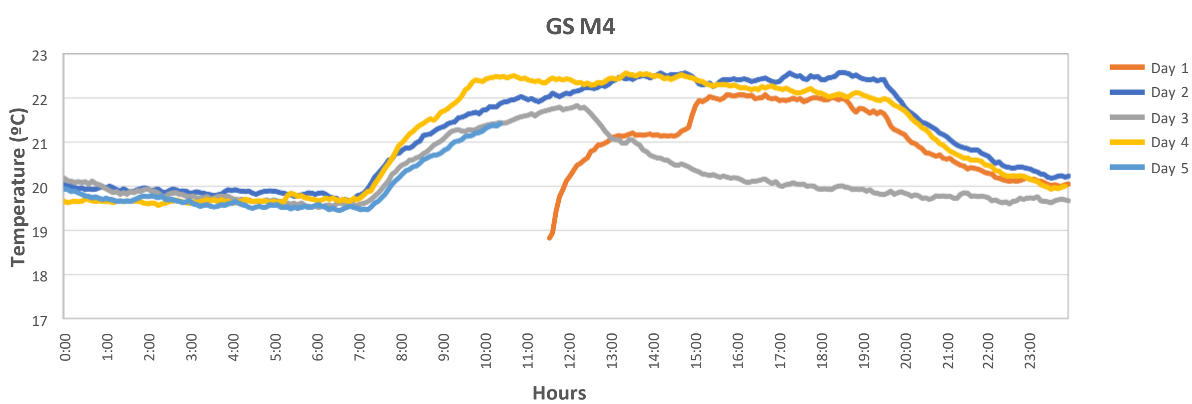

Figure 16 - Variation of temperature during 5 days in GS M4.

The type of facilities in the GSs showed to have a significant impact on temperature (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).

3.5. Relative Humidity

Figure 17 provides the mean RH levels found in all the studied GSs, where an overall mean of 51 ± 6% was found, with a maximum value of 64.7 ± 5.5% (M10, Location A) and a minimum of 39.3 ± 3.5% (M4, Location C).

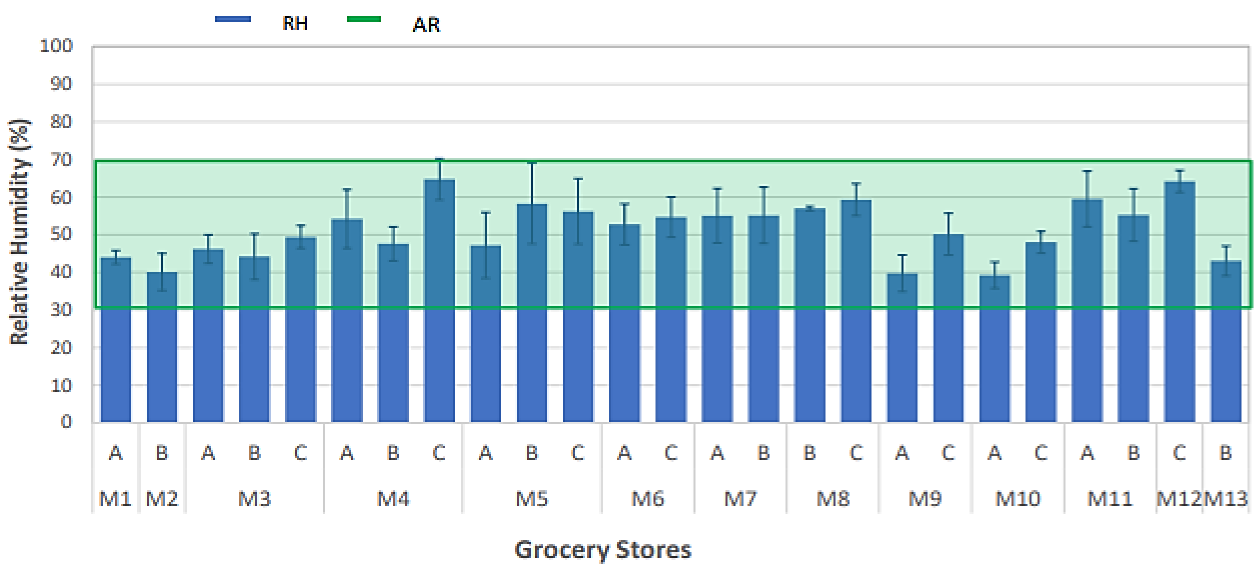

Figure 17 - Mean levels of relative humidity in all the studied grocery stores (GSs), where AR stands for Acceptable Range (30-70%).

Most of the GSs had levels within the acceptable range stablished by the Portuguese legislation Decreto-Lei n.º 243/86 de 20 de Agosto (67), which states that work places as well as common facilities must offer good temperature and humidity conditions, with the workplace optimal relative humidity range set between 50 – 70%. Seven out of 13 GSs, representing 53.8% of the studied GSs (Table S7), presented mean values within the AR, while the remaining GSs were always below the lower recommended limit. Regarding the AR recommended by Arundel et al, 1986 (33), which is set at 40-60%, one of the GSs, which represents 7.7% presented levels above the AR, namely M12, with the remaining 92.3% of the GSs with levels within the AR. However, if the ISO 7730 recommend range is considered, which is set as 30-70%, all of the GS are within the comfort range (63).

The RH levels during themonitoring days in the GSs were very stable, as it can be observed in Figure 18 for the case of GS M4, which shows the RH variability for 5 monitoring days.

