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**Ultrafine particles: world characterisation, occupational assessment and effects on  
human health.**

Universidade Fernando Pessoa

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“TODOS OS DIREITOS RESERVADOS”



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**Ultrafine particles: world characterisation, occupational assessment and effects on human health.**

Thesis presented to Fernando Pessoa University as part of the requirements for obtaining a PhD degree in Ecology and Environmental Health, under the supervision of Professor Nelson Augusto Cruz de Azevedo Barros and Ana Maria da Conceição Ferreira

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Porto, august 2023



**Partículas ultrafinas: caracterização mundial, avaliação ocupacional e efeitos na saúde.**

**RESUMO**

**Introdução:** As partículas ultrafinas (UFP) e seus efeitos na saúde têm sido amplamente estudados, resultando em avanços no conhecimento sobre este poluente. No entanto, a definição de normas de medição e limites legais para controlar a exposição tem sido um desafio. Para abordar essa questão, foi realizada uma revisão da literatura para fazer o estado da arte sobre as UFP e seus os efeitos na saúde humana. Um questionário à escala global também foi conduzido para entender como a avaliação das UFP é feita, onde, por quem, e com que propósito. Por outro lado, foi feita a avaliação das UFP em ambientes internos ocupacionais com diferentes níveis de emissão de material particulado (PM). O estudo tem como objetivo contribuir para um maior entendimento dos efeitos das UFP na saúde humana e promover o estabelecimento de diretrizes e normas para controlar a exposição a essas partículas e proteger a saúde de todos.

**Material e Métodos:** Foi realizada uma revisão sistemática da literatura (SLR) com o objetivo de encontrar, selecionar, analisar e sistematizar informação sobre UFP. Esta informação foi publicada em trabalhos de investigação recentes (2002 a 2022), centrados nas UFP no ambiente profissional e nos seus impactos na saúde humana. Para identificar os métodos de medição mais comuns e suas lacunas, bem como verificar a existência de regulamentações nessa área, foi elaborado um questionário mundial em inglês, utilizando o Google Forms. Além disso, foram conduzidas quatro avaliações de parâmetros ambientais e diversos poluentes em duas instalações industriais (uma carpintaria e uma padaria) e em duas instalações do setor social (uma escola e uma clínica de saúde). As instalações industriais escolhidas geralmente apresentam emissões de PM, ao passo que as outras duas instalações possuem baixos níveis ou nenhuma emissão direta de PM. Os resultados obtidos foram processados e cruzados com dados estatísticos, proporcionando uma análise mais completa sobre as UFP e seus efeitos nos diferentes ambientes avaliados.

**Resultados:** A revisão bibliográfica demonstrou a falta de estudos transversais e as consequências para a saúde já identificadas quanto às ultrafinas assim como as

diferenças entre a vertente de Qualidade do Ar Interior (IAQ) e avaliação do risco na vertente ocupacional. Verificou-se também não existir protocolos definidos para amostragem das UFP. Pensa-se que as UFP são um dos principais fatores que contribuem para os efeitos adversos para a saúde decorrentes da exposição a partículas devido ao seu tamanho extremamente pequeno. No entanto, pouco se sabe sobre a qualidade, os limiares e a concentração destas partículas que causam efeitos adversos na saúde. Sabe-se que a exposição a UFP no ambiente e no local de trabalho tem efeitos adversos para a saúde. O inquérito global realizado sobre UFP permitiu recolher informações de 20 países dos cinco continentes, proporcionando um dos estudos mais abrangentes sobre UFP até à data. Os resultados revelaram uma falta de conhecimento entre os inquiridos, com alguns a confundirem as UFP com partículas maiores como  $PM_{10}$  ou  $PM_{2.5}$ . Este facto realça a necessidade de educação e sensibilização sobre as UFP e os seus potenciais efeitos na saúde. O estudo sublinhou a urgência de desenvolver normas e regulamentos internacionais para a avaliação, o controlo e os limites de exposição às UFP. Denotou-se também que não existem ambientes isentos de UFP e que as fontes interiores são os principais contribuintes para os níveis de UFP em ambientes profissionais, tanto na forma primária como secundária. Verificou-se que fatores como a humidade, a temperatura e a falta de ventilação influenciam as concentrações de UFP e contribuem para a sua formação secundária. Apesar de algumas atividades não terem fontes primárias de UFP, todas as áreas avaliadas apresentaram níveis elevados de UFP, excedendo as diretrizes da Organização Mundial de Saúde (WHO). A ventilação surgiu como um fator crucial para melhorar os parâmetros de UFP.

**Conclusão:** O Controlo dos níveis de UFP é de extrema importância para proteger a saúde humana. Devido às dificuldades encontradas na filtragem de UFP através dos sistemas convencionais de controle de poluição, torna-se imperativo o desenvolvimento de tecnologias mais eficientes para controlar as suas emissões. É fundamental continuar a pesquisa sobre as UFP e seus impactos na saúde humana, pois isso fornecerá informações cruciais para criar medidas regulatórias e estabelecer diretrizes eficazes. A aplicação de metodologias internacionais e o estabelecimento de valores-guia podem desempenhar um papel significativo na redução dos efeitos adversos à saúde resultantes da exposição a essas partículas ultrafinas.

**Palavras-chave:** Partículas Ultrafinas, UFP, Efeitos na Saúde, Saúde Ocupacional, Inquérito mundial

**Ultrafine particles: world characterisation, occupational assessment and effects on human health.**

**ABSTRACT**

**Introduction:** Ultrafine particles (UFP) and their health effects have been widely studied, resulting in advances in knowledge about this pollutant. However, setting measurement standards and legal limits to control exposure has been a challenge. To address this issue, a literature review was conducted to make the state of the art on UFP and its effects on human health. A global scale questionnaire was also conducted to understand how the assessment of UFP is done, where, by whom, and for what purpose. On the other hand, the assessment of UFP in occupational indoor environments with different levels of particulate matter (PM) emission was conducted. The study aims to contribute to a greater understanding of the effects of UFP on human health and to promote the establishment of guidelines and standards to control exposure to these particles and protect the health of all.

**Material and Methods:** A systematic literature review (SLR) was conducted with the aim of finding, selecting, analysing and systematising information on UFP. This information was published in recent research papers (2002 to 2022), focussing on UFP in the occupational environment and its impacts on human health. In order to identify the most common measurement methods and their gaps, as well as to verify the existence of regulations in this area, a worldwide questionnaire was developed in English using Google Forms. In addition, four assessments of environmental parameters and various pollutants were conducted in two industrial facilities (a carpentry shop and a bakery) and two social sector facilities (a school and a Clinic Laboratory). The chosen industrial facilities generally have PM emissions, while the other two facilities have low levels or no direct PM emissions. The results obtained were processed and cross-checked with statistical data, providing a more complete analysis on UFP and its effects in the different environments assessed.

**Results:** The literature review demonstrated the lack of cross-sectional studies and the health consequences already identified regarding ultrafine as well as the differences between the Indoor Air Quality (IAQ) aspect and risk assessment in the occupational aspect. It was also found that there are no defined protocols for sampling. UFP are

thought to be a major contributor to adverse health effects from exposure to particulate matter. Due to their extremely small size. However, little is known about the quality, thresholds and concentration of these particles that cause adverse health effects. Exposure to UFP in the environment and workplace is known to have adverse health effects. The global survey on UFP collected information from 20 countries across five continents, providing one of the most comprehensive studies on UFP to date. The results revealed a lack of knowledge among respondents, with some confusing UFP with larger particles such as PM<sub>10</sub> or PM<sub>2.5</sub>. This emphasises the need for education and awareness-raising about UFP and their potential health effects. The study emphasised the urgency of developing international standards and regulations for the assessment, control and limits of exposure to UFP. It was also noted that there are no environments free from UFP and that indoor sources are the main contributors to UFP levels in occupational environments, both in primary and secondary form. Factors such as humidity, temperature and lack of ventilation were found to influence UFP concentrations and contribute to its secondary formation. Despite some activities having no primary sources of UFP, all areas assessed showed elevated levels of UFP, exceeding World Health Organisation (WHO) guidelines. Ventilation emerged as a crucial factor in improving UFP parameters.

**Conclusion:** The control of UFP levels is of utmost importance to protect human health. Due to the difficulties encountered in filtering UFP through conventional pollution control systems, it becomes imperative to develop more efficient technologies to control their emissions. It is critical to continue research on UFP and its impacts on human health, as this will provide crucial information to create regulatory measures and establish effective guidelines. The application of international methodologies and the establishment of guideline values can play a significant role in reducing the adverse health effects resulting from exposure to these ultrafine particles.

**Keywords:** Ultrafine Particles, UFP, Health Effects, Occupational Health, Global Survey

**Particules ultrafines : caractérisation mondiale, évaluation professionnelle et effets sur la santé humaine.**

**RÉSUMÉ**

**Introduction :** les particules ultrafines (UFP) et leurs effets sur la santé ont été largement étudiés, ce qui a permis de faire progresser les connaissances sur ce polluant. Toutefois, il est difficile de fixer des normes de mesure et des limites légales pour contrôler l'exposition. Pour répondre à ce problème, une analyse de la littérature a été réalisée pour faire le point sur les UFP et leurs effets sur la santé humaine. Un questionnaire à l'échelle mondiale a également été réalisé pour comprendre comment l'évaluation des UFP est effectuée, où, par qui et dans quel but. D'autre part, l'évaluation des UFP dans les environnements intérieurs professionnels avec différents niveaux d'émission de particules (PM) a été réalisée. L'étude vise à contribuer à une meilleure compréhension des effets des UFP sur la santé humaine et à promouvoir l'établissement de lignes directrices et de normes pour contrôler l'exposition à ces particules et protéger la santé de tous.

**Matériel et méthodes :** une analyse systématique de la littérature a été réalisée dans le but de trouver, de sélectionner, d'analyser et de systématiser les informations sur les UFP. Ces informations ont été publiées dans des documents de recherche récents (2002 à 2022), axés sur les UFP dans l'environnement professionnel et leurs effets sur la santé humaine. Afin d'identifier les méthodes de mesure les plus courantes et leurs lacunes, ainsi que de vérifier l'existence de réglementations dans ce domaine, un questionnaire mondial a été élaboré en anglais à l'aide de Google Forms. En outre, quatre évaluations de paramètres environnementaux et de divers polluants ont été réalisées dans deux installations industrielles (une menuiserie et une boulangerie) et deux installations du secteur social (une école et un dispensaire). Les installations industrielles choisies ont généralement des émissions de particules, tandis que les deux autres installations ont peu ou pas d'émissions directes de particules. Les résultats obtenus ont été traités et recoupés avec des données statistiques, ce qui a permis d'obtenir une analyse plus complète des UFP et de leurs effets dans les différents environnements évalués.

**Résultats :** L'analyse de la littérature a démontré le manque d'études transversales et les conséquences sanitaires déjà identifiées concernant les ultrafines, ainsi que les

différences entre l'aspect de la qualité de l'air intérieur (IAQ) et l'évaluation des risques dans l'aspect professionnel. Il a également été constaté qu'il n'existe pas de protocoles définis pour l'échantillonnage. On pense que les UFP contribuent largement aux effets néfastes sur la santé de l'exposition aux particules. En raison de leur taille extrêmement réduite. Toutefois, on sait peu de choses sur la qualité, les seuils et la concentration de ces particules qui ont des effets néfastes sur la santé. On sait que l'exposition aux UFP dans l'environnement et sur le lieu de travail a des effets néfastes sur la santé. L'enquête mondiale sur les UFP a permis de recueillir des informations dans 20 pays répartis sur les cinq continents, ce qui constitue l'une des études les plus complètes sur les UFP à ce jour. Les résultats ont révélé un manque de connaissances parmi les personnes interrogées, certaines confondant les UFP avec des particules plus grosses telles que les  $PM_{10}$  ou les  $PM_{2,5}$ , ce qui souligne la nécessité d'une éducation et d'une sensibilisation aux UFP et à leurs effets potentiels sur la santé. L'étude souligne l'urgence d'élaborer des normes et des réglementations internationales pour l'évaluation, le contrôle et les limites de l'exposition aux UFP. Il a également été noté qu'il n'existe pas d'environnements exempts de UFP et que les sources intérieures sont les principaux contributeurs aux niveaux de UFP dans les environnements professionnels, à la fois sous forme primaire et secondaire. Il a été constaté que des facteurs tels que l'humidité, la température et le manque de ventilation influencent les concentrations d'UFP et contribuent à sa formation secondaire. Bien que certaines activités n'aient pas de sources primaires d'UFP, toutes les zones évaluées présentaient des niveaux élevés d'UFP, dépassant les lignes directrices de l'Organisation mondiale de la santé (WHO). La ventilation est apparue comme un facteur crucial pour améliorer les paramètres de l'UFP.

**Conclusion :** le contrôle des niveaux d'UFP est de la plus haute importance pour la protection de la santé humaine. En raison des difficultés rencontrées pour filtrer les UFP à travers les systèmes conventionnels de contrôle de la pollution, il devient impératif de développer des technologies plus efficaces pour contrôler leurs émissions. Il est essentiel de poursuivre les recherches sur les UFP et leur impact sur la santé humaine, car elles fourniront des informations cruciales pour élaborer des mesures réglementaires et établir des lignes directrices efficaces. L'application de méthodologies internationales et l'établissement de valeurs indicatives peuvent jouer un rôle important dans la

réduction des effets néfastes sur la santé résultant de l'exposition à ces particules ultrafines.

**Mots clés :** particules ultrafines, effets sur la santé, santé au travail, enquête mondiale

## Dedicatory

*To all those who made this journey possible and accompanied me, especially my parents.*



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## **List of abbreviations**

### **A**

ACGIH – American Conference of Governmental Industrial Hygienists

### **C**

CO – Carbon Monoxide

CO<sub>2</sub> – Carbon Dioxide

COPD –Chronic obstructive pulmonary disease

### **D**

DNA – Deoxyribonucleic Acid

### **I**

IAQ – Indoor Air Quality

ILO – International Labour Organisation

IRAMUTEQ – Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires

ISO – International Organization for Standardization

### **N**

NO – Nitrogen Oxide

NO<sub>x</sub> – Nitrogen Oxides

**O**

O<sub>3</sub> – Ozone

**P**

PM – Particulate Matter

PM<sub>2.5</sub> –Particulate Matter<2.5 μm

PM<sub>10</sub> – Particulate Matter<10 μm

PNC – Particle Number Count

ppm – Particles Per Million

PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses

**R**

RH – Relative Humidity

ROS – Reactive Oxygen Species

**S**

SO<sub>2</sub> – Sulphur dioxide

SRL – Systematic Literature Review

SVOC – Semi-Volatile Organic Compounds

**T**

T – Temperature

TLV – Threshold Limit Values

**U**

UFP – Ultrafine Particles

**V**

VOC – Volatile Organics Compounds

**W**

WHO – World Health Organization

## INTRODUCTION

Air quality and its impact on health has been studied over the past decades. It has been the target of several studies and scientific advances, both in terms of the pollutants studied and in terms of the health effects and associated pathologies.

Air quality is a key issue for human health and wellbeing, as well as affecting biodiversity, ecosystems, and the global climate. Air quality degradation is mainly caused by the release of air pollutants from human activities and natural processes. The main air pollutants include particulate matter (PM<sub>2.5</sub>, PM<sub>10</sub> and UFP), carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>), ground-level ozone (O<sub>3</sub>), carbon monoxide (CO) and volatile organic compounds (VOC) (Neto & Bógus, 2003).

The problem of air quality involves several issues of concern:

Greenhouse effect and climate change: Greenhouse gases such as carbon dioxide contribute to global warming, leading to climate change that has significant impacts on ecosystems, water resources and weather patterns (Jacobi, 2003);

Loss of biodiversity: Air pollution can harm vegetation, directly affecting the wildlife that depends on it, as well as contributing to the loss of natural habitats (Sen, 1993);

Human health: Air pollution is strongly linked to a range of health problems such as respiratory diseases (asthma, bronchitis, emphysema, COPD), cardiovascular diseases, lung cancer and even premature death. Fine particles are particularly dangerous as they can penetrate deep into the lungs and enter the bloodstream, affecting the whole organism (WHO, 2021) Respiratory problems and allergies: Air pollution can aggravate pre-existing respiratory conditions, such as asthma, and lead to the development of allergies and other respiratory diseases (Castro et al., 2014);

Indoor Air Quality: Air quality in indoor environments such as homes and offices is also a major issue, as it is often worse than outdoor air due to lack of proper ventilation and the release of indoor pollutants from sources such as cleaning products, building materials and smoking (WHO, 2021).

Air Quality in Occupational Environments: Occupational air quality refers to the atmospheric conditions present in work environments, where employees and workers may be exposed to various pollutants and contaminants while performing their work activities. It is a key concern as continuous exposure to certain pollutants can lead to serious health impacts on workers (Wolf J, Prüss-Ustün A, Ivanov I, Mudgal S, Corvalán C, 2018).

To address these challenges, governments and international organisations are working to establish regulations, standards and targets for reducing air pollution. This includes promoting clean and renewable energy sources, developing emission control technologies, encouraging the use of public transport and raising awareness about the impacts of air pollution on public health and the environment (Bocconi et al., 2021).

Several authors and studies have talked about the problem and carried out research on the effects of air quality, which has led to a closer look at the issues of the particles we breathe. This problem is always present, both in our daily lives and in our professional activities and is of extreme importance for the quality of life and health of the population.

UFP has become an issue of concern in the field of health and the environment. It was considered crucial to carry out further research to better understand the effects of ultrafine particles on health and the environment, in order to establishment of foundations to help develop critical mass and the need to develop more effective regulations to monitor and control these emissions. Raising awareness of the issue is also essential to promote collective action to reduce the negative impact of UFP on air quality, public health and occupational health.

Particulate Matter refers to a complex collection of airborne solid and liquid particles, which can be emitted by various natural and anthropogenic sources. These particles have a wide range of sizes, from the largest to the smallest, some of which are invisible

to the naked eye. Solid particles can include dust, soil particles, smoke, ash and particles from industrial activities and from the burning of fossil fuels such as coal, oil and petroleum products. In addition, liquid particles can also be present in the form of droplets, such as fog and mist (Cartieaux et al., 2011).

Thus, the development of this thesis centres on occupational exposure of workers. Dust, particulate matter and ultrafine particles are at the centre of concern and research due to emerging problems. Therefore, the study will focus on fine (PM<sub>2.5</sub> and PM<sub>10</sub>) and ultrafine (UFP) particles.

Throughout this thesis, the author intends to achieve and answer these questions in order to contribute in a significant way to the scientific evolution and improvement of the quality of life in the occupational sector.

The main objective of this thesis was analysing how ultrafine particles are monitored globally, with particular attention to the occupational health. To analyse the possible effects on workers' health and, finally, to understand, in a comparative study, the exposure of workers to ultrafine particles in four different sectors of activity. These questions led the focus on the occupational exposure of workers. Dust, particulate matter and ultrafine particles are at the centre of concern and research due to emerging issues. The study was therefore focus on fine particles (PM<sub>2.5</sub> and PM<sub>10</sub>) and ultrafine particles (UFP).

The study aimed to answer some questions, namely:

Q1 - What are the main risks associated to UFP exposure?

Q2 - Are there significant differences in the formation of UFP between activities?

Q3 - Could the differences in the formation of UFP justify monitoring only in some activities?

Q4 - Which activities have the highest formation of UFP?