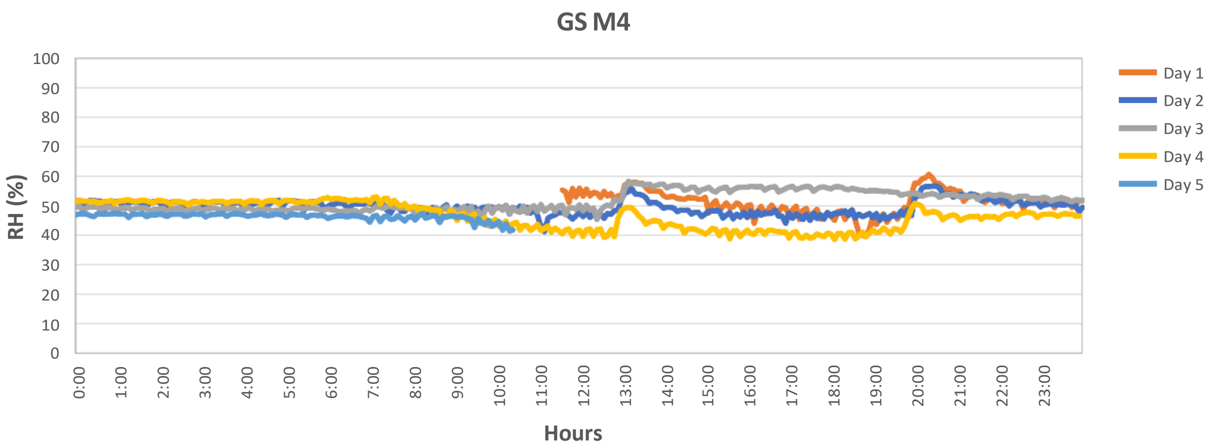

Figure 18 - Variation of RH during 5 days in GS M4.

3.6. Considerations

Particulate Matter

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 (that may indicate 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 bakery and coffee shop, along with facilities related to the confection of consumables.

Some suggestions to reduce the PM levels are:

1) Change from fuel-fired combustion stoves (such as gas) to electric ones;

2) The installation of exhaust fans vented to the outside when preparing the foods;

3) The installation of local air purifies can help to filter PM in the air and to reduce the levels of this pollutant.

However, it is crucial a good maintenance of the equipment's, namely, to replace the filter regularly in order to achieve good results. These strategies may promote the reduction of PM levels due to specific facilities of the GSs.

Carbon dioxide

Although within the LV established by the legislation, it is possible to see that the levels of CO_2 are higher when the number of clients are higher, which indicates that the workers in those spaces are also exposed to higher levels of CO_2.

1) Therefore, it is suggested the improvement of ventilation: to try and maintain the window and door open for good air circulation (if there are no significant outside sources);
2) An air circulator.

Temperature

During this study, it was also found that 23% of the GSs present temperature values below the minimum value recommended for indoor environments. Considering this information, it would be possible to implement measures to improve the thermal comfort of the workers. For instance, the thermal environment can be controlled through different methods, such as a constructive strategy or then organizational measures. This latter type of measures is cheaper, and it is only based on the distribution of tasks and its rotation through the employees. For example, a person carrying boxes is going to feel more heat than a person that is working in the register.

1) Rotative shifts - the tasks can be distributed and rotated by the employees, so that both can do both tasks and divide the load.

2) Individual protective measures are also a possibility but may be considered the last measure that can be applied, from a safety stand point, such as suitable clothing provided by the employer.

Overall, Table 4 presents a summary of all the corrective measures that can be promoted to improve IAQ in grocery stores.

Table 4 - Summary of measures to improve indoor air quality in grocery stores.

	Parameter		
	PM	**CO_2**	**T**
Corrective measures	Change from fuel fired combustion stoves to electric ones	The improvement of ventilation: try and maintain the window and door open for good air circulation	The thermal environment can be controlled through different methods, such as a constructive strategy or then organizational measures
	The installation of exhaust fans vented to the outside when preparing the foods	Use of air circulator	
	Use of local air purifies (with filters) to help minimize PM levels		

4. Limitations

Some limitations were found in the development of this study, namely:

1) The lack of studies in this topic, although it is possible to find a few studies about retail stores, but not specific for this kind of environments, information on health effects in small groceries is scarce;

2) The impossibility to perform measurements near the breathing zone, which would be the best approach in order to assess human exposure;

3) The location of the MBs, since it had to be connected to the power line and, therefore, occasionally it had to stay lower or above the breathing area.

It is also important to highlight that the evaluation of the compliance of the IAQ levels at the GSs performed in this thesis was done regarding the Portuguese legislation for indoor environments, which targets the welfare of the occupants and not the exposure of workers at workplaces.

5. Conclusions

This research aimed to evaluate the indoor air quality in small grocery stores in Lisbon district, Portugal. This information, focused on indoor air pollutants and thermal comfort parameters, allowed to perform an assessment of the workers exposure to the pollutants in their work environment. The study group consisted of 13 small grocery stores located at the Cascais municipality. The studied was carried from November 2021 to February 2022 (during the cold period). The study was carried out also to fulfill a gap in literature, since no IAQ assessment can be found in this specific type of indoor environments.

Overall, it can be concluded that all the studied GSs complied with the Portuguese legislation regarding IAQ, except for fine particulate matter ($PM_{2.5}$), where 61,5 % of GSs exceeded the established limit value for the Portuguese legislation. Regarding temperature, 23,1% were found to have mean levels below the AR established by the Portuguese legislation.

Based on the results obtained by the monitoring performed in the GSs, some control measures should be applied in order to reduce the levels of PM and adjust the thermal parameters. Granting the air temperature obtained were considered low, in order to make an accurate evaluation of the thermal comfort it should be considered the occupant's perception of the thermal environment.

Further research is needed to better understand the perception of the IAQ by the workers and create a bridge between the results found and the possible health implication.

6. References

1. APA. Air and Noise | Relatório do Estado do Ambiente [Internet]. [cited 2022 Jul 4]. Available from: https://rea.apambiente.pt/environment_area/air?language=en
2. Vardoulakis S, Giagloglou E, Steinle S, Davis A, Sleeuwenhoek A, Galea KS, et al. Indoor Exposure to Selected Air Pollutants in the Home Environment: A Systematic Review. Int J Environ Res Public Health. 2020 Dec 1;17(23):1–24.
3. Cincinelli A, Martellini T. Indoor Air Quality and Health. Int J Environ Res Public Heal. 2017;14.
4. Mannan M, Al-Ghamdi SG. Indoor Air Quality in Buildings: A Comprehensive Review on the Factors Influencing Air Pollution in Residential and Commercial Structure. Int J Environ Res Public Heal 2021, Vol 18, Page 3276. 2021 Mar 22;18(6):3276.
5. Centnerová L. On the history of indoor environment and it´s relation to health and wellbeing. REHVA J. 2018 Apr;
6. Zabiegala B. organic compounds in indoor environments. 2005;
7. Simoni M, Jaakkola MS, Carrozzi L, Baldacci S, Di Pede F, Viegi G. Indoor air pollution and respiratory health in the elderly. Eur Respir J Suppl. 2003 May;40(40).
8. Bradford O. Brooks. Understanding Indoor Air Quality - Bradford O. Brooks . 1992.
9. Sundell J. On the history of indoor air quality and health. Indoor Air. 2004;14(SUPPL. 7):51–8.
10. Jones AP. Indoor air quality and health. Atmos Environ. 1999 Dec 1;33(28):4535–64.
11. WHO. National Burden of Disease Estimates. 2007;
12. Balidemaj F, Isaxon C, Abera A, Malmqvist E. Indoor Air Pollution Exposure of Women

in Adama, Ethiopia, and Assessment of Disease Burden Attributable to Risk Factor. Int J Environ Res Public Health. 2021 Sep 1;18(18).

13. WHO. Household air pollution and health [Internet]. 2022 [cited 2022 Aug 24]. Available from: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

14. UNEP. Seven things you should know about household air pollution [Internet]. 2021 [cited 2022 Aug 24]. Available from: https://www.unep.org/news-and-stories/story/seven-things-you-should-know-about-household-air-pollution

15. Colbeck I, Nasir ZA, Ali Z. The state of indoor air quality in Pakistan--a review. Environ Sci Pollut Res Int. 2010;17(6):1187–96.

16. Ramos J. Caracterização do sono em estudantes universitários: A influência da Qualidade do Ar Interior. 2019.

17. How long is the average working life in your country? | World Economic Forum [Internet]. 2020 [cited 2022 Aug 31]. Available from: https://www.weforum.org/agenda/2020/07/europe-eu-work-working-life-duration-countries-comparison

18. Mujan I, Anđelković AS, Munćan V, Kljajić M, Ružić D. Influence of indoor environmental quality on human health and productivity - A review. J Clean Prod. 2019 Apr 20;217:646–57.

19. SEA soluções. A IMPORTÂNCIA DA SEGURANÇA E HIGIENE NO TRABALHO NA SUA EMPRESA - SEA Soluções [Internet]. [cited 2022 Sep 7]. Available from: https://sea-solucoes.com/site/importancia-da-seguranca-higiene-no-trabalho-na-empresa/

20. ILO. World Statistic [Internet]. [cited 2022 Sep 7]. Available from:

https://www.ilo.org/moscow/areas-of-work/occupational-safety-and-health/WCMS_249278/lang--en/index.htm

21. IGAS. MANUAL DE SEGURANÇA E SAÚDE NO TRABALHO. 2018;
22. WHO. Health and Well-Being [Internet]. [cited 2022 Aug 21]. Available from: https://www.who.int/data/gho/data/major-themes/health-and-well-being
23. Olesen BW. INDOOR ENVIRONMENT-HEALTH-COMFORTAND PRODUCTIVITY.
24. EUROPEAN HEALTH21 TARGET. The Right to Healthy Air. 2000;
25. Pleil JD, Ariel Geer Wallace M, Davis MD, Matty CM. The physics of human breathing: flow, timing, volume, and pressure parameters for normal, on-demand, and ventilator respiration. J Breath Res. 2021 Sep 27;15(4):042002.
26. Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E. Environmental and Health Impacts of Air Pollution: A Review. Front Public Heal. 2020 Feb 20;8:14.
27. US EPA. Why Indoor Air Quality is Important to Schools | US EPA [Internet]. [cited 2022 Aug 21]. Available from: https://www.epa.gov/iaq-schools/why-indoor-air-quality-important-schools
28. Wallace LA, Pellizzari ED, Hartwell TD, Whitmore R, Sparacino C, Zelon H. Total exposure assessment methodology (team) study: Personal exposures, indoor-outdoor relationships, and breath levels of volatile organic compounds in New Jersey. Environ Int. 1986;12(1–4):369–87.
29. Righi E, Aggazzotti G, Fantuzzi G, Ciccarese V, Predieri G. Air quality and well-being perception in subjects attending university libraries in Modena (Italy). Sci Total Environ. 2002 Mar 8;286(1–3):41–50.
30. Redlich CA, Sparer J, Cullen MR. Sick-building syndrome. Lancet. 1997 Apr

5;349(9057):1013–6.

31. Quoc CH, Huong GV, Duc HN. Working Conditions and Sick Building Syndrome among Health Care Workers in Vietnam. Int J Environ Res Public Health. 2020 May 2;17(10).

32. Erdmann CA, Apte MG. Mucous membrane and lower respiratory building related symptoms in relation to indoor carbon dioxide concentrations in the 100-building BASE dataset. Indoor Air, Suppl. 2004;14(8):127–34.

33. Arundel A V., Sterling EM, Biggin JH, Sterling TD. Indirect health effects of relative humidity in indoor environments. Environ Health Perspect. 1986;65:351–61.

34. Canha N. Characterization of ventilation, indoor aerosol and pollution sources of primary schools. 2014.

35. Nazaroff WW. Four principles for achieving good indoor air quality. Indoor Air. 2013 Oct 1;23(5):353–6.

36. Bonino S. Carbon Dioxide Detection and Indoor Air Quality Control - PubMed. 2016;

37. Ferng S-F. Indoor Air Quality Assessment of Daycare Facilities with Carbon Dioxide, Te.mperature and humidity as indicator [Internet]. 2002 [cited 2022 Jul 8]. Available from: https://web.s.ebscohost.com/ehost/pdfviewer/pdfviewer?vid=0&sid=7ed10c40-3627-4aa1-8ca9-df382f3014c0%40redis

38. Wang S, Ang HM, Tade MO. Volatile organic compounds in indoor environment and photocatalytic oxidation: state of the art. Environ Int. 2007;33(5):694–705.

39. Anand SS, Mehendale HM. Volatile Organic Compounds (VOC). In: Encyclopedia of Toxicology. Elsevier; 2005. p. 450–5.

40. US EPA. Volatile Organic Compounds' Impact on Indoor Air Quality | US EPA [Internet]. [cited 2022 Jul 5]. Available from: https://www.epa.gov/indoor-air-quality-iaq/volatile-

organic-compounds-impact-indoor-air-quality

41. Enviromnment AS of. Volatile organic compounds | Australia State of the Environment Report [Internet]. [cited 2022 Jul 5]. Available from: https://soe.environment.gov.au/theme/ambient-air-quality/topic/2016/volatile-organic-compounds#Volatile_organic_compounds

42. Loomis D, Grosse Y, Lauby-Secretan B, Ghissassi F El, Bouvard V, Benbrahim-Tallaa L, et al. The carcinogenicity of outdoor air pollution. Lancet Oncol. 2013 Dec;14(13):1262–3.