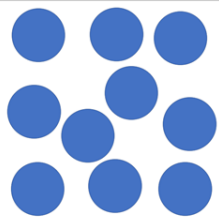
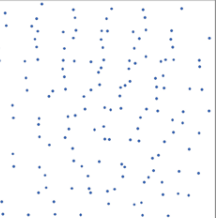
Particulate Matter refers to a complex collection of airborne solid and liquid particles, which can be emitted by various natural and anthropogenic sources. (Cartieaux et al., 2011).

Particulate matter is categorised according to its aerodynamic diameter, which influences its ability to remain suspended in air and its penetration into the human respiratory system. Common classifications include (Jones et al., 2000; Pasquiou et al., 2021):

1. PM<sub>10</sub>: Particles with a diameter of 10 micrometres or less (one micrometre is equal to one thousandth of a millimetre). These particles can be inhaled deep into the respiratory system.

2. PM<sub>2.5</sub>: Particles with a diameter of 2.5 micrometres or less. They are even smaller than PM<sub>10</sub> and can penetrate deeper into the lungs and even the bloodstream, posing a greater risk to human health.

Ultrafine particles (UFP), refer to extremely small solid or liquid particles with dimensions in the nanometre scale. They have a very small size, usually between 1 and 100 nanometres (nm), and are invisible to the naked eye. To give you an idea of the scale, one nanometre is equivalent to one billionth of a metre (1 nm = 10<sup>-9</sup> m) (Marval & Tronville, 2022).

	10 µm (Coarse)	2.5 µm (Fine)	0.1 µm (Ultrafine)
			
<b>Total mass</b>	1	1	1
<b>Particle number</b>	1	64	1,000,000
<b>Surface area per particle</b>	1	0.0625	0.0001
<b>Total surface area per mass</b>	1	4	100
	<ul style="list-style-type: none"> <li>Filtered in proximal airway</li> <li>May irritate skin, mucosa</li> </ul>	<ul style="list-style-type: none"> <li>Reaches peripheral airway</li> <li>Cannot enter systemic circulation</li> </ul>	<ul style="list-style-type: none"> <li>Higher adsorbed toxic material on surface</li> <li>May enter systemic circulation</li> </ul>

**Figure 1**– Comparison size from PM<sub>10</sub>, PM<sub>2.5</sub> and UFP.

**Source** –Kwon et al. (2020).

Due to their extremely small size (Figure 1), ultrafine particles exhibit unique characteristics and properties, which differ from larger particle sizes of the same material. These characteristics make UFP highly interesting and useful in various scientific, industrial and technological applications (Manigrasso et al., 2019).

Some examples of applications of ultrafine particles include:

- Nanotechnology: Nanoparticles are key in the field of nanotechnology, where they are used to create new materials and devices with enhanced properties;
- Medicine: Nanoparticles are used in biomedical applications such as targeted drug delivery systems, diagnostic imaging and therapy;
- Electronics: Ultrafine particles are utilised in the manufacture of electronic components and nanoelectronics devices;
- Energy: They are used in energy storage technologies, solar cells, and catalysts to improve the efficiency of processes;
- Polymers: In the polymer industry, nanoparticles are added to improve the mechanical, thermal or barrier properties of different materials;
- Cosmetics: In cosmetic products, they are used to improve the stability and efficacy of active ingredients;
- Agriculture: Nanoparticles are investigated to improve the delivery of nutrients or pesticides to plants.

Emission of particulate matter occurs under various circumstances, including natural processes such as forest fires, volcanic eruptions, desert dust and pollen. However, human activities are responsible for a large proportion of PM emissions, such as the burning of fossil fuels in vehicles, industries and power plants, as well as inappropriate agricultural practices (Suwa et al., 2002).

The effects of particulate matter on human health can be severe, especially for vulnerable people such as children, the elderly and individuals with respiratory or cardiovascular diseases. Chronic exposure to high levels of PM is associated with respiratory problems such as asthma, chronic bronchitis and emphysema, as well as cardiovascular diseases including heart attacks and strokes (WHO, 2021).

In addition to human health effects, particulate matter also impacts the environment, contributing to haze formation, reduced visibility, acidification of soils and water bodies, and can affect air quality in urban and industrial areas (Castro et al., 2014).

With regard to occupational air quality, it refers to the condition of the air within work environments, where employees and workers are exposed to different types of pollutants and contaminants during their work activities. Concern about occupational air quality is essential because prolonged exposure to certain pollutants can have adverse effects on workers' health (Wolf J, Prüss-Ustün A, Ivanov I, Mudgal S, Corvalán C, 2018).

Some of the most common pollutants found in work environments include:

- Particulate matter And Dust: Work in industries such as construction, mining, agriculture and manufacturing can generate dust and particulate matter, which can be inhaled and cause damage to the respiratory system (Audignon-Durand et al., 2021).
- Toxic gases: Certain industries release toxic gases such as carbon monoxide (CO), sulphur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>) and other hazardous chemical compounds that can lead to respiratory problems and even poisoning in severe cases (Audignon-Durand et al., 2021).
- Volatile organic compounds: These are released in work environments where chemicals such as paints, solvents, cleaning products and pesticides are used. Exposure to VOCs can cause eye, nose and throat irritation, as well as respiratory problems and, in some cases, systemic effects (Audignon-Durand et al., 2021).
- Welding fumes and vapours: Metalworking and welding industries produce fumes and vapours that can contain toxic particles and heavy metals such as lead, cadmium and chromium, posing a significant health risk to workers (Audignon-Durand et al., 2021).
- Asbestos and mineral fibres: Work environments involving the handling of materials containing asbestos or other mineral fibres can lead to exposure to fine particles which, when inhaled, can cause serious lung diseases such as asbestosis and mesothelioma (Trechera et al., 2021).

- Chronic exposure to these pollutants can cause a variety of occupational health problems, including respiratory diseases, allergies, eye irritations, nervous system damage and even cancer (Pibiri et al., 2006).

To ensure occupational air quality, it is essential that companies and employers comply with occupational safety and health standards and regulations set by the competent authorities. This includes implementing control measures such as adequately ventilating workplaces, using appropriate personal protective equipment, replacing toxic substances with less harmful alternatives where possible, and adopting good work practices to minimise the generation of pollutants (The WHOQOL Group, 1995).

In addition, occupational air quality monitoring programmes should be implemented to regularly assess the levels of pollutants present in workplaces and ensure that workers are protected from excessive exposures and health risks. Awareness and education of workers are also key so that they can take preventive measures and report any air quality-related issues in their work environments.

Regarding suspended PM, these studies have focused mainly PM<sub>2.5</sub> and PM<sub>10</sub>, with several studies in the area proving the existence and impact on human health. More recent studies indicate that in addition to PM<sub>2.5</sub> and PM<sub>10</sub>, there are other particles of ultrafine size that may be harmful. This recent approach has not yet allowed the establishment of guiding standards for the assessment and monitoring of UFP (Pietrojusti & Magrini, 2014).

Because of these risks, measuring and controlling particulate matter emissions is important to ensure better air quality and protect public health. Government standards and regulations are established in many countries to limit the concentration of particulate matter in the air and mitigate its negative effects.

So essentially, we have particulate matter:

PM<sub>2.5</sub> particles are a major air pollutant and have a significant impact on air quality and human health. They are considered fine particles because they are so small that they can easily enter the lungs and even the bloodstream when inhaled. Because of their tiny size, they can settle deep into the lungs, causing respiratory problems and other negative health effects (Monteiro et al., 2018).

Common sources of PM<sub>2.5</sub> include the burning of fossil fuels in vehicles, power plants and industries, as well as activities such as biomass burning (e.g. agricultural burning, wood burning in fireplaces and cookers) and soil dust. Meteorological conditions and atmospheric circulation patterns can also influence PM<sub>2.5</sub> levels in a region (Caiaffa et al., 2008).

The main health effects associated with long-term exposure to PM<sub>2.5</sub> include respiratory problems, worsening of heart disease, decreased lung function and increased risk of developing cardiovascular and respiratory diseases such as asthma, chronic bronchitis and emphysema. In addition, high levels of PM<sub>2.5</sub> are associated with environmental problems such as reduced visibility and contribution to haze and smog formation (Ferreira Martins, 2016).

PM<sub>10</sub> particles can be inhaled and have the potential to affect human health and the environment (Monteiro et al., 2018).

Sources of PM<sub>10</sub> are similar to those of PM<sub>2.5</sub> and include the burning of fossil fuels in vehicles, power plants and industries, as well as activities such as biomass burning and soil dust. PM<sub>10</sub> particles can also be formed from chemical reactions in the atmosphere (Caiaffa et al., 2008).

Long-term exposure to PM<sub>10</sub> particles is associated with respiratory problems, worsening of lung and cardiovascular diseases, just like PM<sub>2.5</sub> particles. However, because PM<sub>10</sub> particles are larger, they tend to settle in the upper airways, such as the nose and throat, in greater quantities than PM<sub>2.5</sub> particles, which settle deeper in the lungs (Kwon et al., 2020).

As with PM<sub>2.5</sub>, many countries also set regulatory standards to limit PM<sub>10</sub> levels in the air to protect public health and reduce the negative impacts of air pollution. PM<sub>10</sub> levels are measured in grams per cubic metre (g/m<sup>3</sup>) and are an important indicator of air quality in a given region (Kucbel et al., 2017).

These ultrafine particles can remain suspended in the air for long periods of time and to travel long distances. When inhaled, UFP can penetrate deep into the lungs and, because of their size, even into the bloodstream and other organs of the human body (Kumar et al., 2013).

The main way in which UFP enter the body is by inhalation. During respiration, ultrafine particles can be transported through the upper and lower respiratory tract until they reach the alveoli of the lungs, where gas exchange takes place. However, it is important to point out that due to their tiny size, ultrafine particles can also pose health and environmental risks since they may behave differently from larger particles of the same material. Therefore, proper management and continuous research is needed to understand their effects and ensure the safe use of these particles in various applications(Kranjec et al., 2016).

From this perspective the assessment of ultrafine particles can be challenging due to several reasons, including:

**Small size:** The main difficulty is related to the extremely small size of ultrafine particles (in the nanometre scale). Detecting and measuring them requires specialised techniques and equipment(Sousa et al., 2021).

**Unique behaviour:** Ultrafine particles can behave differently compared to larger particles of the same material, due to their small size and high surface-to-volume ratio. This can affect their physical and chemical properties, making it necessary to understand these differences to properly assess their impacts (Kwon et al., 2020).

**Interactions with the environment:** The behaviour of ultrafine particles in biological or environmental systems can be complex and influenced by several factors, such as pH, temperature and the presence of other compounds. This makes it difficult to predict their effects and assess risks (Kranjec et al., 2016).

**Health effects:** Ultrafine particles have the potential to penetrate deep into the tissues of the human body due to their size, which may raise health concerns, especially when inhaled. However, there are still many uncertainties about the health effects of these particles, which makes assessment more challenging (Sanchez-Crespo, 2019).

**Lack of regulation:** The rapid evolution of ultrafine particle technology outpaces, in many cases, government regulation and guidelines that must be followed to ensure the safe use of these materials. Therefore, there may be gaps in regulations to address the potential risks associated with nanoparticles (WHO, 2021).

Detection and analysis methods: Traditional methods for analysing larger particles may not be suitable for ultrafine particles. Therefore, new detection and analysis methods need to be developed to adequately assess these particles (European Parliament and Council, 2022).

ISO 16000 deals with indoor air quality and the measurement of indoor pollutants. It covers various aspects of air quality, including the measurement of particulate matter. It provides guidelines for sampling, analysis and interpretation of results related to particulate matter.

This standard used in our studies, treats the methods for collecting particulate matter in a similar way for PM<sub>2.5</sub>, PM<sub>10</sub> and UFP. It describes the methods for quantifying concentrations. It is important to stress that these measurements are essential for assessing indoor air quality, especially in places where people spend long periods of time, such as offices, schools, hospitals and homes. ISO 16000-1 provides a technical and procedural basis for ensuring that measurements are accurate and reliable, so that air quality can be properly assessed and corrective action taken if necessary (WHO, 2021).

Considering the characteristics and difficulties in monitoring them, especially UFP, we cannot neglect the adverse effects of PM on human health. The main health problems associated with particulate matter are:

**Respiratory problems:** Fine particles can be inhaled deep into the lungs, causing irritation, inflammation and damage to the airways and lung tissues. This can lead to the development or worsening of respiratory conditions such as asthma, chronic bronchitis and emphysema (Kranjec et al., 2016).

**Cardiovascular diseases:** Fine particles can enter the bloodstream through the lungs and trigger inflammatory reactions in the cardiovascular system. This can increase the risk of heart diseases such as heart attacks, strokes, arrhythmias and high blood pressure (Araujo, 2011).

**Aggravation of existing health conditions:** People with pre-existing health conditions, such as respiratory or cardiovascular problems, are more susceptible to the effects of

particulate matter. Continued exposure can exacerbate these conditions, increasing the risk of complications and hospitalisations (Kuhnen et al., 2010).

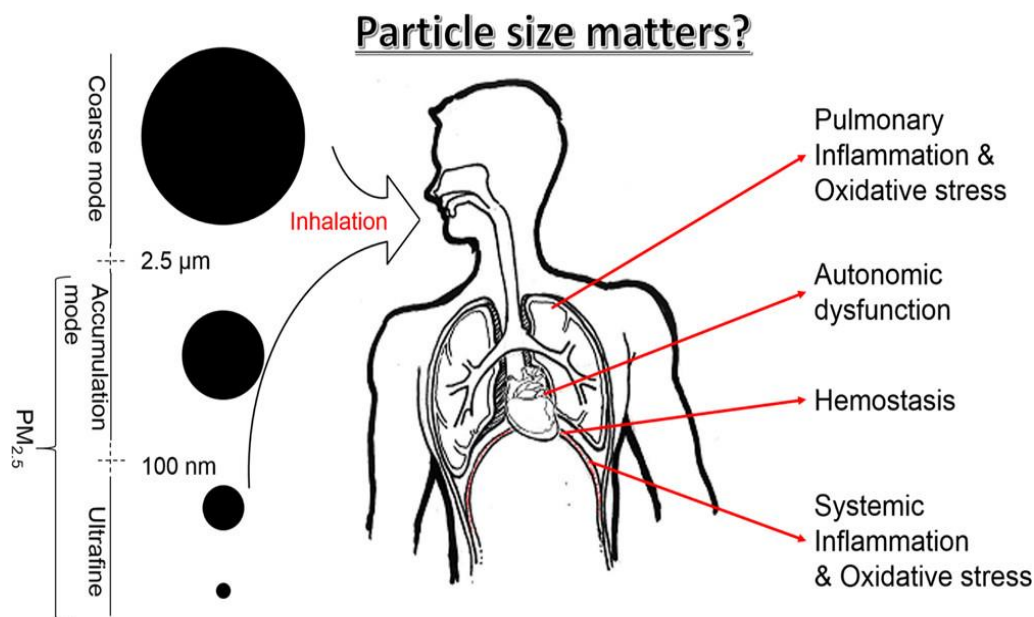
**Premature mortality:** Studies have linked chronic exposure to particulate matter to a significant increase in the risk of premature mortality. This is because fine particles can cause persistent damage to the body's internal organs and vital systems (Donaldson et al., 2001).

**Neurological effects:** Emerging research suggests that ultra-fine particulate matter can cross the blood-brain barrier and enter the brain, where it may be associated with neurological and neurodegenerative problems such as dementia and Alzheimer's disease (Manigrasso et al., 2019).

**Impact on children's health:** Children, especially those in the developmental stage, are particularly vulnerable to the negative effects of particulate matter. Exposure can affect the growth and development of the lungs and increase the risk of respiratory problems throughout life (Kranjec et al., 2016).

**Impact on reproductive health:** Exposure to particulate matter during pregnancy can be associated with obstetric complications such as preterm birth and low birth weight, as well as potentially affecting foetal development (World Health Organization, 2020).

Comparing health effects according to target organ - Figure 2.



**Figure 2**– Size comparison UFP, PM<sub>10</sub> and PM<sub>2.5</sub>.  
**Source** –Gong et al. (2014).

The central nervous system, cardiovascular system and the respiratory system are the most affected, we summarise the main effects that have been studied. It is important to note that research in this area is still developing and more studies are needed to establish a conclusive cause and effect relationship between exposure to ultrafine particles and specific effects. In addition, the potential health effects of ultrafine particles may vary depending on individual susceptibility, duration and intensity of exposure, and other factors (Calderón-Garcidueñas & Ayala, 2022).

Some potential effects of ultrafine particles on the central nervous system include:

**Neuroinflammation:** Ultrafine particles can induce inflammation in the brain, which can lead to activation of the immune system and contribute to neurological disorders (Wu et al., 2021).

**Neurodegenerative diseases:** There is some evidence that exposure to UFP may be associated with an increased risk of neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease (Zhao et al., 2015).

Cognitive impairment: Exposure to UFP has been associated with cognitive impairment, including memory and learning deficits (Gong et al., 2014).

Blood-brain barrier disruption: UFP may affect the integrity of the blood-brain barrier, allowing other potentially harmful substances to enter the brain more easily (Shang et al., 2021).

Some of the main effects of ultrafine particles on the heart and cardiovascular system include:

Systemic inflammation: UFP can trigger an inflammatory response in the body, including the cardiovascular system. Chronic inflammation has been linked to the development of cardiovascular diseases such as atherosclerosis (Lin et al., 2022).

Endothelial dysfunction: UFP can affect the function of the endothelial cells that line blood vessels. A healthy endothelium is important for maintaining proper vasodilation and vasoconstriction and for preventing excessive blood clotting. Endothelial dysfunction can lead to an increased risk of heart disease (Poulsen et al., 2023).

Increased risk of acute cardiovascular events: Studies suggest that exposure to UFP may be associated with an increased risk of acute cardiovascular events such as heart attack and stroke. Inflammation and endothelial dysfunction are thought to play a role in this increased risk (Lin et al., 2022).

Worsening of pre-existing cardiovascular disease: People with pre-existing cardiovascular conditions, such as heart failure or coronary artery disease, may be particularly vulnerable to the effects of UFP. Exposure to these particles may worsen the progression of these conditions and increase the risk of complications (Gong et al., 2014).

Changes in heart rhythm regulation: Some studies have suggested that exposure to UFP may be associated with changes in heart rhythm regulation, such as arrhythmias. This may be of particular concern in people with underlying heart disease (Møller et al., 2020).

High blood pressure: Exposure to ultrafine particles has been associated with increased blood pressure in some studies. Hypertension is an important risk factor for cardiovascular disease (Møller et al., 2020).

It is important to stress that the effects of UFP on the heart and cardiovascular system may vary depending on the concentration of particles in the air, the time of exposure, the general health of the individual and others. For people with pre-existing cardiovascular conditions or other risk factors, it is particularly important to take steps to improve indoor and outdoor air quality, such as avoiding areas with high levels of air pollution, using air filters and seeking medical advice for proper management of health conditions factors (Downward et al., 2018; Marmot, 2005; Møller et al., 2020).

Some of the main effects of UFP on the lungs and airways are:

Pulmonary inflammation: UFP can cause inflammation in the lungs, triggering an immune system response that attempts to remove the invading particles. Chronic inflammation can damage lung tissue and, in some cases, lead to chronic respiratory diseases such as chronic bronchitis (Cohen et al., 2012; Kumar et al., 2013).