43. Nunes RAO, Branco PTBS, Alvim-Ferraz MCM, Martins FG, Sousa SIV. Particulate matter in rural and urban nursery schools in Portugal. Environ Pollut. 2015;202:7–16.

44. Almeida-Silva M, Pilou M, Housiadas C, Almeida SM. Internal dose of particles in the elderly—modeling based on aerosol measurements. Environ Sci Pollut Res. 2018 Aug 1;25(24):23645–56.

45. Wang S, Ang HM, Tade MO. Volatile organic compounds in indoor environment and photocatalytic oxidation: State of the art. Environ Int. 2007;33(5):694–705.

46. Ngoc LTN, Kim M, Bui VKH, Park D, Lee YC. Particulate Matter Exposure of Passengers at Bus Stations: A Review. Int J Environ Res Public Health. 2018 Dec 17;15(12).

47. California Air Resources Board. Inhalable Particulate Matter and Health (PM2.5 and PM10) | California Air Resources Board [Internet]. [cited 2022 Jul 6]. Available from: https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health

48. Ng LC, Musser A, Persily AK, Emmerich SJ. Indoor air quality analyses of commercial reference buildings. Build Environ. 2012 Dec 1;58:179–87.

49. Zhu C, Maharajan K, Liu K, Zhang Y. Role of atmospheric particulate matter exposure in COVID-19 and other health risks in human: A review. Environ Res. 2021 Jul 1;198:111281.

50. Wang F, Liu J, Zeng H. Interactions of particulate matter and pulmonary surfactant: Implications for human health. Adv Colloid Interface Sci. 2020 Oct 1;284.

51. Elkama A, Süküroğlu AA, Çakmak G. Exposure to particulate matter: a brief review with a focus on cardiovascular effects, children, and research conducted in Turkey. Arh Hig Rada Toksikol. 2021 Dec 1;72(4):244–53.

52. Shah ASV, Langrish JP, Nair H, McAllister DA, Hunter AL, Donaldson K, et al. Global association of air pollution and heart failure: A systematic review and meta-analysis. Lancet. 2013;382(9897):1039–48.

53. Ono E, Mihara K, Lam KP, Chong A. The effects of a mismatch between thermal comfort modeling and HVAC controls from an occupancy perspective. Build Environ. 2022 Jul 15;220:109255.

54. CDC. Indoor Environmental Quality: HVAC Management | NIOSH | CDC [Internet]. [cited 2022 Jul 10]. Available from: https://www.cdc.gov/niosh/topics/indoorenv/hvac.html

55. Ivanov KP. The development of the concepts of homeothermy and thermoregulation. J Therm Biol. 2006 Jan 1;31(1–2):24–9.

56. Ling SJ, Moebs W, Sanny J. 1.1 Temperature and Thermal Equilibrium. OpenStax; 2016.

57. Yi T, Wang H, Liu C, Li X, Wu J. Thermal comfort differences between urban villages and formal settlements in Chinese developing cities: A case study in Shenzhen. Sci Total Environ. 2022 Aug 24;158283.

58. Zheng P, Wu H, Liu Y, Ding Y, Yang L. Thermal comfort in temporary buildings: A review. Build Environ. 2022 Aug 1;221:109262.

59. Bueno AM, de Paula Xavier AA, Broday EE. Evaluating the Connection between Thermal Comfort and Productivity in Buildings: A Systematic Literature Review. Build 2021, Vol 11, Page 244. 2021 Jun 7;11(6):244.

60. HSE. HSE - Thermal Comfort: Homepage [Internet]. [cited 2022 Sep 7]. Available from: https://www.hse.gov.uk/temperature/thermal/

61. César N, Gomes A. Nilton César Andrade Gomes Os Efeitos do Ambiente Térmico: Avaliação Subjetiva e Numérica Universidade do Minho Escola de Engenharia.

62. Abbasi AM, Motamedzade M, Aliabadi M, Golmohammadi R, Tapak L. The impact of indoor air temperature on the executive functions of human brain and the physiological responses of body. Heal Promot Perspect. 2019;9(1):55.

63. ISO 7730. ISO 7730:2005(en), 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 [Internet]. [cited 2022 Sep 7]. Available from: https://www.iso.org/obp/ui/#iso:std:iso:7730:ed-3:v1:en

64. Wolkoff P. Indoor air humidity, air quality, and health - An overview. Int J Hyg Environ Health. 2018 Apr 1;221(3):376–90.

65. Portaria n.º 138-G/2021 | DRE [Internet]. [cited 2022 Sep 6]. Available from: https://dre.pt/dre/detalhe/portaria/138-g-2021-166296490?_ts=1657497600034

66. WHO. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. 2006;

67. DRE. Decreto-Lei n.º 243/86 | DRE [Internet]. [cited 2022 Jul 14]. Available from:

https://dre.pt/dre/detalhe/decreto-lei/243-1986-219080

68. ASHRAE. ASHRAE Technical FAQ. Available from: https://www.ashrae.org/technical-resources/technical-faqs/question-51-what-is-bacnet

69. Ramos J, Belo J, Silva D, Diogo C, Almeida SM, Canha N. Influence of indoor air quality on sleep quality of university students in Lisbon. Atmos Pollut Res. 2022 Feb 1;13(2):101301.

70. IPMA. IPMA Boletim Clinmatico novembro 2021 [Internet]. [cited 2022 Aug 28]. Available from: https://www.ipma.pt/resources.www/docs/im.publicacoes/edicoes.online/20211207/EflJizZEllJqeKWDmYro/cli_20211101_20211130_pcl_mm_co_pt.pdf

71. IPMA. IPMA boletim climatico portugal dezembro 2021 [Internet]. 2021 [cited 2022 Aug 28]. Available from: https://www.ipma.pt/resources.www/docs/im.publicacoes/edicoes.online/20220107/zbvqFuHJAcgoIQtzVatZ/cli_20211201_20211231_pcl_mm_co_pt.pdf

72. IPMA. IPMA boletim climatico portugal janeiro 2022 [Internet]. [cited 2022 Aug 28]. Available from: https://www.ipma.pt/resources.www/docs/im.publicacoes/edicoes.online/20220204/FGdTvyAzNYKcsCOxBZMy/cli_20220101_20220131_pcl_mm_co_pt.pdf

73. IPMA. IPMA boletim climatico portugal continental [Internet]. [cited 2022 Aug 29]. Available from: https://www.ipma.pt/resources.www/docs/im.publicacoes/edicoes.online/20220310/SwIlXADgyXIcWQnvaLam/cli_20220201_20220228_pcl_mm_co_pt.pdf

74. Wierzbicka A, Bohgard M, Pagels JH, Dahl A, Löndahl J, Hussein T, et al. Quantification

of differences between occupancy and total monitoring periods for better assessment of exposure to particles in indoor environments. Atmos Environ. 2015 Apr 1;106:419–28.