Exacerbation of pre-existing respiratory conditions: People with pre-existing respiratory conditions, such as asthma or chronic obstructive pulmonary disease (COPD), may experience a worsening of their symptoms due to exposure to ultrafine particles (D'Amato, 2000).

Increased risk of respiratory tract infections: Inflammation and immune system dysfunction caused by exposure to ultrafine particles may make the lungs more susceptible to respiratory infections such as pneumonia and bronchitis (Graham, 2009).

Oxidative damage: UFP can induce oxidative stress in the lungs, leading to the formation of reactive oxygen species, which can damage lung cells and contribute to respiratory disease (Marcias et al., 2018).

Access to the cardiovascular system: As well as directly affecting the lungs, ultrafine particles can enter the bloodstream and be transported to other organs, including the heart, increasing the risk of cardiovascular disease (Kumar et al., 2013; Marcias et al., 2018; Poulsen et al., 2023).

The impact on general health should also be noted, as chronic exposure to ultrafine particles can have systemic health effects, affecting not only the lungs and respiratory tract, but also other organs and systems.

To address these issues, coordinated actions by governments, organisations and individuals are needed to reduce particulate matter emissions and exposure. This includes implementing stricter regulations on air pollutants, promoting cleaner energy sources, and taking personal measures such as avoiding highly polluted areas and wearing masks in risky environments.

This problem, associated with the fact that there are no legal standards or references that allow the control of exposure, and the establishment of protection limits led us to challenge ourselves to conduct a review of scientific literature to summarise the health effects, generation and measurement of ultrafine particles in indoor environments. Comparing such characteristics with those of environments higher PM fractions. The study focuses on UFP generated daily by occupational activities.

Thus, in order to understand the interaction and variations in the occupational environment, we analysed several sites and parameters with the aim of verifying the behaviour essentially of UFP, given their erratic behaviour, which is still relatively unknown and an emerging risk for the population.

This thesis is organized into four chapters: the first one is a literature review; the second one is a global characterisation of ultrafine particles assessment and monitoring; the third one presents a study of occupational exposure in different activity sectors; finally the conclusions. The aim is to address the issue of particulate matter in a first phase and then to verify the specific problem of ultrafine particles and their known effects on human health.

What follows is a description and justification of how the various chapters were written, in the form of papers submitted to refereed journals. These were naturally born out of the evidence gathered and the desire for more complete and realistic information.

## LITERATURE REVIEW OF ULTRAFINE PARTICLES

The systematic literature review aims to use a rigorous and systematic approach to collect, analyse and synthesise existing research evidence on UFP, which we know are not yet widespread and expected. It allowed us to understand the state of scientific knowledge and approaches, both in terms of scientific development, forms of risk assessment and existing standards and legislation.

It was extremely important to create a synthesis of evidence by gathering a valuable base of information and knowledge from relevant studies on the subject under review. Combining the results of these studies provided a comprehensive overview of the available evidence on UFP, from their generation, persistence in the environment, assessment methods and health effects. This approach guided the research team in developing the research questions. It was carried out on the basis of clearly defined research questions:

- What are ultrafine particles?
- How are they produced?
- How do they behave?
- How can we assess them?
- What is their impact on public health?
- What is their impact on the occupational health?

It also made it possible to identify gaps in knowledge by identifying gaps in the existing literature, highlighting areas where there is a lack of research or where results are inconsistent, analysing the quality of studies through a critical appraisal of the studies found, and thus sorting and separating based on the quality and reliability of the evidence available.

It has also given direction to research by identifying gaps in knowledge, inspiring us to conduct additional studies to answer important questions and complement existing knowledge.

## WORLDWIDE SURVEY AND CHARACTERIZATION OF ULTRAFINE PARTICLE EXPOSURE MONITORING AND ASSESSMENT

The intention to create the global questionnaire arose during the literature review, as it did not provide clear answers regarding the standardisation of methodologies, references or regulations used for monitoring, risk assessment and control of UFP. This was not possible in a clear and obvious way in the reviewed articles. Therefore, the intention was to create a global questionnaire that would allow us to know how assessments are carried out around the world and whether there are standards or legislation used. Therefore, the primary objective was to develop and disseminate a global questionnaire to address this lack of information by creating a set of questions that would allow us to identify the knowledge, monitoring and risk assessment of UFP. How this knowledge is processed in terms of indoor air quality and occupational exposure. This set of questions also covered whether or not there were standards and legislation for this assessment and who was carrying it out. This questionnaire was then developed and, after pilot testing, sent to various sites around the world. It was sent to various institutions working on air quality assessments

This questionnaire was important because it allowed for a broad approach and provided an overview of the questions asked. It allowed for a methodologically sound survey and reliable and representative results from the study population.

## OCCUPATIONAL EXPOSURE TO ULTRAFINE PARTICLES IN DIFFERENT SECTORS OF ACTIVITY

The evaluation of UFP was then carried out in four different workplaces. The literature search carried out always shows localised and perfectly defined assessments. We therefore wanted a cross-sectional study that would allow us to verify the behaviour of UFP in different sectors of activity. It was decided to carry out the study in two companies with particulate matter, a carpentry and a bakery, and two others without high level of particulate matter, a school and a Clinic Laboratory. Our main intention was to understand the existence and behaviour of particles in these two places. Monitoring their activities by assessing the existence or not of ultrafine particles. It was intended to understand if the occurrences would arise with the primary formation or if there were other possibilities for their occurrence. It also allowed us to understand the

behaviour of particles in very different sectors of activity with a main focus on occupational health. We were primarily concerned with what the occupational occupation and activity was in each of these locations.

The literature consulted on air quality in bakeries, particularly those handling cereal flours and various additives, including enzymes, chemicals, flavourings and contaminants. These components can cause health problems in bakery workers, such as respiratory, skin and conjunctival reactions, the most serious being Occupational asthma. Exposure to flour dust can cause symptoms such as rhinitis, conjunctivitis, chronic bronchitis and bronchial obstruction. The studies consulted show that a significant proportion of exposures to flour dust exceeded the occupational exposure limit values and that action is needed to reduce exposure. In artisanal bakeries, the total particulate fraction consisted mainly of particles with an aerodynamic diameter of less than 1  $\mu\text{m}$  and more than 10  $\mu\text{m}$  (Chou et al., 2023; Karjalainen et al., 2022).

Air quality in carpentry shops can vary depending on several factors, including the type of work performed, the materials used, and the safety practices adopted. Carpentry often involves cutting, sanding and processing wood, which can generate dust,  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  and chemicals from varnishes, glues and other products used in wood finishing. Prolonged exposure to airborne particles and volatile chemicals can have negative impacts on workers' health, causing respiratory problems, allergies, eye, nose and throat irritations, as well as more serious complications in extreme cases (Law et al., 2018).

School buildings typically pose considerable challenges to meet demanding and interrelated design requirements in terms of high occupant density, indoor air quality (IAQ) and energy performance. Ensuring indoor air quality indoor air quality is essential. The various indoor air pollutants in schools include biological contaminants, carbon dioxide, carbon monoxide, dust, fine particles and others. Typical sources of indoor air pollution in school buildings are diverse: emissions from building materials, paints, varnishes, solvents, combustion products from heating, products derived from the activities of building occupants, biological sources, etc. In schools, PM concentrations are usually higher indoors than outdoors, especially when particulate sources have been replaced in the immediate neighbourhood (attributed to gas and coal cookers for cooking, boilers for space heating, tobacco and smoking, as well as

situations demonstrated in several studies. They usually do not have direct sources of PM formation (Angela et al., 2021; Ielpo et al., 2021; Ray, 2022).

Air quality in Clinic Laboratorys depends not only on outdoor sources, but also on activities in these locations. Contaminants and their assessment and identification are essential in hospitals to prevent harm to both patients and staff. Moulds and dust can cause air quality to deteriorate. Maintaining air quality is of paramount importance in hospitals. The studies consulted have no indication of large indoor sources of particulates in the working areas related to the operation. There are many possibilities for pollutants but not for dust (Eshleman et al., 2017a; Graham, 2009; Hancock, 1986; Kumar et al., 2013).

In this phase, we determined the parameters to cross-check. We decided to monitor UFP, PM<sub>2.5</sub>, PM<sub>10</sub>, CO<sub>2</sub>, CO, temperature, and relative humidity. These parameters are primary sources of UFP, and in the case of PM<sub>2.5</sub> and PM<sub>10</sub>, they are also precursor sources of UFP.

The interactions are:

- Ultrafine particles and particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) are interrelated due to their common origin and the transformations that occur in the atmospheric environment. They may have a common origin: Particulate matter is a complex mixture of solid and liquid particles suspended in air, originating from a variety of sources, including natural processes and human activities. Ultrafine particles are part of this particulate matter and are also produced from these sources. They can also undergo transformations where ultrafine particles can transform into larger particles through condensation or coagulation growth mechanisms, contributing to the increase in mass of PM<sub>2.5</sub> and PM<sub>10</sub>. In addition, PM<sub>2.5</sub> and PM<sub>10</sub> particles can also be fragmented into ultrafine particles due to mechanical or chemical processes in the atmospheric environment. Therefore, the formation of ultrafine particles and the presence of PM<sub>2.5</sub> and PM<sub>10</sub> are closely related, with complex interactions between these particles of different sizes. Understanding these relationships is essential to mitigate health and environmental impacts and to develop effective air pollution control strategies (Audignon-Durand et al., 2021; Marval & Tronville, 2022; Pasquiou et al., 2021; Sousa et al., 2021).

- UFP - CO - The formation of ultrafine particles is related to several emission sources, including the incomplete burning of fossil fuels, such as carbon monoxide (CO). The formation of ultrafine particles usually occurs as a result of complex particle nucleation and growth processes. In the specific case of carbon monoxide, the formation of ultrafine particles can be related to nucleation, oxidation and condensation, and particle growth: As ultrafine particle nuclei form, they may grow through condensation of gaseous precursors or by absorption of other atmospheric compounds such as sulphates, nitrates and salts, contributing to the growth of the ultrafine particles into larger particles (Cassee et al., 2019; Marcias et al., 2019).
  
- UFP - CO<sub>2</sub> - The relationship between these pollutants is complex and multifaceted. The main points of connection between these two phenomena is the possibility that they have the same origin, such as the burning of fuels or other diverse sources such as vehicle emissions, industrial processes, biomass burning, atmospheric chemical reactions. They can also be generated as secondary products, as in some situations carbon dioxide can be indirectly linked to the formation of ultrafine particles. For example, in industrial processes or in internal combustion engines, the burning of fossil fuels releases carbon dioxide and other gases, and these emissions can interact with volatile organic compounds (VOC) to form ultrafine particles through photochemical reactions in the atmosphere. Effects of measures to increase energy efficiency, for example measures taken to minimise heat exchange in buildings and improve the efficiency of air-conditioning in spaces, which sometimes impairs the ventilation of spaces. Current climate changes also promote the increase of carbon dioxide concentration in the atmosphere contributing to global warming and climate change. These changes can affect the formation and behaviour of ultrafine particles in the atmosphere, influencing their distribution and impact on health and the environment (Kwon et al., 2020; Sousa et al., 2021).

- UFP - Temperature - The relationship between ultrafine particle formation and temperature is a complex and widely studied phenomenon as temperature can affect the formation, growth and stability of ultrafine particles in several ways. The main interactions are Nucleation as UFP formation usually starts with this process. Nucleation is the initial phase in which individual molecules or atoms aggregate to form small nuclei that can grow into larger particles. The rate of nucleation is highly dependent on temperature, lower temperatures favour the nucleation of ultrafine particles as the thermal energy is lower and molecules are more likely to clump together to form nuclei. It also allows particle growth as the growth rate of UFP is also affected by temperature. Higher temperatures can lead to faster growth rates, while lower temperatures can result in slower growth. In addition, temperature influences the final particle size and may favour the formation of ultrafine particles over larger particles, depending on the environmental conditions. The stability of ultrafine particles is also related to temperature. Higher temperatures can cause greater agglomeration and coalescence between particles, reducing the number of ultrafine particles present in the system. In summary, temperature plays a critical role in the formation, growth, stability and behaviour of ultrafine particles (Donaldson et al., 2001; Kembel et al., 2012; World Health Organization, 2020).
  
- UFP - Relative humidity - The formation of ultrafine particles can be related to the relative humidity (RH) of the environment in which these particles are generated. Relative humidity is a measure that indicates the amount of moisture present in the air relative to the maximum amount that the air can contain at a given temperature. It is expressed as a percentage. The relationship between relative humidity and the formation of ultrafine particles is often associated with the following phenomena: coagulation, relative humidity can influence the rate of coagulation of ultrafine particles, this process in which particles collide and stick together to form larger particles. Humidity can affect the likelihood of collisions between particles and hence the rate of coagulation. Some ultrafine materials are hygroscopic, which means that they have an ability to absorb water from the environment. This can result in growth of the ultrafine particles in environments

with high relative humidity. It can also influence the chemical reactions influenced by humidity: as the presence of water vapour can influence the chemical reactions that lead to the formation of ultrafine particles. In some cases, reactions that produce particles can be catalysed or accelerated in the presence of humidity (Bocconi et al., 2021; Boudjema et al., 2021; Donaldson et al., 2001; Eshleman et al., 2017b; Kembel et al., 2012; World Health Organization, 2020).

Importantly, the formation of ultrafine particles is influenced by a variety of other factors, including the availability of gaseous precursors, ambient temperature, humidity and the presence of other air pollutants (Manigrasso et al., 2019).

## CHAPTER I

### ULTRAFINE PARTICLES - FORMATION, CONTAMINATION AND HEALTH EFFECTS – A LITERATURE REVIEW

*In this chapter, which has been submitted in a peer-reviewed, SCOPUS-indexed international scientific publication, the general aspects of the literature search that supported the study will be addressed, with evidence for the published scientific articles with peer review. For this purpose, the Prisma methodology and the IramuTeq software were used, which assisted in the search for more evident terms and fundamentals. Next, a framework was carried out regarding the problematic training and possible health impacts.*

#### **1.1.Introduction**

According to health guidelines, as the population grows, with 54% of the world's population currently living in urban areas, most residents live in cities with inadequate air quality. In fact, in the last two decades, several studies show that air pollution, especially in urban environments, has become a major concern (Kwasny et al., 2010; Kwon et al., 2020).

In addition to poor outdoor air quality the top five environmental risks to public health is indoor air pollution, with pollutant levels inside buildings being two to five times higher than outdoors, and in extreme cases, being 100 times higher. Currently, society spends much of its day indoors, in personal and occupational activities making these levels of contamination of great importance(Knibbs & Morawska, 2012;Nunes, 2018).

Indoor air pollution can be characterized by the presence of chemical, physical or biological pollutants in the indoor air of buildings, such as in schools, offices, homes and commercial and service buildings and also inside the means of transport (Marval & Tronville, 2022). The characterisation of indoor sources is much less defined. Buildings provide moderate but incomplete protection against outdoor UFP. The infiltration of outdoor UFP is quantified by the infiltration factor, which in turn depends on several parameters, such as building construction characteristics, air exchange mechanisms, outdoor meteorological conditions and indoor air circulation (Bocconi et al., 2021). Other sources that contribute to increased indoor air pollution are outdoor air, smoke, cleaning activities, humidity, and proximity to main roads and industrial activities (Moreno et al., 2019).

Ultrafine particles are generally defined as the fraction of particles with a diameter of less than 100nm and, due to their size, they manage to enter the bloodstream, causing several adverse effects on the health of the population, using inhalation as the main route of entry into the body (Marcias et al., 2019). Several epidemiological studies associate the presence of ultrafine particles in the atmosphere with total mortality, respiratory and cardiovascular causes, acute airway inflammation, compromised lung function, and increased asthma symptoms. These particles in the outdoor environment are formed through natural and anthropogenic sources that can enter the indoor environment through ventilation (Monteiro et al., 2018; Viitanen et al., 2017) and can enter the human body by inhalation, through the respiratory tract; by absorption, through the skin; by ingestion, through the mouth or a combination of these. It is very likely that inhalation is the most important route of human exposure to these particles. In this way, and due to their size and other characteristics, ultrafine particles can reach the alveolar region, giving rise to inflammatory processes in the lungs and subsequent cardiovascular morbidity and mortality (Jordakieva et al., 2018).

Bearing in mind that society spends a lot of time in closed spaces, it is important to monitor the air quality, as well as implement preventive measures, in order to safeguard human health (Bourdrel et al., 2017).

## **1.2.Methodology**

A SLR was carried out in order to find, select, analyze and systematize information on Ultrafine Particles. This information was published in recent research papers focusing on UFP in the occupational environment and their impacts on human health.

SLR are based on a replicable, scientific and transparent process that comprises a logical sequence (Snyder, 2019):

- Planning the review process;
- Carrying out the review;
- Elaboration and dissemination of the results obtained.

Through SLR, it is possible to synthesize knowledge about the topic that is intended to be deepened, identifying research trends, as well as the gaps that exist and ways to fill them.

In the first stage of this SLR, the planning of the review process was done by selecting the keywords and topics to be addressed. Using three online research database: B-on, Science Direct and Web of Science were then consulted. According to the objective of the present study, keywords used were UFP or Ultrafine Particles combined with Occupational Health and Health Effects, considering the aim of the thesis. The selection criteria for studies focusing on Ultrafine Particles (UFP) included peer review, a combination of keywords, and articles published after 2002.

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology is a set of guidelines that aims to improve the quality and transparency of systematic reviews and meta-analyses in the scientific literature. It is a widely used tool to ensure consistency and improve the presentation of systematic reviews, making it easier for readers to assess the validity and reliability of the results.

The main steps of the PRISMA methodology are:

1. Protocol Development: Defining a detailed protocol before starting the systematic review is essential. The protocol should include the eligibility criteria of the studies, search strategy, data extraction and analysis.

2. Search Identification: Describe the search sources used, such as databases, online libraries, and other means of identifying relevant studies.
3. Selection Criteria: Specify the inclusion and exclusion criteria of the studies, such as the type of study, target population, intervention or exposure, outcomes and publication period.
4. Selection Process: Detail the strategy for selecting studies, including the initial screening process based on titles and abstracts and the full assessment of relevant articles.
5. Data Extraction: Explain how data will be extracted from the selected studies, including information on participants, interventions, outcomes, methodology and results.
6. Assessment of Risk of Bias: Describe the approach to assessing the risk of bias in individual studies as well as the overall quality of the evidence.
7. Synthesis of Results: Present the results of the studies included in the review clearly and objectively, using tables, graphs and meta-analyses to combine the quantitative data.
8. Appraisal of the Quality of the Evidence: Consider the overall quality of the evidence and provide an assessment of the servitude (degree of confidence) in the outcome estimates.
9. Discussion and Conclusions: Interpret the results, highlighting clinical or practical implications and providing recommendations for future research.

PRISMA also recommend that authors report the sources of funding for the review, any potential conflicts of interest, any acknowledgements, and a complete list of references (Snyder, 2019).

We therefore turned to three scientific search engines:

B-On - The Online Knowledge Library (b-on) is an initiative that offers unlimited, permanent access to the full texts of thousands of scientific journals and eBooks online from renowned content providers. Through nationally negotiated subscriptions, it provides access to higher education and research institutions, enabling them to enjoy a vast range of scientific information.

Launched in March 2004, b-on already had a large collection of scientific publications available at that time and has since become a reference in access to international scientific information. It brings together institutions of different typologies, such as higher education, scientific research, technological development, hospitals, public administration and private non-profit organisations.