75. Almeida-Silva M, Almeida SM, Pegas PN, Nunes T, Alves CA, Wolterbeek HT. Exposure and dose assessment to particle components among an elderly population. 2014;

76. Canha N, Alves AC, Simão MC, Lage J, Belo J, Faria T, et al. Compliance of indoor air quality during sleep with legislation and guidelines e A case study of Lisbon dwellings *. 2020;

77. Almeida-Silva M, Wolterbeek HT, Almeida SM. Elderly exposure to indoor air pollutants. Atmos Environ. 2014 Mar 1;85:54–63.

78. Vicente ED, Ribeiro JP, Custódio D, Alves CA. Assessment of the indoor air quality in copy centres at Aveiro, Portugal. Air Qual Atmos Heal 2016 102. 2016 Apr 1;10(2):117–27.

79. Morawska L, Ayoko GA, Bae GN, Buonanno G, Chao CYH, Clifford S, et al. Airborne particles in indoor environment of homes, schools, offices and aged care facilities: The main routes of exposure. Environ Int. 2017 Nov 1;108:75–83.

80. Canha N, Mandin C, Ramalho O, Wyart G, Rib Eron J, Dassonville C, et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. 2015;

81. Marta Almeida S, Canha N, Silva A, do Carmo Freitas M, Pegas P, Alves C, et al. Children exposure to atmospheric particles in indoor of Lisbon primary schools. 2011;

82. Wallace L. Indoor Sources of Ultrafine and Accumulation Mode Particles: Size Distributions, Size-Resolved Concentrations, and Source Strengths. Aerosol Sci Technol. 2006;40(5):348–60.

83. Zaatari M, Nirlo E, Jareemit D, Crain N, Srebric J, Siegel J. Ventilation and indoor air

quality in retail stores: A critical review (RP-1596). 2014;20:276–94.

84. Faria T, Martins V, Correia C, Canha N, Diapouli E, Manousakas M, et al. Children's exposure and dose assessment to particulate matter in Lisbon. Build Environ. 2020 Mar 15;171:106666.

85. Gardner DE, Kirkpatrick DT. Respiratory Tract. Encycl Toxicol. 2005 Jan 1;665–98.

86. Buonanno G, Giovinco G, Morawska L, Stabile L. Tracheobronchial and alveolar dose of submicrometer particles for different population age groups in Italy. Atmos Environ. 2011 Nov 1;45(34):6216–24.

7. Appendix

Table S1 - Survey for characterization of the GSs.

Survey	
Grocery Store ID	
Identification nº	:
Name	:
Adress	:
Area	:
Workin hours	:
Sales area	:
Storage area	:
Nº of employers	:
Nº of customers/day	:
Ventilation	
Type of ventilation system	:
A/C	:
Fan	:
Door open or closed	:
Cleaning	
Products	:
Frequency	:
Period	:
Surrounding Area	:
Metereology	:
Type of products	:

POLITÉCNICO DE LISBOA

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DE LISBOA
INSTITUTO POLITÉCNICO DE LISBOA

Table S2 - Summary of the characteristics of the studied GSs, including cleaning procedures

IDENTIFICATION		CHARACTERIZATION					CLEANING		ADDITIONAL INFORMATION		
ID	Adress	Nº of workers	Type of Facilities	Products	Sales Area	Storage Area	Period	Products	Open hours	Closed days	Nº clients/day
M1	AV 25 DE ABRIL, EDIF ALVORADA Nº 672, RCH. A/B, Cascais	3 (2 male and 1 female)	Grocery and charcuterie	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	110 m2	2m2	Closing time everyday	Biodegradable environmental friendly products	09:00-20:00	Sunday	150
M2	AV das Esmeraldas , 257-B, SD Rana	2 (1 male and 1 female)	Grocery, charcuterie and pastry	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	110 m2	5m2	Closing time everyday	Domestic use products	09:00 - 14:00 16:00 - 20:00 saturdays 09:00-14:00	Saturday afternoon and Sunday	250
M3	JARDIM DO BUZANO , Nº 134, SD RANA	N/A	Grocery , coffe shop and confection of food	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	200 m2	20 m2	Before open everyday	Biodegradable environmental friendly products	08:00 - 19:00 saturdays 08:00-16:00	Sunday	130
M4	R ALVES REDOL, N 17-A, aldeia de juzo	7	Grocery, with sales of bread, charcuterie and butchery	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread, butchery	200 m2		2 to 3 times a day	Professional use products with FT/FDS	07:00 - 13:00 15:00 - 20:00 saturdays 07:00-17:00	Sunday	200-250
M5	R DAS LAPAS, Nº 140, LJ 5, Charneca	2 (1 male and 1 female)	Grocerie, charcuterie, bakery, pastry and meals	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	80 m2	10m2	2 to 3 times a day	Professional use products with FT/FDS	09:00 - 20:00	Sunday	70-100
M6	RUA DE ALVIDE, 883 A, ALCABIDECHE	2 (1 male and 1 female)	Grocery, charcuterie, bakery and pastry	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	150 m2	5m2	Closing time everyday	Domestic use products	07:30 -14:00 16:00 - 20:00	Sunday	80-90
M7	R SANTA MARGARIDA N 8 LOJA, Cascais	2 (1 male and 1 female)	Grocery, charcuterie and bakery	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	110 m2	2m2	2 times a day	Domestic use products	dias uteis 08:00 - 20:00 sat and sun 09:00-19:00	Sunday	150
M8	Travessa Domingos Correia, lote B, Cascais	2 (1 male and 1 female)	Grocery and charcuterie	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	30 m2	5m2	Closing time everyday	Domestic use products	N/A	Sunday	10
M9	LARGO DA ASSUNÇÃO, 17, 18 R/C, Cascais	3 (2 male and 1 female)	Grocery, coffe shop and meals	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	120 m2	2m2	Closing time everyday	Professional use products with FT/FDS	08:00 - 18:00	Sunday	150- 170
M10	RUA FLORBELA ESPANCA, 174, Atibá	3 females	Grocery, charcuterie and bakery	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	180 m2	40m2	2 to 3 times a day	Professional use products with FT/FDS	08:00 - 20:00 saturday 08:00-19:00	Sunday	200-250
M11	RUA DO C HA FARI Z nº40, VI VEN DA S. JOSÉ, ALCABIDECHE	2 (1 male and 1 female)	Grocery and charcuterie	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread, clothing	75 m2	NA	Closing time everyday	Domestic use products	09:00 - 13:00 16:00 - 19:30/20:00 saturday 09:00-13:00	Sunday	60 -70
M12	LARGO OSTENDE, Edificio Palmeira, loja 14 B, Estoril	2 (1 male and 1 female)	Grocery and charcuterie	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	200 m2	20m2	2 times a day	Professional use products with FT/FDS	08:30 - 13:00 14:00 - 20:00 saturday 08:30 - 19:00 sunday 08:30 - 13:00	Sunday afternoon	200
M13	PRACETA CARLOS PAIÃO, 32-B SD RANA	2 male	Grocery and charcuterie	Fruits, vegetables, beverages, dry products, consumables, charcuterie, bread	80 m2	5m2	Closing time everyday	Professional use products with FT/FDS	08:00 - 13:00 15:00 - 19:00	Sunday	80-100

Table S3 - Identification of the studied GSs and the monitoring boxes used during the study, including the type of location and monitoring period.

Identification		Monitoring period		Monitoring Boxes		
ID	**Grocery**	**Start**	**End**	**A**	**B**	**C**
M1	Bioshop	22/11/21 - 10:25	25/11/21 - 10:00	Register		
M2	Amanhecer esmeralda	22/11/21 - 12:35	25/11/21 - 10:30		Register	
M3	Biofrade	25/11/21 - 10:51	29/11/21 - 10:06	Register	Fruits/vegetables	Office
M4	Mercado da Aldeia	29/11/21 - 11:00	03/12/21 - 10:30	Register	Storage	Office
M5	Amanhecer Charneca	03/12/21 - 10:50	06/12/21 - 10:00	Register	Fruits/vegetables	Storage
M6	Minimercado Valor Certo	06/12/21 - 10:20	10/12/21 - 10:20	Register		Fruits/vegetables
M7	Meu Super cobre	10/12/21 - 11:10	14/12/21 - 09:30	Register	Hallway	
M8	Ton Sin	14/12/21 - 10:05	16/12/21 - 09:30		Register	Storage
M9	Leitaria Estrela da Assunção	17/01/22 - 12:00	19/01/22 - 10:30	Fruits/vegetables		Register
M10	Meu Super atibá	19/01/22 - 10:50	22/01/22 - 15:30	A/E		Register
M11	Comércio tradicional (Fernanda nunes [Atrozela])	16/02/22 - 11:40	21/02/22- 11:00	Register	Store	
M12	Perola do monte	16/02/22 - 12:00	19/02/22 - 16:30			Register
M13	Cruz & Bras	19/02/22 - 16:40	21/02/22 - 10:30?		Register	

Table S4 - Description of the independent variables considered in the statistical analysis regarding their influence on the IAQ levels at the GSs.

Independent Variable	Description of categories
Number of clients per day	(1) < 100, (2) 100-200, (3) > 200
Selling area (m^2)	(1) <= 110 m^2, (2) > 110 m^2
Type of facility	(1) "charcuterie", (2) "charcuterie with bakery and coffee shop", (3) "charcuterie, meals and butchery"
Type of products	(1) "Regular Grocery products", (2) "Regular Grocery products + Clothes", (3) "Regular Grocery products + Butchery"
Storage	(1) "no storage", (2) "<= 5m^2", (3) ">5m^2"
Cleaning procedure	(1) "Daily at closing", (2) "Daily at opening/several times"
Type of cleaning products	(1) "Domestic use", (2) "Professional with FT/FD", (3) "Domestic use - Environment Friendly"
Days that groceries are closed	(1) "Sunday Afternoon", (2) "Sunday", (3) "Saturday afternoon and Sunday"

Table S5 - Results of the statistical analysis to the mean levels of IAQ parameters registered in all the locations of the studied GSs.

IAQ parameter	Variable studied	n	Statistical test	p-value	Pair-wise comparation		
					(1)-(2)	**(1)-(3)**	**(2)-(3)**
CO_2	Number of clients per day	3	Kruskal-Wallis	**0.007**	0.118	**0.009**	0.67
	Selling area (m2)	2	Mann-Whitney	**0.007**			
	Type of facility	3	Kruskal-Wallis	0.308			
	Type of products	3	Kruskal-Wallis	0.062			
	Storage	3	Kruskal-Wallis	0.083			
	Cleaning procedure	2	Mann-Whitney	**0.033**			
	Type of cleaning products	3	Kruskal-Wallis	**0.033**	0.558	**0.030**	0.238
	Days that groceries are closed	3	Kruskal-Wallis	0.911			
VOCs	Number of clients per day	3	ANOVA	**0.009**	0.199	**0.009**	0.334
	Selling area (m2)	2	ANOVA	**0.002**			
	Type of facility	3	ANOVA	0.430			
	Type of products	3	ANOVA	0.252			
	Storage	3	ANOVA	0.086			
	Cleaning procedure	2	ANOVA	**0.014**			
	Type of cleaning products	3	ANOVA	**0.048**	0.360	0.057	0.120
	Days that groceries are closed	3	ANOVA	0.282			
T	Number of clients per day	3	ANOVA	0.223			
	Selling area (m2)	2	ANOVA	0.957			
	Type of facility	3	ANOVA	**0.042**	0.099	0.064	1.000
	Type of products	3	ANOVA	0.223			
	Storage	3	ANOVA	0.077			
	Cleaning procedure	2	ANOVA	0.906			
	Type of cleaning products	3	ANOVA	0.946			
	Days that groceries are closed	3	ANOVA	0.641			
HR	Number of clients per day	3	ANOVA	0.482			
	Selling area (m2)	2	ANOVA	0.483			
	Type of facility	3	ANOVA	0.381			
	Type of products	3	ANOVA	0.596			
	Storage	3	ANOVA	0.266			
	Cleaning procedure	2	ANOVA	0.597			
	Type of cleaning products	3	ANOVA	0.391			
	Days that groceries are closed	3	ANOVA	0.275			