The main mission of b-on is to ensure that the academic and scientific community has access to a variety of electronic journals and services, providing them with an environment conducive to the pursuit of knowledge and the realisation of advanced research. This initiative plays a key role in the advancement of scientific knowledge in Portugal, promoting collaboration and the dissemination of relevant information ([www.b-on.pt](http://www.b-on.pt) in 09/10/2022).

Pub-Med - PubMed is one of the largest and most important bibliographic databases specialising in scientific publications in the biomedical and life sciences fields. Maintained by the National Center for Biotechnology Information, a part of the US National Institutes of Health, the platform has become a key resource for researchers, health professionals, students and others interested in finding relevant information related to medical, biological and health topics.

The comprehensiveness of the database is remarkable, covering a wide range of sources, including scientific journals, periodicals and academic literature published worldwide. The process of including articles in PubMed involves peer review, which means that they undergo rigorous evaluation by other experts before being published. This ensures the quality and reliability of the content available on the platform.

PubMed offers an advanced search interface, allowing users to utilise keywords, filters and other options to refine search results. The ease of access to articles and abstracts, free of charge, makes the platform highly accessible and useful to the community at large.

Since 1994, PubMed has established itself as an essential source for health professionals, scientists, students and anyone seeking to keep up to date with the latest research and advances in the biomedical and life sciences fields. Its contribution to the advancement of scientific knowledge is invaluable, enabling the sharing of important

discoveries and driving progress in these areas crucial to the health and well-being of society.

Over time, PubMed has established itself as an essential source for health professionals, scientists, students and anyone seeking to keep up to date with the latest research and advances in the biomedical and life sciences fields. Its contribution to the advancement of scientific knowledge is invaluable, enabling the sharing of important discoveries and driving progress in these areas crucial to the health and well-being of society (<https://pubmed.ncbi.nlm.nih.gov> in 09/10/2022).

The Web of Science (formerly known as Web of Knowledge) is a website that provides subscription-based access to multiple databases that provide comprehensive citation data for many different academic disciplines. It was originally produced by the Institute for Scientific Information (ISI) and is currently maintained by Clarivate Analytics. Web of Science is described as a unifying research tool that allows the user to acquire, analyse and disseminate database information in a timely manner. This is realised due to the creation of a common vocabulary, called ontology, for varied search terms and varied data. In addition, search terms generate related information across categories. Acceptable Web of Science content is determined by an evaluation and selection process based on the following criteria: impact, influence, timeliness, peer review, and geographic representation (Boccuni et al., 2021). Web of Science employs several search and analysis capabilities. First, citation indexing is employed, which is enhanced by the ability to search for results across disciplines. The influence, impact, history and methodology of an idea can be followed from the first instance, notice or reference to the present day. This technology points to a deficiency of the keyword-only search method.

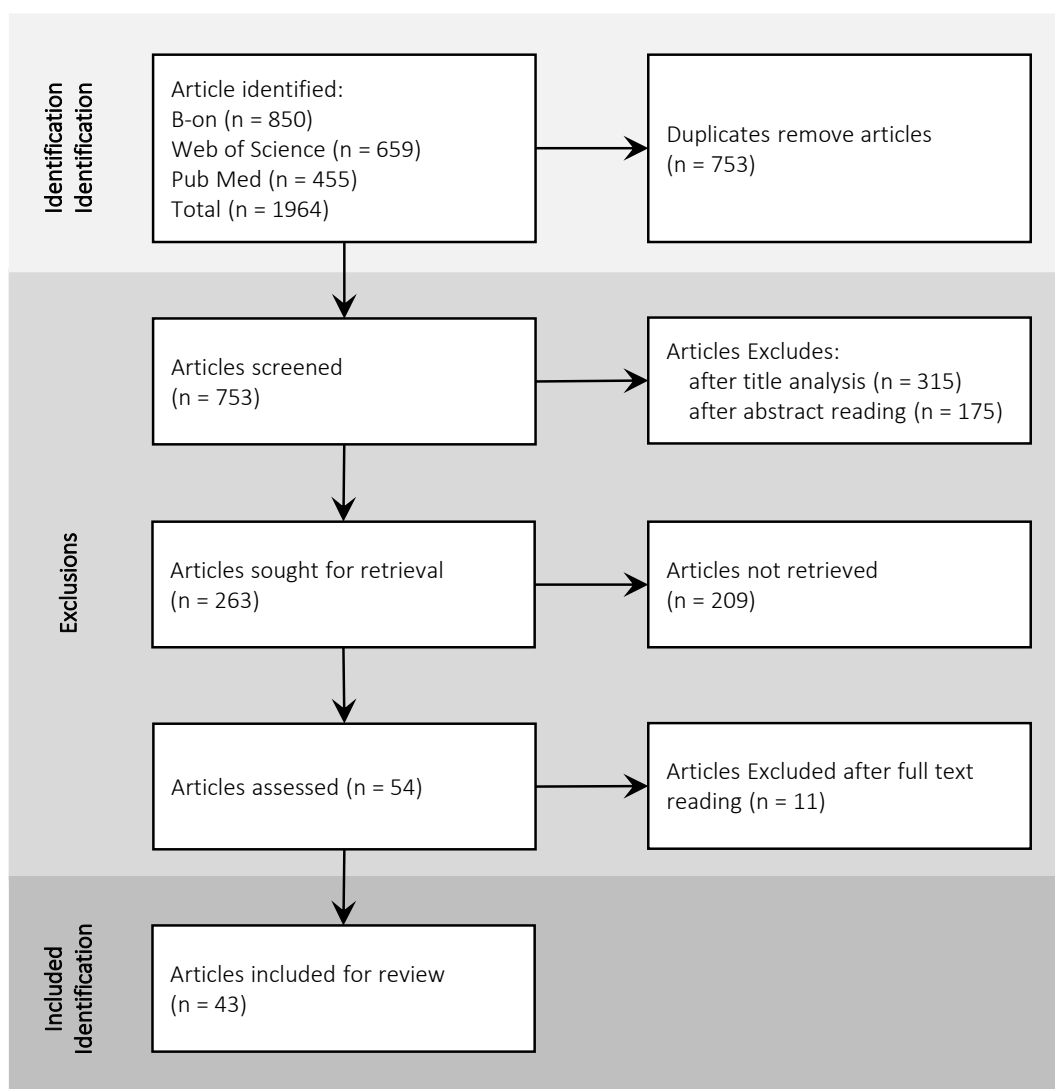
The Web of Science, formerly known as Web of Knowledge, is a subscription website offering access to several databases that provide comprehensive citation information across multiple academic disciplines. Initially developed by the Institute for Scientific Information (ISI) and currently maintained by Clarivate Analytics, Web of Science is considered an integrative research tool, allowing users to acquire, analyse and disseminate information from the database in an agile manner.

This goal is achieved through the creation of a common vocabulary, called ontology, which standardises search terms and various data. By standardizing search terms, related information is generated across categories, making it easier to navigate and discover relevant connections.

Acceptable content in Web of Science is selected through an evaluation process based on criteria such as impact, influence, timeliness, peer review and geographic representation. This ensures the quality and relevance of the information available on the platform.

Web of Science offers several search and analysis tools, including citation indexing, which allows you to search for results across all disciplines. This functionality allows tracking the influence, impact, history, and methodology of ideas from their first instance, notice or reference to the present day. This approach overcomes the limitations of the traditional search method based on keywords alone ([www.webofscience.com](http://www.webofscience.com) in 10/10/2022).

The PRISMA flow diagram for the present SLR is shown in Figure 3.



**Figure 3**– PRISMA flow diagram for the present SLR.

The search in the bibliographic bases was carried out in November and December 2022, and a total of 1964 records were found, reduced to 668 articles after removing duplicates. The first screening of articles derived from 753 articles after removing duplicate records. The first screening of articles derived from a title, excluding those that did not specifically focus on Ultrafine Particles from a title analysis, then those that did not fit with effects in occupational health area and later with effects on health were excluded. This step reduced the sample to 263 articles. Afterwards, the abstracts were read, at this stage it was reduced to 43 articles, which were later used in full.

### **1.3.Results**

For the SLR textual analysis, we also used the application IraMuTeq - Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires. This is a free tool for the analysis of textual and questionnaire data. It has been developed in R, a programming language widely used for statistical analysis and data visualisation. Was used as a tool to provide text analysis of keywords and abstracts. It is based on Software R and the python programming language and was developed in 2009 by Pierre Ratinaud.

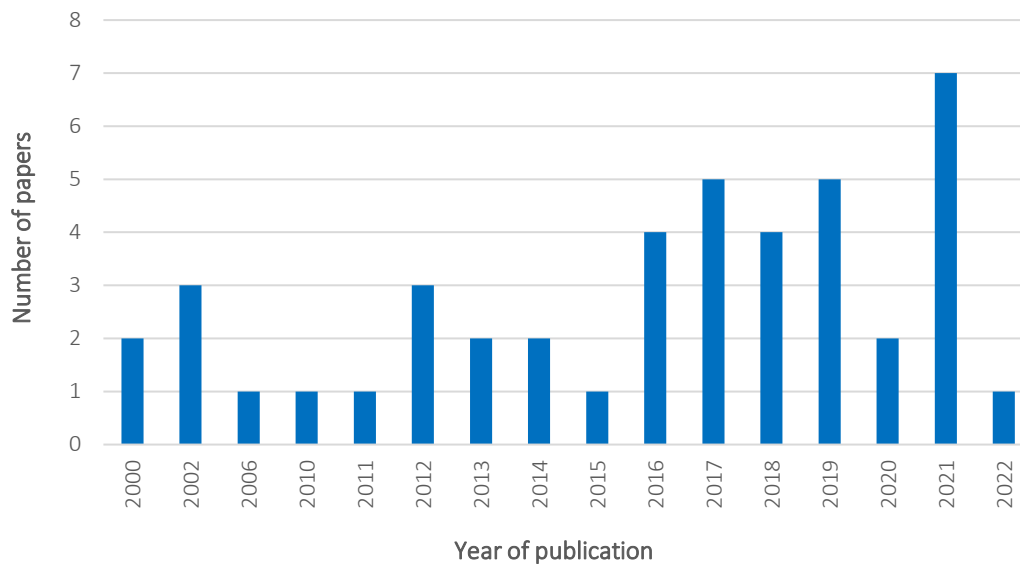
The IRAMUTEQ application is particularly useful for researchers, social scientists and students who want to extract meaningful information from large textual datasets, such as interviews, open-ended survey responses, social media texts, and others. The tool allows qualitative and quantitative analysis to be carried out in a systematic and efficient manner.

IRAMUTEQ is a powerful text analysis tool that provides valuable insights for researchers who want to explore and understand qualitative and quantitative data in an integrated way. It is a useful option for studies in health, social sciences, psychology, communication, cultural studies and other fields that involve the analysis of textual data.





of the study could give the investigation team the background of the areas we can investigate.



**Figure 6** – Count publication year.

If we analyse Figure 6, we can see the distribution of the year of publication. The largest number of articles, seven, were published in 2021. Most articles were published between 2016 and 2019, with fewer articles published in 2020. This probably explains the even greater interest in the subject of theme.

These are the focus articles found in the bibliographic research consulted after these schematic analyses we have a close lecture of the texts can improve knowledge above the peculiarities, differences between IAQ and Occupational Exposure, and the generation of the UFP.

#### **1.4. Ultrafine particles peculiarities and health effects**

Particles the same size as UFP may be introduced purposely to benefit from their unique nanoscale capabilities, in addition to being released accidentally as a result of the chemical and physical changes that materials go through. They are known as nanomaterials and nanoparticles in this situation. Nanomaterials are defined as "Any form of a material that is composed of discrete functional parts, many of which have

one or more dimensions of the order of 100 nm or less" and "A discrete entity which has three dimensions of the order of 100 nm," respectively (Commission, 2005).

The production of ultrafine particles in the atmosphere involves several steps. The new process of ultrafine particle formation may produce such particles. It involves the creation and formation molecular clusters and the ensuing expansion of such clusters to bigger sizes. Recognizing the initial stages of atmospheric aerosol formation requires an in-depth knowledge of neutral and charged the gaseous components, chemical makeup, and cluster densities involved in their development and creation (Marval & Tronville, 2022).

The main feature of the UFP is that they are rapidly evolving, especially in their smaller fractions <20 nm. These particles move in diffusion-based motions via concentration gradients, so in situations with a high concentration number near emission sources, UFP easily collide with adjacent particles to coagulate into particles larger or settle on available surfaces. Moreover, particle growth mainly occurs due to the coagulation and condensation of Semi-Volatile Organic Compounds (SVOC) on the particle surface. Consequently, UFP have very short atmospheric lifetimes, generally on the order of a few hours, and their concentrations decrease rapidly (Kwon et al., 2020).

Understanding the first stages of formation of particles and aerosols requires knowledge of their formation process, as well as the cluster of physicochemical composition and aerosols. The first step of formation is nucleation with stable nuclei, of very small size, less than 2 nm, therefore very difficult to detect with the instruments used in current assessments. Thus, gaseous components such as Volatile Organic Compounds (VOC), and SVOC, interact with each other to form new nuclei or else they condensed with existing nuclei (Marval & Tronville, 2022).

The next process is coagulation, which we can define as the creation of a new particle resulting from the collision between two. These newly formed particles, an ultrafine particle, in the case of solid particles we call agglomeration and the resulting particles we determine as agglomerates (Zhao et al., 2015).

Exposure to particulate matter has been pointed out by experts as a possibility for the development of various diseases, from changes in lung function, inflammation of the

upper respiratory tract, increased allergic reactions, vascular thrombosis, changes in heart rate, brain inflammation, are pathologies identified in recent studies. These are consistent with exposure to particulate matter, which is fine or ultrafine, except for the cerebral ones which are more consistent in brain pathologies (Glantz, 2002).

Mass-based measurement of UFP using current technologies is challenging due to the extremely low mass of UFP. However, to demonstrate compliance with regulatory requirements, measurements of particle number or areal concentrations alone are not sufficient because mass balance is not stored or reported in any of the units alone (Viitanen et al., 2017).

Exposure to UFP can reduce vascular reactivity and significantly reduce venous nitric oxide (NO) concentrations. The impact of these delayed and cumulative effects of UFP pollution is also debatable; the cumulative effects of high levels of UFP over 5 days are stronger than the health effects that appear shortly after exposure. This exposure is associated with a decrease in the electrical activity of the heart, which can lead to myocardial infarction (Kranjec et al., 2016). Long-term exposure studies have investigated the cardiovascular effects of air pollution after annual variations in pollutant concentration, most studies have extrapolated the level of individual exposure to air pollution, in taking into account background concentrations of pollutants or exposure to road traffic in the home (Bourdrel et al., 2017).

The pro-inflammatory effects caused by exposure to UFP, through the oxidative stress response and with the formation of Reactive Oxygen Species (ROS), stimulate the progression of atherosclerosis and the precipitation of the cardiovascular response acute, which involves all responses from increased blood pressure to myocardial infarction and heart attack. In addition to the effect on the development of respiratory and cardiovascular diseases, UFP have other effects on human health, such as increasing levels of neutrophil biomarkers of inflammation. In patients with chronic respiratory diseases, exposure to UFP may induce a white blood cell (monocyte) immune response. UFP can modify the structure of Deoxyribonucleic acid (DNA). The contradictory effects of UFP stem, in part, from increased oxidative stress in tissues and their subsequent impairment of alveolar macrophage phagocytic capacity and phagocytic activity (Kranjec et al., 2016).

After entering the respiratory system, UFP is potentially translocated to the heart, liver and brain within minutes of being inhaled. Instead, larger particles are usually detected only in lung tissue and less likely in blood. We can conclude that UFP could reach the brain by entering directly through the olfactory bulb. Several studies have found a direct correlation between exposure to the ultrafine fraction and permanent DNA damage, as cells are subjected to systemic oxidative stress (Marval & Tronville, 2022).

### **1.5.Occupational vs. Indoor human exposure to the ultrafine fraction**

UFP are widely distributed in both indoor and outdoor environments, hence the proper indicator of their presence is their numerical concentration. Due to their size being similar to those of cellular structures, these particles may have an effect on targets inside of cells. They can also be disseminated through the blood circulation to peripheral organs thanks to their small size, which enables them to enter the respiratory system and do so with high efficiency all the way to the alveolar region. These particles surface area is a significant physical characteristic with potential health implications. Due to its capacity to absorb harmful compounds and transport them into the body, this parameter is significant (Manigrasso et al., 2019).

Almost any type of indoor activity produces a considerable amount of UFP. Thus, and according to the review of the literature, it can be said that combustion, electrical heating and cleaning are the main generators of UFP, at the level of IAQ. They also demonstrated that internal particle events are intermittent and highly variable, requiring the uninterrupted use of instruments for their characterization (Marval & Tronville, 2022).

In working environments, UFP are generated in processes involving high temperatures, in combustion, and in mechanical processes involving massive energies. Typical examples of this are respectively welding, motors and grinding. Other indoor sources in the workplace are, for example, the kitchen, office supplies and building materials. The formation and dynamics of interior UFP are described and generally occur through the nucleation of vaporized compounds or as primary particles from combustion sources. Additionally, apart from the work environment, UFP are formed from both natural and anthropogenic sources (Viitanen et al., 2017).

UFP from external sources can enter the working environment through ventilation, which in turn influences the overall exposure load of workers. In general, exposure levels in the workplace can be higher than exposure levels in the environment and therefore the risk for some groups of workers can be higher than the average risk for the general public. In recent years in particular, the emerging industry around electrical vehicles has drawn attention to worker exposure to ultrafine sized particles. Workers can be exposed different types of UFP: engineered nanoparticles; incidental engineered nanoparticles have been measured in several workplace studies. Articles have been written on the subject (Suwa et al., 2002).

### **1.6.Generation of ultrafine particles**

In residential and commercial buildings, almost all activities are a potential source of UFP. Several studies have analysed UFP generation from everyday activities such as cooking, smoking, lighting candles, cleaning, spraying, ironing, electrical heating, vacuuming, digital and 3D printing. When assessing the UFP generation associated with a given event, in addition to the particle number concentration, it is necessary to assess the time required to reach the highest particle concentration and the time required to return, again to the background particle concentration. These parameters are essential to understand the behaviour of the particles generated by the event and to assess the dose correlated to such exposure to UFP (Marval & Tronville, 2022; Schraufnagel, 2020).

To find the initial concentration of background particles, the time required is much longer, ranging from a few tens of minutes to a few hours. The decrease in concentration follows an exponential law. Moreover, it turned out that the lower the ventilation rate, the longer the particle decay time, as expected. Particles generated by smoke seem to have the longest decay time, with values of several hours. To find the initial concentration of background particles, the time required is much longer, ranging from a few tens of minutes to a few hours. The decrease in concentration follows an exponential law. Moreover, it turned out that the lower the ventilation rate, the longer the particle decay time, as expected. Particles generated by smoke seem to have the longest decay time, with values of several hours (Wallace & Howard-Reed, 2002).

In order to establish a baseline for the background concentration, various studies have measured an average particle number concentration in microenvironments with limited

human activity and no combustion activity), internal particles are highly dependent on transport dynamics and those become external. Some researchers have concluded that the ratio of internal to external particle size distribution is constant under all conditions, whether for ultrafine or larger fractions of PM. Lower infiltration values were found for ultrafine and coarse particles than for fine particles. In the case of the ultrafine fraction, this behaviour is explained by both the removal efficiency of the building's air conditioning system and deposition by Brownian diffusion (Suwa et al., 2002).

For coarse particles, such behaviour is explained by gravitational sedimentation. Deposition rates (both theoretical and experimental) in several studies were compared, concluding that indoor particle deposition depends on particle size and other site-specific conditions. Therefore, when indoor particle generation is low, human exposure to PM can be predicted by knowing the outdoor aerosol and ventilation characteristics of the building (Jordakieva et al., 2018; Monteiro et al., 2018).

On the other hand, in buildings with high indoor particle generation (e.g., restaurants), the average indoor/outdoor UFP ratio can be around 5, with peaks reaching ratio values of 14. This behaviour is also typical of poorly ventilated homes (Hussein et al., 2006). Almost any type of indoor activity produces a considerable amount of UFP. Several studies have concluded that combustion, electrical heating and cleaning are the main generators of UFP. They also demonstrated that internal particle events are intermittent and highly variable, requiring the uninterrupted use of instruments for their characterization (Marval & Tronville, 2022).

Therefore, in buildings with a significant generation of indoor UFP, the particle size distribution and the internal composition are very different from the external ones. Indoor generated UFP is responsible for 50% to 80% of total indoor UFP (Wallace & Howard-Reed, 2002).

As many activities produce UFP in high concentrations, future studies on exposure and its impact on health should take a broader approach. Examining only emissions caused by traffic or other external sources leaves a critical part of the health impact unaddressed (Kwasny et al., 2010).

The activities produced the highest amount of UFP with a generation rate of  $2.16 \times 10^{12}$  PNC /min between  $1.27 \times 10^{11}$  PNC /min and  $7.86 \times 10^{12}$  PNC/min. Furthermore, it takes between 4 and 6 hours for UFP to return to its initial concentration (Pasquiou et al., 2021). Zhao et al. (2015) found that people are exposed to very high levels of UFP during working hours, with concentrations 550 times higher than natural levels. A study of non-smoking women in Asia found a direct link between lung cancer and occupational activities that produced UFP. It was also found that the longer the exposure time, the greater the risk of developing lung cancer (Bourdrel et al., 2017).

## **1.7. Conclusion**

This reviews the literature studies on the sources of ultrafine particles that occur indoors (in the workplace and in residential areas) and outdoors. Information is provided on the relevant emission factors, particle concentrations, sizes and compositions, and the health relevance of UFP and NPs is discussed. Particular attention is given to the proportion of particles that are deposited on the olfactory bulb after inhalation, as these particles can potentially reach the brain and their possible role in neurodegenerative diseases is an important topic in recent literature. UFP are believed to be a major contributor to the adverse health effects of exposure to PM. Due to their extremely small size. Inhalation exposure to fine and ultrafine particles is associated with respiratory illness. However, little is known about the quality, thresholds and concentration of these particles that cause adverse health effects. Exposure to UFP in the environment and the workplace is known to have adverse health effects. However, little is known about how these aerosols trigger the development of pathophysiological mechanisms in the body or how ultrafine particles behave in the lungs after inhalation. The development of aerosols of different origins that can be labelled in great variety with radionuclides compatible with clinical gamma camera systems opens up the possibility of using lung scintigraphy imaging to study these causalities in detail. Lung scintigraphy (planar or SPECT) allows regional mapping of aerosol deposition in the lung and dynamic assessment of particle clearance and translocation from healthy and affected human lungs. In this article, we will introduce the unique features of lung scintigraphy in the study of aerosol clearance in humans. UFP are defined as particles with an aerodynamic diameter of less than 100 nm.

## **1.8. Chapter summary**

This reviews literature studies on indoor (workplace and residential) and outdoor sources of ultrafine particles. Information is provided on relevant emission factors, particle concentrations, sizes and compositions, and the health relevance of UFP and PM is discussed. UFP are defined as particles with an aerodynamic diameter of less than 100 nm. Special attention is given to the fraction of particles deposited in the olfactory bulb after inhalation, as these particles can potentially reach the brain and their possible role in neurodegenerative diseases is an important topic in recent literature. UFP are thought to be one of the main contributors to the adverse health effects of particulate matter exposure. This is due to their extremely small size. Inhalation exposure to fine and ultrafine particles is associated with respiratory disease. However, little is known about the quality, thresholds and concentrations of these particles that cause adverse health effects. Exposure to UFP in the environment and in the workplace is known to cause adverse health effects. However, little is known about how these aerosols trigger the development of pathophysiological mechanisms in the body or how ultrafine particles behave in the lung after inhalation.

## CHAPTER II

### COMPREHENSIVE GLOBAL STUDY:

#### MONITORING AND ASSESSMENT OF ULTRAFINE PARTICLE EXPOSURE

*This chapter, which has been which has been submitted in a peer-reviewed, SCOPUS-indexed international scientific publication, covers the general aspects of the literature review that informed the construction of the global questionnaire, as well as the description of the methodology of construction and analysis. Interpretation of the data collected and discussion of the supporting bibliography. The questionnaire was designed to understand the knowledge on the subject and to verify if and how the evaluation of UFP is carried out at a global level.*

### **2.1. Introduction**

Particulate matter is a mixture of solid or liquid airborne particles of different sizes and compositions containing a variety of constituents such as dust, dirt, soot, pollen or small metal and plastic particles, smoke and liquid droplets, some of which may be toxic and classified as pollutant. These particles are PM<sub>10</sub> (i.e. particles up to 10µm in aerodynamic equivalent diameter), coarse particles or PM<sub>2.5-10</sub> (particles between 2.5 µm and 10µm in aerodynamic equivalent diameter), PM<sub>2.5</sub> or fine particles (particles up to 2.5µm in aerodynamic equivalent diameter) (Kirešová et al., 2023).

Particle size is important because it affects how aerosols interact with their environment. Smaller particles can stay in the air longer, travel further and penetrate deeper into the lungs. Larger particles, on the other hand, are more likely to fall out of

the atmosphere quickly and are less likely to reach the lungs. In addition, the size of particles can affect how they interact with other components of the environment, such as water vapor, sunlight and other pollutants. Particle size can also affect how aerosols interact with other particles, such as how they agglomerate to form larger particles. All of these factors can have a significant impact on air quality and public health (Marval & Tronville, 2022).

The term "equivalent diameter" describes the size of particles of unknown composition and/or shape as spheres of specified density.

Over the last 30 years,  $PM_{2.5}$  and  $PM_{10}$  have been the most used parameters to assess human exposure to particulate matter. Either  $PM_{2.5}$  or  $PM_{10}$  also includes the fraction below 100 nm (i.e. ultrafine particles) but, in fact, UFP is a minor contributor to the total mass concentration of indoor and outdoor aerosols (Marval & Tronville, 2022). For this reason, the concentration of UFP is defined as the particle number concentration (i.e., the number of particles in a given volume of air), as the mass concentration is too low to be measured reliably and effectively. There are two main aspects that differentiate UFP from larger airborne particles ( $PM_{2.5}/PM_{10}$ ) in terms of toxicology: differences in inhalation deposition (local dose) and differences in intrinsic toxicity due to physicochemical properties. Notably, associations between UFP exposure and health effects have been observed independent of other air pollution measures such as  $PM_{2.5}$  and  $NO_x$ . Interestingly, some UFP may translocate from the lung to the circulatory system and other organs, whereas larger PM (Cassee et al., 2019).

Ultrafine particles refer to extremely small solid or liquid particles that have a diameter in the nanometre range, usually below 100 nanometres. These particles are so small that they can be considered to be the size of individual molecules. This means that they are extremely small in comparison to other particulate matter. Because of this they have a large surface area compared to their mass, resulting in a greater interaction with the surrounding environment, making them highly reactive. This increases their potential for transport and toxicity. UFP have a greater tendency to agglomerate, and form aggregates due to the forces of attraction between them. This agglomeration can influence their properties and behaviour in different media, such as liquids or atmosphere. Because of their small size and ability to remain suspended in the air for

prolonged periods, ultrafine particles are more likely to be inhaled and carried by the human body. This can lead to health and toxicity concerns (Boudjema et al., 2021; Jordakieva et al., 2018; Marval & Tronville, 2022; Sousa et al., 2021).

One of the most important anthropogenic sources of UFP is combustion. This includes primary emissions from industrial plants, vehicles and machines that use biomass or fossil fuels. Vehicle emissions, including non-exhaust emissions, are a major source of UFP in urban areas (Manigrasso et al., 2019). Other sources of UFP are the secondary formation, which is a complex and dynamic process influenced by several factors, including precursor gas concentrations, atmospheric conditions and the presence of other aerosol particles. This process occurs when the concentration of precursor gases reaches a critical level and favourable environmental conditions, such as low temperature and high humidity, are present (Verma et al., 2009). On the other hand, looking to buildings air quality, any type of indoor activity can produce a large amount of UFP (Jones et al., 2000). Several studies have identified sources of UFP in dwelling indoor air from activities such as cooking, smoking, burning candles, cleaning, using a spray, ironing, electric heating, vacuum cleaning and printing (Marval & Tronville, 2022; Su et al., 2019; Wallace & Howard-Reed, 2002).

The deposition patterns and clearance mechanisms of aerosol particles depend mainly on particle size. In general, larger particles ( $> 10 \mu\text{m}$ ) tend to be deposited in the nose and upper airways, whereas smaller particles ( $< 10 \mu\text{m}$ ) are more likely to reach the alveolar region. The clearance mechanism for larger particles is mainly due to sedimentation, whereas for smaller particles it is mainly due to the action of alveolar macrophages. In addition, deposition patterns and clearance mechanisms are influenced by particle shape, particle density and the breathing patterns of the exposed individual (Leso et al., 2021).

The first site of interaction for  $\text{PM}_{0.1}$  is the lung. The surface area of the lung is estimated to be greater than  $100 \text{ m}^2$ , but this is usually estimated by measuring linear intersections with a  $1 \mu\text{m}$  probe by light microscopy. The estimated surface area will be greater the smaller the sampling probe is, to account for the additional area of an irregular surface. The surface area of the lung for a  $\text{PM}_{0.1}$  nanoprobe would be orders of magnitude larger than the light microscopy estimates, which Weibel called the "Coast of Wales" effect (Schraufnagel, 2020).

Studies have shown that UFP causes systemic inflammation and coagulation changes that predispose to ischemic cardiovascular disease, circulating polymorphonuclear leukocytes, platelets, fibrinogen, plasma viscosity and other markers. UFP promotes endothelial dysfunction, vascular inflammation, and atherosclerosis. Previous studies have attributed this effect primarily to PM<sub>2.5</sub>, but a growing number of studies show that UFP plays an important role in virtually all of these factors. In fact, most studies show a much broader effect, as UFP also causes increased heart rate variability, loss of sympathetic vagal balance and altered inflammatory and haemostatic functions in exposed humans (Schraufnagel, 2020).

There, work was published on the effects on the brain or nervous system and on the mechanisms by which UFP affects the brain and its development. Translocated UFP can be found in the brain after inhalation. UFP inhaled through the nose can reach the brain via the olfactory nerves. After exposure to UFP aerosols, brain uptake is greatest in the olfactory bulb, even seven days after exposure. In an animal inhalation study, up to 20% of UFP deposited on the olfactory mucosa reached the olfactory bulb. This route, which may bypass the blood-brain barrier, may be even more direct in humans. UFP not only translocate and directly damages nervous tissue, but also affects autonomic function. Exposure to UFP increases sympathetic nervous system activity by decreasing norepinephrine clearance, a property that is enhanced in humans (Suwa et al., 2002).

Assessing exposure to UFP is much more complex than assessing particulate matter (PM<sub>2.5</sub> or PM<sub>10</sub>) because UFP concentrations exhibit considerable spatial and temporal variations within a few seconds and over a few meters, which can be up to an order of magnitude above background levels as people move closer to or away from pollution sources or move between different microenvironments (Bocconi et al., 2021). These large variations in UFP concentrations in different environments may be important for human exposure assessment and epidemiological studies (Sanchez-Crespo, 2019). The influence of temporal activity and movement can easily be overlooked when using averaged results, so that mean and median concentrations over a time-averaged period may not reflect all aspects of population exposure patterns. It should be kept in mind that an exposure assessment approach for epidemiological studies should be designed to be easy to measure and universally applicable so that uncertainties shrink, but still be able to relate it to entities that can be measured, modelled and also regulated. The

absence of an exposure-response relationship makes it difficult to propose health guidelines for UFP, so it is not surprising that, here are still no air quality guidelines for UFP anywhere in the world (Marval & Tronville, 2022). Nevertheless, there is already considerable evidence of the toxicological effects of UFP. However, at an early stage, evidence from epidemiological studies was insufficient to establish guidelines, although now an increasing number of studies does support the need to establish reference guidelines (WHO, 2021).

On the other hand, the European Commission has already set out its intentions to monitoring and control the UFP levels regarding indoor air quality in the Directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe, published on 26 October 2022 (European Parliament and Council, 2022) and WHO has also expressed concern about UFP, suggesting distinguish between low (<1000 particles.cm<sup>-3</sup>, 24 hour mean) and high Particle Number Concentration (PNC) (>10 000 particles.cm<sup>-3</sup>, 24 hour mean or 20 000 particles.cm<sup>-3</sup>, 1 hour) to guide decisions on priorities for emission control of UFP sources (Cassee et al., 2019). Safe Work Australia and the British Standard Institute have also provided some references and concern to UFP control (Pietroiusti & Magrini, 2014).

There seems to be a huge information gap on UFP on such common aspects as who, when and why monitors this pollutant, what means and methods they use and, finally, whether there is a guideline reference value. Based on our literature review, ISO 16000-34:2018 is the only document that provides us with a method for all the particulate matter (PM) measurements, including UFP.

This work aimed to answer the following questions:

- Are there national laws or regulations that set guideline values for UFP?
- What methodologies and instruments are used by the international community to assess UFP?
- Who monitors and assesses UFP exposure?

To answer these questions, a literature review on UFP monitoring was firstly conducted, assessing the possible existence of limit values as well as the existence of regulations and standards for monitoring methods. Afterwards, a worldwide survey based on a

questionnaire was distributed to the international scientific community. The results of that questionnaire are interpreted and discussed in this manuscript.

## **2.2. Materials and methods**

In order to elaborate the questionnaire presented in this work, bibliographic research was carried out in the scope of UFP, which allowed the identification of the measuring methods generally used and their gaps, as well as the knowledge of the existence, or not, of regulations in this subject.

Subsequently, a questionnaire was created in English using Google forms. To test the level of understanding and intent of the survey, ensuring its reliability, a pilot questionnaire was carried out and presented to three native English speakers and five native speakers of other languages. The pilot test included fields for comments, which were carefully analysed and considered in the review of the structure and functioning of the questionnaire. After evaluation, the questionnaire was revised and sent through the International Federation for Environmental Health (IFEH), the *Sociedade Portuguesa de Saúde Ambiental* (SPSA) and other international contacts national and continental associations, such as *Sociedad Española de Salud Ambiental* (SESA), *Association Santé Environnement France* (ASEF), European Federation of Environmental Health (EFEH). These sent the questionnaire to their members who voluntarily agreed to respond.

Monitoring of indoor air pollutants and particulate matter in particular, can be done in an occupational or non-occupational setting. For this reason, the questionnaire was designed taking into account this difference and questions were asked orientated to these two realities. The questionnaire was divided into 6 sections. The first section was a presentation of the questionnaire and explanation of the research. Next (section 2) was the socio-demographic characterization. In this section we asked for age, sex, country, place of work and main area of practice or research, were we had the possibility to the inquiry give their contributes in open answers, as well as whether they had experience in air quality assessment, both in indoor air quality and occupational health. In section 3, we asked about national regulations on the assessment of ultrafine particles. The questions focused on the type of UFP assessment carried out in the respondent's

country, if in a non-occupational context (IAQ assessment of buildings) and/or if in an occupational health context and if there were legislation/standards for such assessment. In section 4 we only asked which method was used for the assessment of ultrafine particles, whether it was based on estimation or whether specific equipment was used. If it is by estimate, it goes to section 5; if it is by utilisation of equipment, to section 6. In section 5 only a summary of the regularly used methodology and the guidelines used for the estimation of ultrafine particles is requested. Section 6, asked about the methodology followed, the equipment used (brand and model) and measurement methodologies, i.e., duration of the sampling (1 minute; 2 to 4 minutes; 5 to 10 minutes; 11 to 15 minutes; more than 15 minutes); Number of repetitions (one, two, three, or more than 3); When is performed (before, during or after the occupation /activity) and the equipment position (without a specific position from the floor; 1 meter from the floor; 1.50 meters from the floor; in a point central area; near to the possible pollutants source).

At the end of the questionnaire, we asked if respondents would like to receive the results. After coding, the statistical treatment was carried out with IBM SPSS 28.

### **2.3. Results and discussion**

The questionnaire was applied to 250 entities in 20 countries resulting in 51 valid responses from 16 countries. The results allowed to verify which professions /training courses control /study the ultrafine particles, as well as the objectives and the means used (equipment and measurement methodologies applied).

Regarding socio-demographic data, Table 1 shows the characterization of participants by age and gender.

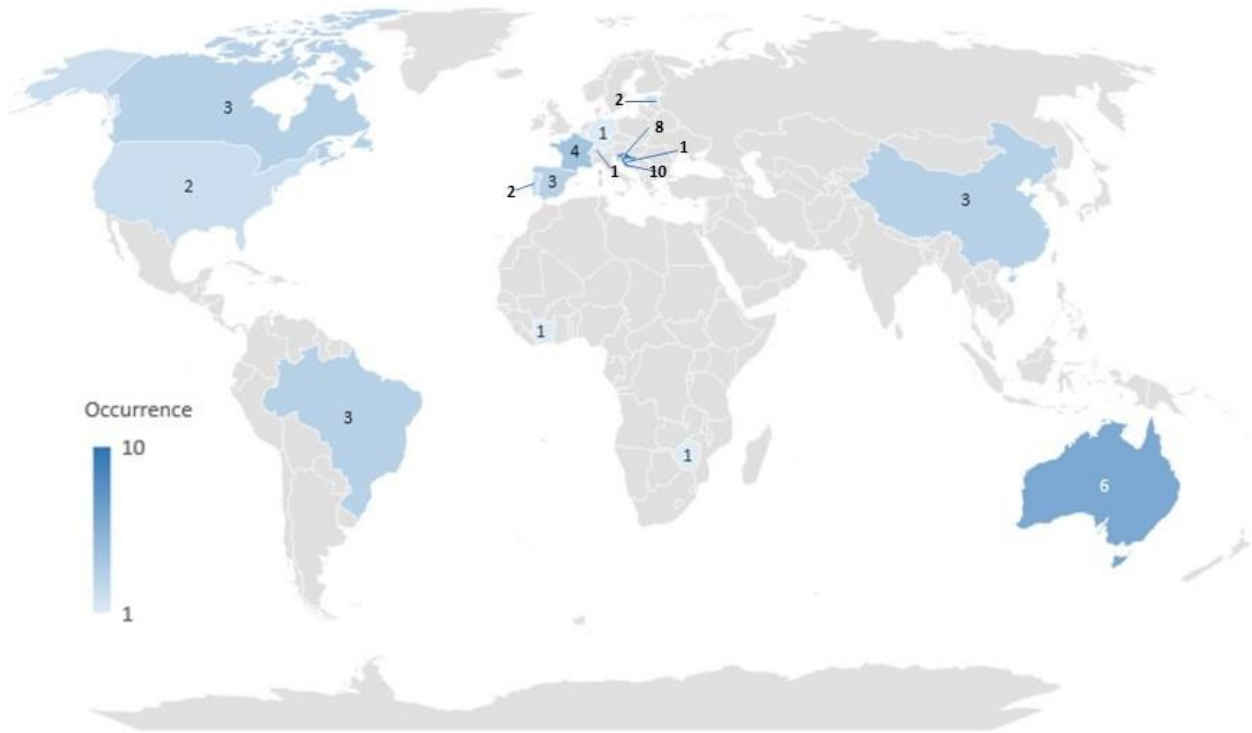
**Table 1**– Characterization of participants by age and gender.