	Number of clients per day	3	ANOVA	0.285			
	Selling area (m2)	2	ANOVA	**0.039**			
	Type of facility	3	ANOVA	0.440			
	Type of products	3	ANOVA	0.159			
$PM_{2.5}$	Storage	3	ANOVA	0.199			
	Cleaning procedure	2	ANOVA	0.900			
	Type of cleaning products	3	ANOVA	0.119			
	Days that groceries are closed	3	ANOVA	0.21			
	Number of clients per day	3	ANOVA	0.285			
	Selling area	2	ANOVA	**0.040**			
	Type of facility	3	ANOVA	0.427			
	Type of products	3	ANOVA	0.165			
PM_{10}	Storage	3	ANOVA	0.207			
	Cleaning procedure	2	ANOVA	0.893			
	Type of cleaning products	3	ANOVA	0.121			
	Days that groceries are closed	3	ANOVA	0.214			

Table S6 – Summary of the mean levels of the considered parameters during the occupied period in the studied Grocery Stores, at each studied location.

OCCUPIED PERIOD IN THE GROCERY STORES													
Identity		Temperature (ºC)		Relative Humidity (%)		CO_2 (ppm)		VOCs (ppb)		PM_{10} ($\mu g.m^{-3}$)		$PM_{2.5}$ ($\mu g.m^{-3}$)	
ID	BOX	Mean ± SD	Range [min-max]	Mean ± SD	Range [min-max]	Mean ± SD	Range [min-max]	Mean ± SD	Range [min-max]	Mean ± SD	Range [min-max]	Mean ± SD	Range [min-max]
M1	A	20.3 ± 0.3	[19.8 - 20.9]	44.0 ± 1.8	[40.4 - 48.5]	438 ± 33	[380 - 548]	47.4 ± 19.9	[17.5 - 140]	15.3 ± 8.0	[5.2 - 67.6]	13.8 ± 8.1	[3.5 - 67.0]
M2	B	21.4 ± 1.2	[19.2 - 23.4]	40.1 ± 4.9	[32.0 - 48.3]	458 ± 27	[414 - 546]	11.1 ± 12.7	[0.7 - 106]	14.0 ± 8.9	[2.9 - 43.0]	12.8 ± 9.2	[1.4 - 42.8]
M3	A	19.5 ± 0.7	[18.0 - 20.6]	46.2 ± 3.8	[39.1 - 57.9]	545 ± 95	[391 - 810]	82.3 ± 25.1	[33.4 - 170]	33.6 ± 25.0	[5.1 - 172]	32.3 ± 25.0	[3.5 - 169]
	B	22.1 ± 2.5	[17.9 - 26.9]	44.2 ± 6.1	[30.8 - 58.3]	632 ± 89	[454 - 1012]	86.8 ± 24.4	[32.8 - 189]	33.5 ± 27.7	[2.9 - 179]	32.7 ± 28.1	[1.4 - 182]
	C	20.3 ± 0.5	[18.6 - 21.2]	49.4 ± 3.0	[43.7 - 59.3]	585 ± 94	[383 - 983]	62.9 ± 31.1	[2.6 - 143]	26.9 ± 19.4	[3.1 - 157]	26.5 ± 19.9	[1.8 - 160]
M4	A	18.5 ± 2.0	[13.7 - 24.9]	54.2 ± 7.8	[30.5 - 70.3]	528 ± 98	[363 - 808]	56.3 ± 20.7	[1.7 - 136]	18.6 ± 8.7	[5.1 - 50.3]	17.2 ± 8.8	[3.5 - 49.3]
	B	21.4 ± 0.9	[18.8 - 22.6]	47.6 ± 4.5	[38.4 - 57.5]	864 ± 178	[474 - 1144]	80.1 ± 10.0	[50.9 - 121]	10.3 ± 6.2	[2.9 - 45.0]	9.0 ± 6.4	[1.4 - 44.9]
	C	18.6 ± 0.2	[18.2 - 19.3]	64.7 ± 5.5	[53.3 - 78.2]	785 ± 180	[391 - 1199]	58.5 ± 21.4	[10.7 - 178]	13.0 ± 7.6	[3.1 - 59.6]	12.1 ± 7.8	[1.8 - 58.8]
M5	A	23.8 ± 0.8	[22.2 - 27.2]	47.2 ± 8.7	[22.4 - 59.5]	382 ± 14	[354 - 439]	53.3 ± 19.3	[8.0 - 85]	15.5 ± 9.5	[5.1 - 106]	14.0 ± 9.5	[3.5 - 102]
	B	19.8 ± 0.7	[18.4 - 21.5]	58.3 ± 10.7	[38.9 - 72.1]	438 ± 16	[408 - 515]	28.8 ± 14.4	[3.9 - 59]	11.5 ± 7.2	[2.9 - 73.0]	10.3 ± 7.4	[1.4 - 71.8]
	C	22.1 ± 0.4	[21.0 - 22.7]	56.2 ± 8.7	[43.2 - 69.2]	374 ± 26	[335 - 462]	17.0 ± 9.4	[2.6 - 59]	11.9 ± 9.3	[3.1 - 71.9]	11.0 ± 9.4	[1.8 - 71.7]
M6	A	21.6 ± 1.3	[18.3 - 23.1]	52.7 ± 5.4	[40.5 - 65.8]	401 ± 31	[347 - 556]	68.0 ± 20.9	[9.9 - 130]	24.4 ± 30.0	[5.1 - 279]	23.0 ± 29.9	[3.5 - 279]
	C	22.3 ± 0.7	[18.6 - 23.6]	54.7 ± 5.4	[44.6 - 65.7]	386 ± 36	[319 - 502]	13.9 ± 10.7	[1.3 - 53]	16.5 ± 22.2	[3.1 - 157]	15.8 ± 22.8	[1.8 - 160]
M7	A	21.1 ± 1.0	[19.0 - 23.1]	55.1 ± 7.3	[43.2 - 69.9]	371 ± 19	[347 - 452]	58.7 ± 19.0	[25.7 - 152]	20.8 ± 8.2	[5.1 - 64.1]	19.4 ± 8.3	[3.5 - 63.4]
	B	21.0 ± 0.6	[19.4 - 22.0]	55.1 ± 7.5	[45.6 - 70.6]	476 ± 23	[419 - 588]	39.2 ± 13.5	[0.7 - 77]	17.7 ± 7.3	[2.9 - 103]	16.7 ± 7.5	[1.4 - 103]
M8	B	19.5 ± 0.1	[19.2 - 20.0]	57.0 ± 0.5	[55.8 - 58.3]	484 ± 59	[433 - 863]	35.5 ± 7.2	[22 - 59]	21.9 ± 7.5	[2.9 - 57.0]	21.0 ± 7.5	[1.4 - 55.3]
	C	18.8 ± 0.4	[17.6 - 19.3]	59.3 ± 4.2	[51.1 - 65.5]	385 ± 33	[335 - 644]	33.4 ± 16.7	[1.3 - 101]	23.9 ± 9.1	[3.1 - 82.5]	23.4 ± 9.3	[1.8 - 82.8]
M9	A	22.0 ± 1.6	[14.4 - 26.7]	39.8 ± 4.9	[28.3 - 65.0]	407 ± 19	[371 - 478]	40.4 ± 17.3	[1.7 - 91]	27.9 ± 11.2	[5.1 - 74.5]	26.6 ± 11.4	[3.5 - 74]
	C	20.9 ± 1.0	[15.3 - 26.0]	50.1 ± 5.6	[40.0 - 72.1]	431 ± 50	[369 - 601]	56.9 ± 13.1	[27.3 - 90]	29.5 ± 12.2	[3.1 - 109]	29.2 ± 12.4	[1.8 - 110.4]
M10	A	18.9 ± 1.0	[15.9 - 20.2]	39.3 ± 3.5	[30.6 - 48.5]	457 ± 45	[366 - 683]	71.7 ± 19.5	[11.7 - 138]	40.4 ± 30.9	[5.1 - 231]	39.1 ± 30.7	[3.5 - 229]
	C	19.5 ± 0.6	[16.6 - 20.5]	48.0 ± 2.9	[43.8 - 56.7]	543 ± 62	[399 - 701]	109.5 ± 18.6	[76.6 - 167]	40.2 ± 32.1	[3.1 - 164]	40.0 ± 32.8	[1.8 - 167]
M11	A	18.5 ± 1.0	[16.1 - 20.4]	59.5 ± 7.4	[41.8 - 67.6]	491 ± 76	[349 - 709]	68.2 ± 15.5	[25.7 - 93]	20.0 ± 18.5	[5.1 - 248]	18.5 ± 18.5	[3.5 - 247]
	B	18.4 ± 1.1	[16.0 - 20.7]	55.3 ± 7.0	[41.2 - 67.9]	365 ± 16	[345 - 465]	13.5 ± 16.6	[0.7 - 91]	16.9 ± 11.8	[2.9 - 147]	15.9 ± 12	[1.4 - 149]
M12	C	19.0 ± 0.7	[17.5 - 20.0]	64.2 ± 2.9	[59.6 - 67.9]	532 ± 69	[454 - 711]	60.4 ± 9.8	[46.5 - 96]	9.2 ± 5.1	[3.1 - 36.6]	8.1 ± 5.3	[1.8 - 36.7]
M13	B	20.0 ± 0.3	[19.3 - 20.7]	43.1 ± 4.0	[35.2 - 47.6]	390 ± 27	[355 - 465]	25.8 ± 4.9	[17.5 - 34]	17.9 ± 5.5	[2.9 - 38.9]	16.9 ± 5.6	[1.4 - 38.7]