		<b>Occurrence</b>	<b>Frequency (%)</b>
Age	<25	6	11.8
	26-35	7	13.7
	36-45	16	31.4
	46-55	15	29.4
	>56	7	13.7
	>56	7	13.7
	<b>Total</b>		51
Gender	Female	28	54.9
	Male	23	45.1
	<b>Total</b>		51

It can be seen that the highest frequency of occurrences is in the age group 36-45 and 46-55 years, with 31.4% and 29.4% respectively. On the other hand, about 26% of the frequency is below 36 years and about 14% above 56 years.

With regard to gender, the distribution of technicians involved in this type of measurement is relatively balanced, with around 54% women and 46% men.

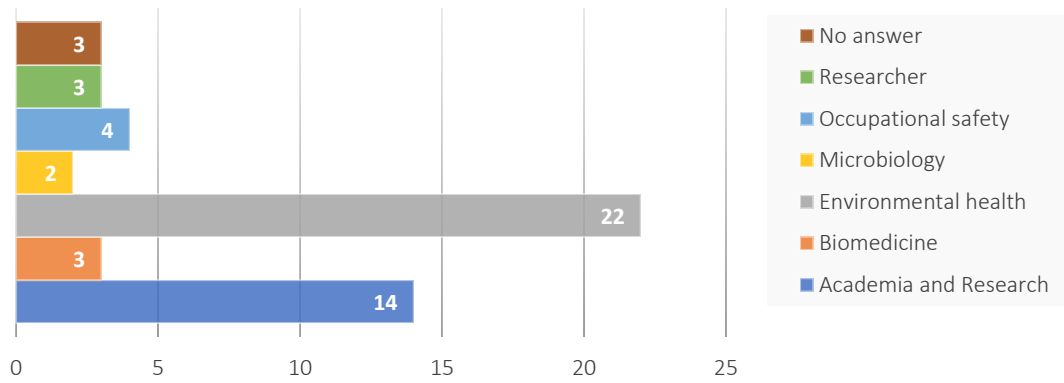
Concerning the participants' countries of origin, responses were obtained from 16 countries on five continents (Figure 7).



**Figure 7** – Countries of origin of the questionnaire participants.

Over 60% are Europeans, about 16% are from American countries (which include Canada, Brazil and USA), 12% from Australia, 6% from China and 4% are from Africa. The country with the largest participation was Croatia (10 participants) and three countries had only one participation each (Belgium, Bosnia and Herzegovina and Zimbabwe).

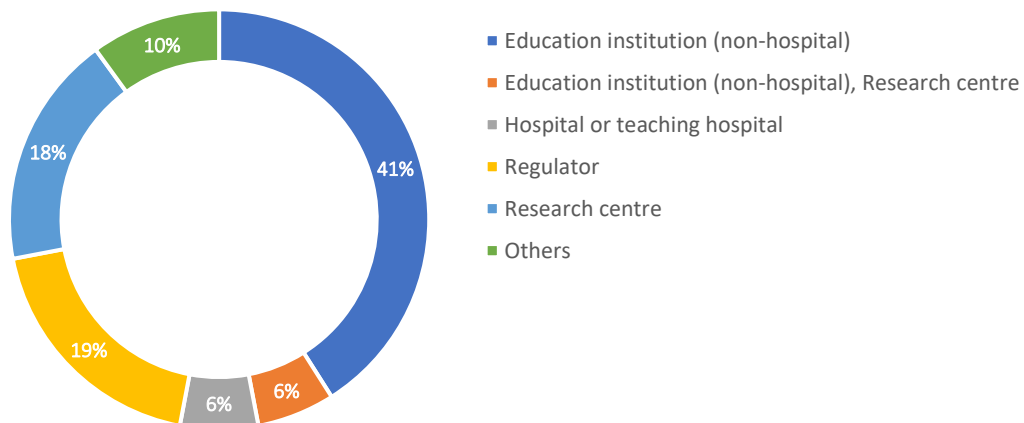
Regarding to professional affiliation, Figure 8 presents the results of the questionnaire. Three closed options were included: Occupational safety, environmental health and academia and research. However, respondents also had the possibility to answer in an open-ended way according to their actual professional area, which justifies the spreading of responses across other areas.



**Figure 8** – Professional affiliation of the questionnaire participants.

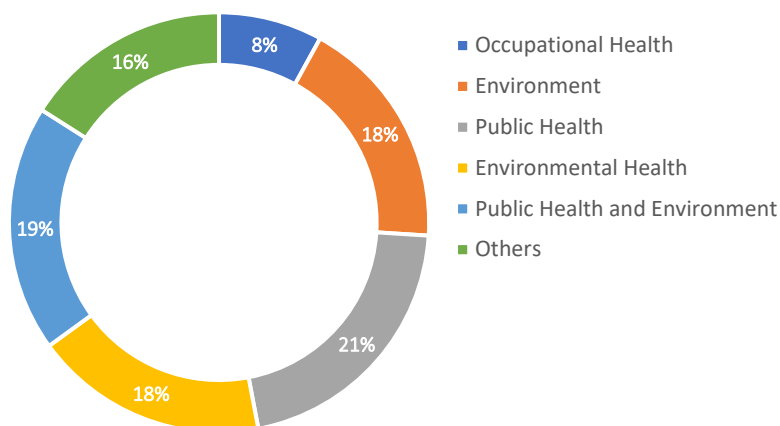
As can be seen, the largest proportion, almost half (43.1%), is from the environment and health sector, followed by the academic and research sector (27.5%). The remaining participants are from the occupational safety, research, biomedicine and medicine sector.

Concerning to participants workplace, they mainly work at education sector (41.2%) and regulators, with about 20% of the participants (Figure 9). The remaining participants work in research centres and other locations, which may indicate that UFP is being assessed, not only for research, but in routine measurements in worker protection.



**Figure 9**– Participants professional workplace.

Figure 10 shows the results by professional work area of the participants.



**Figure 10** – Participants professional work area.

There is a large convergence in the domains of work of the respondents, mostly oriented towards public and environmental health, being lower for those who answered working in the area of occupational health. These values are similar to what would be expected, since the vast majority of the studies found are in the field of indoor and outdoor air quality, which is effectively studied by public health and environmental health (Manigrasso et al., 2019; Morales Betancourt et al., 2017).

Participants were also asked if they had experience in measuring UFP. More often, 37.3%, stated that they had no experience of measuring UFP, while 33.3% reported having some experience. A slightly smaller proportion (29.4%) reported having experience. As a new area of intervention, these values are not surprising and are in line with studies that point to the lack of studies and the need for more and better studies in different countries worldwide (Bocconi et al., 2021; Kirešová et al., 2023; WHO, 2021).

We also asked whether the assessment was carried out using equipment or estimation. All participants said they use equipment to measure UFP.

When participants were asked whether they knew if UFP monitoring is carried out in their country for buildings IAQ assessment, it was found that, 70.6% said yes, 25.5% said they did not know and only 3.9% said no (Table 2).

Regarding occupational indoor assessment, in Table 2 can be observed that there is less reference to measurements being taken, with only 49% of the responders saying yes. A very similar number, 43.1%, say do not know and an insignificant number, 7.8%, say

that this type of measurement is not carried out. In fact, from the literature review, the studies and assessments published about UFP are in very specific areas, such as during laser hair removal procedures (Eshleman et al., 2017b), steel industry, police officers (Jordakieva et al., 2018), taxi drivers (Moreno et al., 2019) or occupational exposure to particulate UFP in metal additive manufacturing (Sousa et al., 2021).

On the other hand, in the questionnaire there is a higher number of answers that refer to the IAQ assessment in buildings. We believe that this can be justified by the growing interest in this area of research in recent years, in particular after the Covid 19 pandemic.

**Table 2** – UFP monitoring objectives in the collected responses.

		<b>Occurrence</b>	<b>Frequency (%)</b>
Buildings IAQ	No	2	3.9
	Yes	36	70.6
	I don't know	13	25.5
	<b>Total</b>	51	100.0
Occupational (indoor)	No	4	7.8
	Yes	25	49.0
	I don't know	22	43.1
	<b>Total</b>	51	100.0

From all the answers to the questions asked on this matter, one gets the idea of uncertainty on the part of those who are making the UFP measurements about the reason /objective for the measurement.

When we asked the participants about the existence of standards and legislation in the control and monitoring of UFP, some mentioned their existence (Table 3).

In fact, 45.1% of respondents for buildings IAQ assessments and 49% for occupational assessments confirmed the existence of legislation or legal standards in their country. Only 23.5% of respondents for buildings IAQ assessments and 15.7% for occupational assessments, respectively, stated that there was no standard or legislation applicable to UFP in their country. It should be noted that about 1/3 of the respondents did not know

whether or not there were standards or legislation in their country. These figures contradict the previous literature review conducted in this work where no references to legal standards for the assessment or control of UFP were identified, either for indoor air quality assessment or occupational health control.

**Table 3** – National legislation and standards in UFP.

		<b>Occurrence</b>	<b>Frequency (%)</b>
Buildings IAQ	No	12	23.5
	Yes	23	45.1
	I don't know	16	31.4
	<b>Total</b>	<b>51</b>	<b>100.0</b>
Occupational (indoor)	No	8	15.7
	Yes	25	49.0
	I don't know	18	35.3
	<b>Total</b>	<b>51</b>	<b>100.0</b>

Nevertheless, as mentioned earlier, concern about UFP has already led the Guideline Development Group from World Health Organization (WHO) to establish best practice limits (WHO, 2021) and the European Parliament and the Council to propose an obligation to measure UFP in their Directive on ambient air quality and cleaner air for Europe, published on 26 October 2022 (European Parliament and Council, 2022).

From these responses, we begin to realize that there may be some confusion between measurements of UFP and those of buildings IAQ assessments or occupational exposure to PM<sub>2.5</sub> or PM<sub>10</sub> particulates. Particularly, only in recent years, emerging industry has drawn attention to worker exposure to ultrafine particles. These have been measured in several workplace studies and several review articles have been written on the subject (Moreno et al., 2019; Viitanen et al., 2017). Safe Work Australia proposes to include standards aggregates and agglomerates with a size >100nm, leaving the threshold undefined. In this guidelines UFP are categorized into different risk groups, which may vary from organization to organization. In the British Standard Institute's approach, four groups provide a basis for categorizing nanomaterials, but without defined values (Pietroiusti & Magrini, 2014). In fact, workers are exposed to UFP in a

variety of work environments, but this exposure is not currently regulated as a separate part of the usual occupational exposure limits (Viitanen et al., 2017).

When asked whether they use a legally established methodology for UFP measurements, only 23.5% said yes and 76.5% answered no (Table 4).

**Table 4** – Legally established methodology for UFP measurements.

<b>With experience</b>	<b>Occurrence</b>	<b>Frequency (%)</b>
No	39	76.5
Yes	12	23.5
<b>Total</b>	51	100.0

When the participants were asked about the duration of the measurements and the routine of the procedures, we obtained some relevant results. Of the 51 participants, only 12 (24%) mentioned the existence of a routine in the measurements. The vast majority (76.5%), did not know or did not answer on this subject. Given these data, apparently UFP is not routinely measured for occupational health or for indoor air quality control purposes in buildings (Table 5).

**Table 5** – Measure time and routine.

	<b>Occurrence</b>	<b>Frequency (%)</b>	
Measure time	1 min	2	3.9
	5 to 10 min	6	11.8
	More than 15 min	4	7.8
	Doesn't know or doesn't answer	39	76.5
Measure routine (number of measures made in each point)	One	3	5.9
	Three	3	5.9
	More than three	6	11.8
	Doesn't know or doesn't answer	39	76.5

In addition, literature review show that measurement methods and instruments are not currently standardized, which means that measurement strategies and methods vary

widely. Although, the sampling distance has a significant influence on the measurement results, as the concentration of UFP is rapidly diluted after leaving the original exposure source (Viitanen et al., 2017), some studies have sampled workers' in breathing zones, while others have used stationary sampling, which shows again that there is no standard on this subject.

Considering the equipment mentioned, only 14 (27,5%) of the participants reveal the equipment they use to perform the quantification of UFP. Table 6 shows the equipment used by the responders of the survey.

**Table 6** – Used equipment by the responders of the survey.

	Occurrence	Frequency (%)
GRIMM	2	3.9
Laser Particle Sensor PM2008-API	5	9.8
FLUKE 985 particle counter	2	3.9
TSI counter	4	7.8
Not known	1	2.0
<b>Total</b>	<b>14</b>	<b>27.5</b>

It was possible to verify the variability of the equipment used, some accurate and advanced, such as the Laser Particle Sensor PM 2008-API, whose cutting-edge technology allows the sample characterization by size (5 particles) or the TSI UFP Counter, specifically designed for occupational hygiene (4 participants), or the Grim which later allows an evaluation with quantification in the laboratory. However, two of the participants reported using the FLUKE 985, designed for PM<sub>2.5</sub> and PM<sub>10</sub> assessment and not applicable to UFP measurement. Again, we believe that this confusion may be related to the fact that there is no specific regulation or legislation defining UFP.

#### **2.4. Portuguese situation**

Specifically considering the situation in Portugal. Although there were only two responses, they align with the global results. UFP is being studied and assessed in academic research, using the same criteria as for other types of particulate matter. Professionals who conduct these assessments are from the Public Health and Environment sector. They reported there is no legislation for UFP monitoring, but assessments are conducted in both occupational and IAQ environments. The measurement time, equipment placement and number of repetitions are similar to assessing PM<sub>2.5</sub> and PM<sub>10</sub>.

## **2.5. Conclusions**

The added value of implementing this survey is a global understanding of how UFP are being evaluated in different institutions around the world. In fact, information was obtained from 16 different countries in five continents making this survey, to the best of the authors' knowledge, the most extensive work done on this subject.

The following conclusions could be drawn:

- The inexistence of guideline values for the assessment of UFP. To the best of the research team's knowledge, monitoring and quantifying ultrafine particles (UFP) is not yet required by law in any country; only WHO, International Organization for Standardization (ISO) and the European Commission show some concern about this pollutant;
- There are no defined protocols for the assessment of UFP levels, which means that assessments do not follow the same methodologies, making it impossible or very difficult to inter-compare the results obtained. The literature review showed that only the ISO 16000-34:2018 give us a method for all the particulate matter (PM) measurements, including UFP;
- Lack of knowledge about UFP; Some of the respondents confuse ultrafine particles with larger particles, such as PM<sub>10</sub> or PM<sub>2.5</sub>; this is evident by the type of equipment they say they use to measure UFP which, according to the technical characteristics, is not suitable for the purpose.

International methodologies for the measurement of UFP are urgently needed, as well as the establishment of guide values for the protection of human health. This need is reflected by the respondents, most of whom are academic heads. They are concerned about the emerging issue and the need to control and set standards to monitor this pollutant. Until then, we suggest using the ISO standards (ISO 16000-34:2018) to determine the level of UFP and the best practice limits already advanced by WHO.

## **2.6. Chapter summary**

Several studies show that air pollution has become a major problem and a source of great concern. Part of the observed poor air quality can be attributed to the levels of ultrafine particles (UFP), generally defined as the fraction of particles with diameter less than 100 nm which, by their size, are able to enter the blood circulation causing adverse health effects. As the main route of entry into the body is inhalation, several epidemiological studies associate the presence of UFP to total mortality, cardiovascular and respiratory problems. Since there are apparently no worldwide normative references for the control of these particles, this global study aimed to characterize the methods and techniques used worldwide regarding the monitoring and management of UFP. For this purpose, a survey was carried out based on a questionnaire applied at global scale. The questionnaire design was based on a preliminary literature review on the main search engines for scientific publications to establish the state of the art. As a result of the application of the questionnaire, a total of 51 responses were obtained from 16 different countries on five continents, which provided an insight into the global profile of professionals interested in the control/study of UFP, the measurement methodologies they follow and the guideline values they apply, if any. Among them are public health professionals, academics, and health engineers from various institutions, such as education, hospitals, research centres and regulators in the health sector. Most responses said are no specific methodologies for the measurement of UFP, nor national standards for it. Through the results obtained in this study, it can be concluded that it is urgent to adopt regulations to standardize the assessments as well as to establish guide values for the protection of the human health.



## CHAPTER III

### DETERMINATION OF OCCUPATIONAL EXPOSURE TO ULTRAFINE PARTICLES IN DIFFERENT SECTORS OF ACTIVITY

*This chapter, which has been submitted for publication in an international scientific journal, discusses the general aspects of occupational exposure to ultrafine particles. This is followed by a description of the assessment methodology and the sites assessed. The aim is to assess exposure to UFP at four different sites, two with primary UFP formation and two without. The data will then be interpreted and cross-checked to determine the behaviour of UFP formation.*

#### **3.1. Introduction**

Over time, man has found polluted air to be harmful to health and well-being. Indoor air can be contaminated by several emissions of different contaminants, thus becoming an increasing environmental concern (Monteiro et al., 2018).

Today, we spend around 90% of our lives inside places such as offices, homes, schools, vehicles, aeroplanes, and other spaces. Consequently, the way these environments are designed and used has a profound impact on the health of their occupants (Kembel et al., 2012).

Exposure to air pollutants is associated with several effects on human health. Studies indicate that such effects have been present since the beginning of the last century, with increases in morbidity and mortality rates being detected after short episodes with high

levels of air pollutants (Marval & Tronville, 2022; Pasquiou et al., 2021; Viitanen et al., 2017).

Particulate matter or airborne aerosols are pollutants composed of a complex mixture of solid and liquid particles in a gas. Particulate Matter (PM) varies in size and composition depending on its source and formation (Jones et al., 2000).

PM are classified according to their size and formation mechanism into primary or secondary. Primary particles result from direct emission sources, both natural and anthropogenic, while secondary particles are formed in the atmosphere through chemical and photochemical reactions or physical processes involving the primary particles. The chemical composition is determined by the emission process of the particles (Ferreira Martins, 2016). These particles are PM<sub>10</sub> (i.e. particles up to 10 µm in aerodynamic equivalent diameter), coarse particles or PM<sub>2.5-10</sub> (particles between 2.5 and 10 µm in aerodynamic equivalent diameter), PM<sub>2.5</sub> or fine particles (particles up to 2.5 µm in aerodynamic equivalent diameter) (Kirešová et al., 2023).

One of the main sources of Particulate Matter are anthropogenic, androgenic sources which refer to the sources of pollutants that have the potential to release particulate matter into the air and which are related to characteristics or activities typically associated human activity (Castro et al., 2014). These sources may vary depending on the context, but can be important sources of emissions, such as from fuel combustion and other anthropogenic activities that emit different forms of particulate matter. Many industrial activities, such as metallurgy, foundry, cementing and materials processing, can generate large amounts of particulate matter during their processes (Sousa et al., 2021). Construction and demolition activities also generate particulate matter in the air, especially when excavating soil, handling particulate materials, cutting and using heavy equipment (Fireman et al., 2017).

Occupational exposure to Ultrafine Particles (UFP) is currently a new and increasing risk, which classifies it as an emerging risk.

Ultrafine particles are extremely small solid or liquid particles, typically less than 100 nanometres in diameter. These particles are so small that they can be compared to the size of individual molecules, making them significantly smaller than other forms of

particulate matter. Because of this tiny size, they have a remarkably large surface area relative to their mass, resulting in extensive interactions with the surrounding environment, making them highly reactive. This increases their transport potential and toxicity. In addition, ultrafine particles tend to aggregate and form clusters due to the attractive forces between them. This agglomeration significantly affects their properties and behaviour in different environments, such as liquids or the atmosphere. Because of their small size and ability to remain suspended in the air for long periods, these ultrafine particles are more likely to be inhaled and transported within the human body. This raises health and toxicity concerns (Boudjema et al., 2021; Jordakieva et al., 2018; Marval & Tronville, 2022; Sousa et al., 2021).

Ultrafine Particles is also a minor contributor to the total mass concentration of indoor and outdoor aerosols (Marval & Tronville, 2022). Due to the limited detectability and reliability issues of mass concentration, the focus on UFP is on particle number concentration, which refers to the number of particles present in a given volume of air.

Human exposure routes to UFP may include inhalation via the respiratory tract; absorption via the skin; ingestion via the mouth; or combinations of these routes (Kranjec et al., 2016).

In fact, the most important route of human exposure to UFP is inhalation. By this route, and due to their size and other characteristics, UFP may reach the alveolar region and behave similarly to fine particles, giving rise to inflammatory processes in the lungs and subsequent cardiovascular morbidity and mortality (Audignon-Durand et al., 2021).

Several epidemiological studies have shown that dust in the workplace is a risk factor for workers exposed to it, and that it can cause pathologies and affect the quality of life of workers (Pasquiou et al., 2021).

UFP have different toxicological properties compared to larger airborne particles such as PM<sub>2.5</sub>/PM<sub>10</sub>. These differences are mainly due to differences in inhalation deposition (local dose) and intrinsic toxicity related to their physicochemical properties. Remarkably, health effects associated with exposure to UFP have been observed independently of other air pollution measures such as PM<sub>2.5</sub> and NO<sub>x</sub>. Interestingly,

certain UFP, unlike larger PM particles, may move from the respiratory system to the cardiovascular system and other organs (Cassee et al., 2019).

The main question we want to answer is what levels of UFP workers are exposed to in environments with different direct particle emission patterns.

For that purpose, the main questions we want to answer are:

- What are the levels of UFP in traditionally particulate polluted sites?
- Are UFP also present at sites where PM emissions are low or non-existent?
- What is the relationship between the presence of UFP and other pollutants such as PM<sub>10</sub>, PM<sub>2.5</sub>, carbon dioxide (CO<sub>2</sub>) and carbon monoxide (CO)?
- What is the relationship between the levels of UFP and other parameters, such as temperature (T) and relative humidity (RH)?
- How do the values measured indoors relate to the values observed outdoors?

In order of that, the study involved monitoring industrial workplaces with PM emissions, such as a carpentry and a bakery, as well as at social sector sites without or almost without direct PM emissions, such as a school and a Clinic Laboratory.

### **3.2. Methodology**

The present study was observational, descriptive, analytical in nature, and cross-sectional in time. The type of sampling was non-probabilistic.

The study consisted of monitoring environmental parameters and various pollutants at two industrial sites, a carpentry and a bakery, and at two social sector sites, a school and a Clinic Laboratory. The industrial sites chosen typically have PM emissions, unlike the other two sites, where direct PM emissions are low or non-existent.

The carpentry was open space facility of approximately 500 m<sup>2</sup>, made of masonry and with a ceiling height of 5 m. Ventilation is natural, although there is local extraction when needed in the wood cutting and sanding machines. Monitoring was carried out at several points representative of the work areas: pain, sawing (includes sanding) and assembly.

The bakery was an area of 200 m<sup>2</sup> and a ceiling height of 4 m. The space is divided into several rooms of about 30 m<sup>2</sup> each. The rooms are made up of metal sandwich panel walls to facilitate hygiene and cleaning. Different measurement points were defined to characterize the various locals: manufacture, production, dispatch, warehouse and office.

In the school, as the perspective of this study is the verification of occupational conditions, only work offices and workrooms usually places where workers stay longer, were assessed. The workrooms had about 40 m<sup>2</sup> each and the offices about 20 m<sup>2</sup> Both with ceiling height of 3.5 m. was masonry construction covered with paint and with natural ventilation. The windows were kept closed during the measurements.

The clinic laboratory is a clinical analysis laboratory consisting of 3 laboratories of about 10 m<sup>2</sup> each and an administrative and waiting room of about 30 m<sup>2</sup>. The walls of the laboratories are clad in ceramic and stainless steel. The reception area is painted masonry. The laboratories had air conditioning with air recirculation, the reception had natural ventilation. The windows were also kept closed during the measurements.

The measurements were carried out during 2022 and early 2023, consisting of several collection moments, with a total of 1926 measurements, at workplaces, including an outdoor control site. The assessments were carried out during normal operation of the facilities, during working hours, so that the sample was representative of occupational exposure to pollutants. Fifteen-minute measurements were taken throughout the day to characterise daily exposure, and then average values adjusted to standard values were calculated to assess exposure levels.

In accordance with WHO recommendations, measurements were taken at a central point in the room, about one and a half metres from the floor, at a height closest to the occupant's airways, ensuring a distance of at least one metre from walls or other obstacles, outside the action zones of ventilation systems, air currents or sources of contamination(WHO, 2021).

For the analytical collection of the parameters evaluated, specific portable equipment of real time reading was used (Table 7).

**Table 7– Monitoring equipment.**

Equipment	Pollutant	Equipment range
TSI Q-Track Plus (Figure 11)	CO (ppm)	0 - 500
	CO <sub>2</sub> (ppm)	0 - 5000
	T (°C)	0 - 50
	RH (%)	5 - 95
P-Trak Ultrafine Particle Counter – 8525 (Figure 12)	UFP (PNC)	0 - 5x10 <sup>5</sup>
Lighthouse, model 3016 IAQ (Figure 13)	PM <sub>10</sub> (mg.cm <sup>-3</sup> )	0 - 350
	PM <sub>2.5</sub> (mg.cm <sup>-3</sup> )	0 - 350



**Figure 11–TSI Q-Track Plus.**

**Source–**TSI datasheet (TSI Incorporated, 2005)..

The Q-TRAK Plus (Figure – 11) monitor and large, easy-to-read graphs provide simultaneous, Realtime visualisation of temperature, relative humidity, CO<sub>2</sub> and CO. The Q-TRAK Plus also provides key reference measurements such as dew point, wet bulb and outdoor air percentage. The Q-TRAK Plus has a menu-driven user interface for ease of operation. On-screen prompts and step-by-step instructions guide the user through operation and field calibration(TSI Incorporated, 2005).



**Figure 12** – TSI- P-Trak Ultrafine Particle Counter.

**Source** – TSI datasheet (TSI Incorporated, 2022).

The P-Trak Ultrafine Particle Counter (Figure – 12) measures the levels of ultrafine particles in the workplace and helps to eliminate indoor air quality or IAQ problems. The occupational health risks associated with the manufacture and use of nanomaterials are not clearly understood. As a result, there is a need to assess workplace conditions. Using TSI's proven technology, the P-Trak provides direct, real-time measurement of ultrafine particle levels in the workplace. The P-Trak Ultrafine Particle Counter locates obvious sources such as boilers, furnaces and vehicles, and also detects less obvious sources such as photocopiers and printers. Use this instrument to detect the migration of toxic

fumes, malfunctioning office equipment, pinhole gasket leaks in boilers and a host of other problems (TSI Incorporated, 2022).



**Figure 13** – Lighthouse, model 3016 IAQ.

**Source** – Lighousedatasheet(LightHouse website, 2016).

Lighthouse Portable Particle Counters IAQ 3016 (Figure – 13) are feature-rich instruments that are ideal for spot checking within your critical environments or Indoor Air Quality applications. It has compact size and weight along with its sleek handle, you can use this unit with ease. These units provide immediate results that allow you to proactively monitor your environment. Providing up to 6 simultaneous count particle size channels, Lighthouse portable particle counters can display cumulative and differential particle count data as well as temperature/relative humidity data on the quick and easy to read colour touch screen. The Handheld can be used as a mobile particle monitor or become part of a large facility monitoring and management system (LightHouse website, 2016).

The data collected during the study were statistically treated using Statistical Package for Social Sciences (IBM SPSS) software version 28.0 for Windows. A 95% confidence

level and a random error of less than or equal to 5% were taken into account for the estimation of statistical inference.

Pearson's correlation, also known as linear correlation, was performed in the statistical tests. It is a statistical measure that quantifies the linear relationship between two continuous variables. This correlation is represented by the Pearson correlation coefficient ( $r$ ), whose value ranges between -1 and 1.

Regarding the reference values that will be used to discuss the results, as these are buildings that are being assessed from an occupational health perspective, American Conference of Governmental Industrial Hygienists - Threshold Limit Values (ACGIH – TLV) to PM<sub>10</sub>, PM<sub>2.5</sub>, CO and CO<sub>2</sub> have been used.

The provision of occupational health and safety measures to protect health workers is also fundamental to well-functioning and resilient health systems, quality of care and the maintenance of a productive health workforce. WHO work to protect the health and safety of health workers includes developing norms and standards for the prevention of occupational hazards in the health sector (Wolf J, Prüss-Ustün A, Ivanov I, Mudgal S, Corvalán C, 2018). In the case of UFP, given the absence of guidelines, the values suggested by the WHO for prioritising the control of UFP emitting sources were used as reference values (Table 8)(Boudjema et al., 2021; Castro et al., 2014)

**Table 8** – Guidelines /recommended concentrations.

<b>Pollutant</b>	<b>Limit/Recommended Values</b>	<b>Standard /recommendation</b>
CO (ppm/8h)	30	ACGIH – TLV
CO <sub>2</sub> (ppm/8h)	1000	ACGIH – TLV
T (°C)	22	ILO
RH (%)	65	ILO
	< 1000 Low	
UFP (PNC 24h mean)	1001 – 9999 Medium	WHO
	> 10000 High	
PM <sub>10</sub> (mg.m <sup>-3</sup> /8h)	10	ACGIH – TLV

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PM <sub>2.5</sub> (mg.m <sup>-3</sup> /8h)	3	ACGIH – TLV
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PNC - Particle number concentration - WHO 2021  
ILO – International Labour Organization

### 3.3. Results and discussion

Table 9 shows the number of measurement points at the different evaluation sites. A total of 1926 measurements were taken.

The number of collections was elaborated according to the evaluation area, as well as the number of tasks and workplaces to be assessed. This justifies the discrepancy in the number of assessments we have. In the bakery 58.1% of the measurements were made, followed by the carpentry with 35.7% and finally the school and the Clinic Laboratory with 3.3% of the measurements each in a total of 1926 measurements.

**Table 9** – Total of measures performed per workplace.

	Occurrence	Frequency (%)
Carpentry	630	32.7
Bakery	1 170	60.8
School	63	3.3
Clinic Laboratory	63	3.3
Total	1 926	100.0

Table 10 presents the results of indoor and outdoor measurements. Indeed, the concentrations observed indoors indicate the presence of relevant indoor sources of the observed pollutants. Outdoor air apparently does not contribute to the degradation of indoor air. We can even conclude that, if the ventilation level is higher, outdoor air could have an important contribution to the improvement of indoor air quality. The CO and CO<sub>2</sub> values show differences of significance. Regarding CO, the values observed indoors and outdoors are close to each other. On the other hand, CO<sub>2</sub> values indoor /outdoor have greater differences, probably due to contamination by the occupants.

**Table 10** – Indoor and outdoor concentration level comparison.

Pair	Indoor/Outdoor	Mean	N	Std. Deviation	Std. Error Mean
PM <sub>10</sub> (mg.m <sup>-3</sup> )	Indoor	0.0496	1926	0.25471	0.00580
	Outdoor	0.0153	1926	0.00485	0.00011
PM <sub>2.5</sub> (mg.m <sup>-3</sup> )	Indoor	0.3760	1926	1.00371	0.02287
	Outdoor	0.0887	1926	0.41357	0.00942
CO (ppm)	Indoor	2.0462	1926	0.21002	0.00479
	Outdoor	1.9410	1926	0.09122	0.00208
CO <sub>2</sub> (ppm)	Indoor	553.7980	1926	239.07591	5.44763
	Outdoor	351.15	1926	21.78422	0.49638
UFP (PNC)	Indoor	24487.14	1926	27216.882	620.330
	Outdoor	2513.45	1926	2709.181	61.748

PNC - Particle number concentration - WHO 2021

The next step was to check compliance with the PM<sub>10</sub> and PM<sub>2.5</sub> standard according to the ACGIH - TLV guidelines. The figures found are somewhat interesting, as they are almost all within the guidelines limits, probably due to the collective protection systems (in the carpentry extraction located at dust producing workstations and forced ventilation in the bakery). In fact, only 0.3% of the values in PM<sub>2.5</sub> and 0.1% in PM<sub>10</sub> are over the guidelines limits (Table 11).

**Table 11** – Comparison of observed PM values with guidelines limits.

		Occurrence	Frequency (%)
PM <sub>2.5</sub>	Above Limit	6	0,3
	Below limit	1920	99,7
	<b>Total</b>	1926	100,0
PM <sub>10</sub>	Above Limit	2	0,1
	Below limit	1924	99,9
	<b>Total</b>	1926	100,0

In Figure 14 we can see the PM<sub>2.5</sub> levels by activity, as expected the highest are coincident with the activities with primary formation of particles. This helps to understand that this formation occurs according to the existing literature.



Figure 14 – PM<sub>2.5</sub> levels (g.m<sup>-3</sup>) by activity.

In Figure 15 we can see the levels of PM<sub>10</sub> by activity, as in the case of PM<sub>2.5</sub>, PM<sub>10</sub>. They show expected values for the activities evaluated.

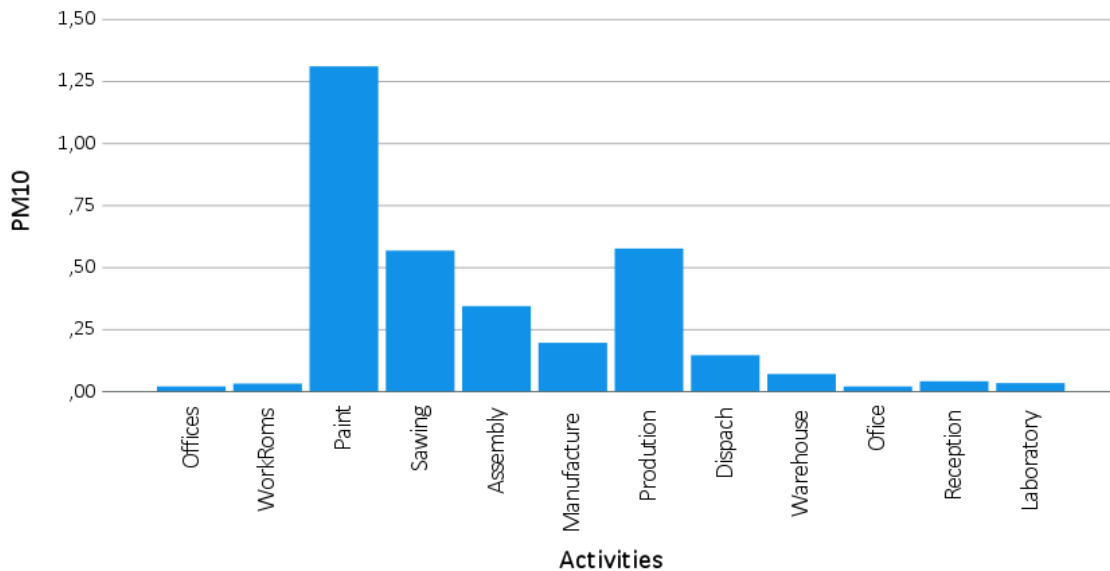


Figure 15- PM<sub>10</sub> levels (g.m<sup>-3</sup>) by activity.

Checking the UFP values according to WHO recommendations to 24h mean PNC levels, it turns out that the recorded values are not so favourable for the workers. Of the UFP measurements, more than half (53.4%, 1028 occurrences) are medium values. The remaining 46.6% (898 measurements), are above the WHO recommendations for PNC

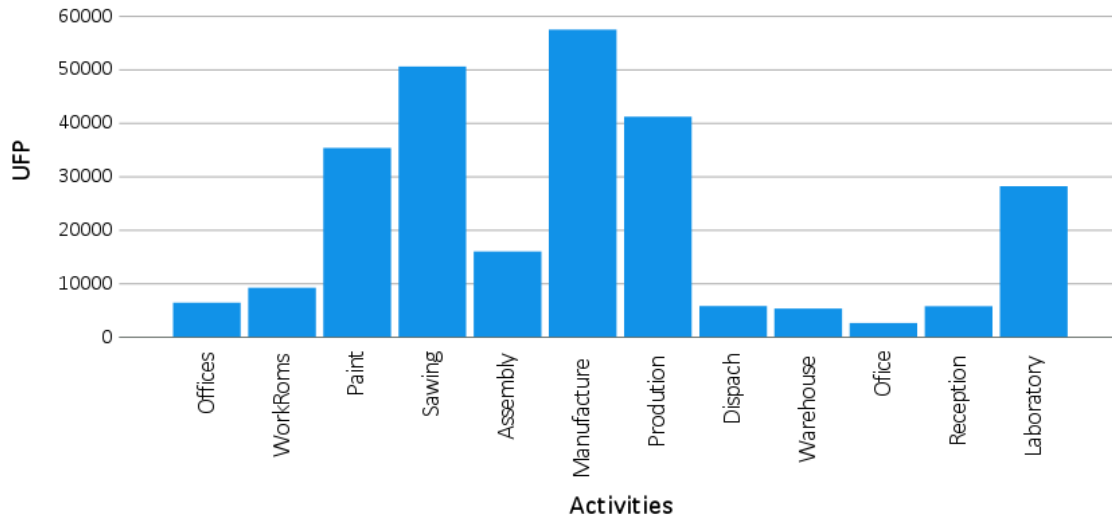
24hmean. The results found indicate that individuals exposed to UFP in their occupational environment may experience higher exposure levels compared to the background concentration (Table 12). This suggests that certain occupational activities or environments may have higher exposure to UFP (Eshleman et al., 2017a; Geiss et al., 2016; Marval & Tronville, 2022; WHO, 2021).

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**Table 12**– UFP values compared with WHO guidelines.

	<b>WHO guidelines</b>	<b>Occurrence</b>	<b>Frequency (%)</b>
	1001 - 9999 - Medium	1028	53,4
UFP	>10000 - High	898	46,6
	<b>Total</b>	1926	100,0

In Figure 16 we can see the levels of UFP by activity, as in the case of PM<sub>2.5</sub>, PM<sub>10</sub>. We can observe that the most relevant production activities are in carpentry the sawing and painting. In the Bakery the manufacture and production. In the school the workrooms and in the Clinic Laboratory the laboratories. Then we will analyse the possible justification of these values with the other pollutants analysed.



**Figure 16**-UFP levels (PNC) by activity.

We then looked at UFP levels by workplace in line with WHO recommendations. As expected, carpentry is the one with the highest frequency of high values with 65.4%, followed by bakery with 38.6%. In the school and in the Clinic Laboratory, values are similar although the lowest values are, as expected, in the school where offices and workrooms were monitored (Table 13).