Table S7 - Summary of the mean levels of the studied parameters assessed in each GSs (considering all locations within the GSs for the mean assessed at a specific GS), during the occupied period.

OCCUPIED PERIOD						
ID	Temperature (ºC)	RH (%)	CO_2(ppm)	VOCs (ppb)	PM_{10} (µg.m^{-3})	$PM_{2.5}$ (µg.m^{-3})
M1	20.3 ± 0.3	44.0 ± 1.8	438 ± 33	47.4 ± 19.9	15.3 ± 8.0	13.8 ± 8.1
M2	21.4 ± 1.4	40.1 ± 4.9	458 ± 27	11.1 ± 12.7	14.0 ± 8.9	12.8 ± 9.2
M3	20.6 ± 1.2	46.6 ± 4.3	587 ± 93	77.3 ± 26.8	31.3 ± 24.1	30.5 ± 24.3
M4	19.5 ± 1.0	55.5 ± 5.9	726 ± 152	65.0 ± 17.8	14.0 ± 7.5	12.8 ± 7.7
M5	21.9 ± 0.6	53.9 ± 9.4	398 ± 19	33.0 ± 14.4	13.0 ± 8.7	11.7 ± 8.8
M6	22.0 ± 1.0	53.7 ± 5.4	393 ± 33	41.0 ± 15.8	20.5 ± 26.1	19.4 ± 26.34
M7	21.1 ± 0.8	55.1 ± 7.4	423 ± 21	49.0 ± 16.2	19.2 ± 7.8	18.0 ± 7.9
M8	19.2 ± 0.2	58.2 ± 2.4	435 ± 46	34.5 ± 11.9	25.0 ± 26	24.4 ± 26.7
M9	21.4 ± 1.3	44.9 ± 5.2	419 ± 35	48.6 ± 15.2	28.7 ± 11.7	27.9 ± 11.8
M10	19.2 ± 0.8	43.6 ± 3.2	500 ± 56	90.6 ± 19.1	40.3 ± 31.5	39.6 ± 31.8
M11	18.4 ± 1.0	57.4 ± 7.2	428 ± 46	40.9 ± 16.0	18.5 ± 15.1	17.2 ± 15.2
M12	19.0 ± 0.7	64.2 ± 2.9	532 ± 69	60.4 ± 9.8	9.2 ± 5.1	8.1 ± 5.3
M13	20.2 ± 0.3	43.1 ± 4	390 ± 27	25.8 ± 4.9	17.9 ± 5,5	16.9 ± 5.9