These values are in line with the literature presented, as carpentry is a primary source of UFP due to the tasks developed (Marval & Tronville, 2022; Viitanen et al., 2017; Zhao et al., 2015). As mentioned before, UFP can be emitted directly from anthropogenic sources or combustions, or even more frequently in chemical reactions and dynamic processes such as nucleation, condensation, and coagulation. These cases can be the origin of the UFP found in this assessment (Jones et al., 2000; Manigrasso et al., 2019; Marcias et al., 2019; Ragde et al., 2016; Zhao et al., 2015).

**Table 13** – Results in different sectors compared with WHO guidelines.

Sector	WHO guidelines	Occurrence	Frequency (%)
Carpentry	1001 - 9999 - Medium	218	34,6
	>10000 - High	412	65,4
	<b>Total</b>	<b>1</b>	<b>0,2</b>
Bakery	1001 - 9999 - Medium	718	61,4
	>10000 - High	452	38,6
	<b>Total</b>	<b>1170</b>	<b>100,0</b>
School	1001 - 9999 - Medium	52	82,5
	>10000 - High	11	17,5
	<b>Total</b>	<b>63</b>	<b>100,0</b>
Clinic Laboratory	1001 - 9999 - Medium	40	63,5
	>10000 - High	23	36,5
	<b>Total</b>	<b>63</b>	<b>100,0</b>

Now analysing the workplaces in more detail, Table 14 shows the results of the measurements taken in the various sectors of each workplace.

**Table 14** –Average, maximum and minimum values of UFP (PNC) by sector and activities.

Sector	Activity	Average	Minimum	Maximum
Carpentry	Paint	42612	3331	140883
	Sawing	45711	8115	153566
	Assembly	8313	1799	48426
Bakery	Manufacture	48580	22308	139233
	Production	36209	16356	86846
	Dispatch	5578	2882	9964
	Warehouse	5038	2410	10138
	Office	3107	1092	5036
School	Offices	2970	1574	70730
	Workrooms	5298	1467	87653
Clinic Laboratory	Reception	4776	2397	12384
	Laboratory	22698	1315	114248

To verify the exposure levels, we calculated the adjusted mean values of the measurement points and looked for the minimum and maximum values recorded for the UFP. We can affirm that the highest average and maximum values coincide with what would be expected according to what is indicated in the literature for the sources that generate UFP. In carpentry, the average values are as expected, where the areas with primary sources with special emphasis on sawing and painting because the tasks are primary generators of particles. As expected, the assembly has lower values and in line with the WHO average values (Audignon-Durand et al., 2021; Ragde et al., 2016; Trechera et al., 2021). In the bakery, the production area stands out (average 36209; maximum 86846) and even higher the manufacturing (average 48580) agreeing with the literature that refers to industrial and combustion activities as generating UFP (Audignon-Durand et al., 2021; Eshleman et al., 2017b; Marcias et al., 2018; Wallace & Howard-Reed, 2002). As expected, the school, without primary sources of UFP, has average exposure values. As expected, the school, without primary sources of UFP, has a typical exposure values. The highest values would be expected to occur in industries where UFP are more likely to be generated or released, such as manufacturing, construction or mining. Work processes that involve activities such as cutting, grinding, burning or the use of certain chemicals may generate UFP as by-products, leading to higher exposure of workers in these environments (Eshleman et al., 2017a; Ferreira Martins, 2016; Marval & Tronville, 2022). Contrary to initial expectations, the laboratories of the Clinic Laboratory have very high values.

Finally, to better understand what is influencing the UFP, we checked Pearson's correlation between the pollutants assessed, including UFP, per assessment site (Table 15).

In this analysis we were able to verify a number of correlations, some of which were expected, but others were completely unexpected. In carpentry, as expected, there is a strong positive correlation between CO and UFP, as well as between RH and UFP. These results can probably be explained by the presence of combustion sources and humidity in the air, which favour the secondary formation of UFP. On the other hand, and in a less expected perspective, there is a strong negative correlation between UFP and Temperature. Here, some of the studies that talk about the formation of UFP associate these problems with the agglutination of particles that can cause them to cease

to belong to the spectrum of ultrafine particles (Fireman et al., 2017; Jordakieva et al., 2018; Marcias et al., 2018; World Health Organization, 2020; Zhao et al., 2015). Another strongly negative correlation is that between UFP and CO<sub>2</sub>. As expected, this can be strongly influenced by the ventilation that takes place after painting by aerating the room; this air renewal can favour the improvement of UFP levels. Also in carpentry, sawing, which includes sanding, shows a strong positive correlation with PM<sub>10</sub> and PM<sub>2.5</sub>, in line with the direct formation of UFP. In assembly, this correlation is exactly the opposite, strongly negative, probably due to the lack of direct formation of UFP. There is no wood decomposition in this zone (Boudjema et al., 2021; Eshleman et al., 2017b; Ferreira Martins, 2016; Li et al., 2016).

**Table 15** – Correlations between UFP and other pollutant, by sector and activities.

Activity		CO	CO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	RH	T	
Carpentry	r	0.819**	-0.702**	-0.020	0.030	0.860**	-0.895**	
	Paint	Sig. (2-tailed)	0.000	0.000	0.750	0.710	0.000	0.000
	N	210	210	210	210	210	210	
	r	-0.050	0.010	0.524**	0.718**	0.026	-0.004	
	Sawing	Sig. (2-tailed)	0.480	0.900	0.000	0.000	0.708	0.957
	N	210	210	210	210	210	210	
	r	-0.090	-0.060	-0.292**	-0.530**	0.049	-0.029	
	Assembly	Sig. (2-tailed)	0.190	0.430	0.000	0.000	0.480	0.678
	N	210	210	210	210	210	210	
Bakery	r	0.100	0.788**	-0.140	0.050	0.192*	0.491**	
	Manufacture	Sig. (2-tailed)	0.230	0.000	0.100	0.520	0.019	0.00
	N	150	150	150	150	150	150	
	r	0.050	0.524**	0.783**	0.100	-0.075	0.824**	
	Production	Sig. (2-tailed)	0.410	0.000	0.000	0.080	0.198	0.00
	N	300	300	300	300	300	300	
	r	-0.210**	0.321**	0.010	0.386**	0.413**	-0.084	
	Dispatch	Sig. (2-tailed)	0.010	0.000	0.880	0.000	0.000	0.304
	N	150	150	150	150	150	150	
	r	0.889**	-0.162**	-0.564**	-0.645**	-0.641**	-0.303**	
	Warehouse	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.00
	N	300	300	300	300	300	300	
r	0.533**	-0.251**	-0.731**	-0.722**	0.049	-0.005		
Office	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.420	0.938	
N	270	270	270	270	270	270		
School	r	0.120	0.160	-0.090	-0.060	0.217	0.100	
	Offices	Sig. (2-tailed)	0.550	0.440	0.640	0.770	0.276	0.621
	N	27	27	27	27	27	27	
	r	0.020	-0.290	0.586**	0.781**	0.109	-0.226	
	Services	Sig. (2-tailed)	0.920	0.080	0.000	0.000	0.526	0.185
	N	36	36	36	36	36	36	
Clinic Laboratory	r	-0.130	0.320	0.618**	0.739**	0.073	-0.037	
	Reception	Sig. (2-tailed)	0.430	0.050	0.000	0.000	0.672	0.832
	N	36	36	36	36	36	36	
	r	-0.030	0.750**	0.445*	0.26	-0.004	0.016	
	Laboratory	Sig. (2-tailed)	0.860	0.000	0.020	0.190	0.985	0.936
	N	27	27	27	27	27	27	

Test: Pearson Correlation

\*\* . Correlation is significant at the 0.01 level (2-tailed).

\* . Correlation is significant at the 0.05 level (2-tailed).

In the bakery, as expected, the greatest influence is from CO<sub>2</sub>, which in areas with a higher number of workers increases the UFP. These strongly positive correlations may be due to a greater formation of these particles as well as the tasks performed allow a greater permanence or elevation of these in the air. Interestingly, in manufacturing and production there is also a strong positive correlation with Temperature. Is a local with relative high temperature, but with very large gradients, which may induce the presence of gaseous and other precursors for the formation of ultrafine particles by condensation of vapours or by favouring chemical reactions (Hussein et al., 2006; Jones et al., 2000; Manigrasso et al., 2019; Marcias et al., 2018; Viitanen et al., 2017). On the other hand, RH has a significant effect in the shipping area and less so in the production area. Again, this may be due to favouring condensation or secondary formation of UFP (Songmene et al., 2018). An unexpected influence was that of CO in the warehouse and office, which can only be justified by the contamination of the room, since it is closer to the oven area. This low occupancy is reflected in negative correlations with all other pollutants. In reality, this occupation is concentrated in the unloading of materials and the loading of raw materials into the production area, 3 to 4 times a day for short periods of time. The same reasoning applies to PM<sub>10</sub>, PM<sub>2.5</sub> and CO<sub>2</sub> in the office (Eshleman et al., 2017a; Kirešová et al., 2023).

In the school the only correlation we found is of the remaining particulate matter PM<sub>10</sub> and PM<sub>2.5</sub> in the workrooms, this may be due to the movement of materials or people and the agitation in particulate matter that makes the occurrence of this in the air. As expected at the beginning of the study the UFP values are not very relevant in this activity (Marval & Tronville, 2022; Monteiro et al., 2018).

In the Clinic Laboratory, in the reception area, as in the school, the only positive correlation is with PM<sub>10</sub> and PM<sub>2.5</sub>, most likely due to the movement of people. The strong positive correlation with CO<sub>2</sub> was not expected in the laboratories. This must be due to the density of occupation of the space and the greater constraints on ventilation, avoiding contamination, for reasons of safety of samples and results. The less significant correlation with PM<sub>10</sub> may be due to the presence and operation of equipment for the tasks.

### **3.4. Conclusions**

The assessments carried out and processed allowed us to observe the relationships between UFP and some commonly monitored parameters. One of the most important conclusions to be drawn from this study is the fact that the UFP are very high if we consider the values indicated by the WHO although almost all the other pollutants evaluated are within the reference limits. We found the expected correlations according to the studies consulted in the preparation of the study, where there is a positive correlation between the presence of UFP, either by the generation of dust or by the combustion of materials, and secondary formation, as in some cases where RH favours the appearance of UFP.

The cross-sectional study between companies that typically have sources that generate UFP and others that do not has allowed us to alert to the need to control them in all locations.

In carpentry, as expected in tasks with dust production, UFP increase with them, as well as in painting, they increase also with combustion and humidity due to the appearance of secondary formation of UFP and decrease with temperature due to particle agglutination.

In the bakery, we also obtained the expected results in manufacturing and production in which the primary and secondary generations of particles corresponded to the expected, little expected were the contaminations of the office and warehouse. Dispatch, on the other hand, benefits from ventilation to improve UFP levels.

At school, the high levels of UFP in the workrooms are the least expected and most surprising values.

The biggest novelty of the study was the presence of high levels of UFP in the Clinic Laboratory, especially in the laboratories, especially due to the occupation and little ventilation characteristic for the non-contamination of the spaces.

We can also conclude that indoor sources are the main factors for the occurrence of pollutants, since outdoor values are always lower.

It is clear that the primary sources of UFP are related, but that they are not the only source of the problem. Many of our assessments emphasise the need to control sources of PM that favour formation of UFP.

On the other hand, it is important to control the other factors CO, CO<sub>2</sub>, Temperature and RH as these are precursors of secondary UFP formation.

Key findings:

- Sources of UFP are indoor.
- All activities have high UFP levels.
- Activities without primary sources of UFP also have high levels compared to WHO guidelines.
- Occupancy rate, temperature and relative humidity are precursors of secondary UFP formation.
- Ventilation of rooms is of paramount importance to improve UFP parameters.

We must therefore realise that the control of UFP is of paramount importance for human health and the environment. Because they are extremely small particles, with diameters of less than 0.1 micrometres, they have the ability to penetrate deep into the lungs and even the bloodstream, posing a health risk. Reducing ultrafine particles is a challenge because they are difficult to filter out by conventional pollution control systems. There is an urgent need for standards and regulatory measures to control polluting sources or utilise more efficient emission control technologies. We should therefore not underestimate the importance of monitoring and controlling UFP. It is also necessary to encourage further and more in-depth studies on this subject.

### **3.5. Chapter summary**

The main sources of particulate matter are associated with anthropogenic activity. Some particulate emissions, particularly the finer ones, can have a significant impact on human health, making them one of the pollutants of greatest concern. Ultrafine particles (UFP), with a diameter of less than 100 nm, are probably the ones of greatest concern, not only because of the effect on human health, but also because of the difficulty in

controlling them. Occupational concentration levels to UFP is currently a new and increasing risk, which classifies it as an emerging risk. Human exposure routes to UFP may include inhalation via the respiratory tract; absorption via the skin; ingestion via the mouth; or combinations of these routes. The main question we want to answer with this study is what levels of UFP workers are exposed to in environments with different direct particle emission patterns. For this purpose, measurements were carried out and the results compared with the levels recommended by the WHO. The study involved monitoring industrial workplaces with direct particulate matter emissions, such as a carpentry and a bakery, as well as at social sector sites without or almost without direct particle emissions, such as a school and a Clinic Laboratory. Among the conclusions that can be drawn from this study is the fact that, contrary to expectations, there are no tasks or occupations that are not susceptible to high levels of UFP, since the values recommended by the WHO are clearly exceeded in virtually all monitored environments. We should therefore not underestimate the importance of monitoring and controlling UFP. It is also necessary to encourage further and more in-depth studies on this subject.

## **CHAPTER IV**

### **CONCLUSIONS**

Air quality is a key factor in human health and quality of life. As we spend a lot of time indoors, this problem is aggravated by staying in our homes, by social and leisure spaces, by the places where we work, and can be further aggravated by the activities that take place in the space.

These premises led us to want to develop the area, within the various pollutants existing in professional environments, particulate materials are of particular importance because they can, depending on their constitution, cause various health problems such as respiratory problems. In the last decades an emerging problem has been studied and consequently more and more inherent problems have been revealed, the ultrafine particles. These particles are so small in size (between 1 and 100 nm) that they can enter our body and pose a considerable health risk. Their ability to penetrate deep into the lungs and even enter the bloodstream, lodging in various tissues, can cause adverse health effects. Respiratory problems are a major concern, as UFPs can reach the most sensitive respiratory regions, causing tissue irritation, inflammation and irreversible lung damage. In addition, UFP have been associated with several bad health effects. The potential neurotoxicity of UFP is also a growing concern, due to their ability to cross the blood-brain barrier and potentially contribute to neurodegenerative diseases. Although limited, some research suggests that UFP may have carcinogenic potential, increasing the risk of lung, bladder and other cancers.

Three related areas of research were therefore developed. A systematic literature review that would allow us to know, in the field of occupational health, what the expected effects on work and health are, a worldwide survey that would allow us to know how different countries are dealing with the problem of UFP, how they are being assessed, in which contexts and if there are procedures, standards or regulations. Finally, a comparative study between four different activities that would allow us to verify, in a cross-sectional study, the exposure of workers to UFP. We chose a carpentry shop and a

bakery because they are traditionally particulate-generating activities, and a school and a Clinic Laboratory because they are not traditionally particulate-generating activities. In these assessments we monitored other parameters to correlate and understand the behaviour of UFP.

This problem, coupled with the fact that there are no known standards or legal references to control exposure and set protection limits for ultrafine particles, led us to challenge ourselves to conduct a review of the scientific literature to summarise the health effects and impact of ultrafine particles in indoor occupational environments.

From the systematic literature review, we can say that it presents an overview of existing studies in the literature on indoor and outdoor sources of UFP, both in the workplace and in residential environments. It covers emission factors, particle concentrations, sizes and compositions. Furthermore, it delves into the health implications of UFP and nanoparticles, focussing particularly on particles deposited in the olfactory bulb after inhalation, which can potentially reach the brain, and their link to neurodegenerative diseases - an increasingly significant topic in recent research.

In the last twenty years, in the area in which we conducted the research considering that we were looking for effects on occupational health and environment, not a large number of articles were found. The year in which the highest number of articles was found was 2021 with seven. Most articles were published between 2016 and 2019, with fewer articles published in 2020. This probably explains the even greater interest in the subject matter of the theme.

There were a few specific studies and no cross-sectional studies, but the problem is also very dependent on the primary and secondary training of the UFP, as well as their very specific behaviour in terms of half-life from minutes to hours and the way they stay in the environment.

It was also found that the adverse health effects of PM exposure, mainly caused by UFP, are widely recognised. Inhalation of fine and ultrafine particles is associated with respiratory diseases, but the specific quality, thresholds and concentrations that lead to these health effects remain less well understood. In addition, the mechanisms by which UFP from the environment and workplace induce pathophysiological responses in the

body and how these particles behave in the lungs after inhalation remain areas of limited knowledge.

The global survey provided valuable information on the assessment of UFP in various institutions around the world. It should be noted that the survey collected information from 20 different countries on five continents, making it the most extensive study on this topic to date.

Several important conclusions can be drawn from the survey:

- Lack of guidance values: The assessment of UFP lacks universally established guidance values. Currently, no country legally requires the monitoring and quantification of UFP. However, bodies such as the World Health Organisation, the International Organisation for Standardisation and the European Commission express some concern about this pollutant.
- Lack of defined protocols: There are no standardised protocols for the assessment of UFP levels. As a result, assessments employ various methodologies, making it difficult to compare results. ISO 16000-34:2018 is the only method available to measure all PM, including UFP.
- Limited knowledge of UFP: Some respondents demonstrated a lack of knowledge about UFP, often confusing them with larger particles such as PM<sub>10</sub> or PM<sub>2.5</sub>. Their choices of equipment to measure UFP indicate this confusion, as the tools selected may not be suitable for the purpose.

Given these results, it is clear that international methodologies for measuring UFP are urgently needed, as well as the establishment of health-based guideline values. Respondents, mainly academics, express concern about this emerging issue and emphasise the need for standards to monitor and control this pollutant. Until such international guidance is developed, ISO standards (ISO 16000-34:2018) are recommended for determining UFP levels, along with best practice limits suggested by the WHO.

The assessments carried out and analysed provided valuable information on the relationships between UFP and various commonly monitored parameters. A crucial finding of this study is the fact that the levels of UFP are considerably high compared to

the WHO recommended values, although most other pollutants are within acceptable limits. As expected from previous research, there is a positive correlation between the presence of UFP, whether generated through dust production or combustion of materials, and secondary formation, with humidity (RH) playing a role in some cases.

The cross-sectional study comparing companies with and without UFP-generating sources emphasised the need to control these particles at all sites. In carpentry and painting tasks, which involve dust production and combustion respectively, UFP levels increase. On the other hand, humidity triggers secondary formation of UFP, while temperature reduces particle agglutination. The bakery industry demonstrated the expected results, with primary and secondary particle production meeting expectations, with the exception of contaminations in office and warehouse spaces. Ventilation was found to benefit UFP levels in the despatch area.

In particular, the study revealed unexpectedly high levels of UFP in school and Clinic Laboratory workrooms, especially laboratories, due to poor ventilation and high occupancy. Indoor sources were identified as the main factors influencing the occurrence of pollutants, as outdoor values remained consistently lower.

The study emphasises the importance of controlling PM sources that promote UFP formation. In addition, factors such as CO, CO<sub>2</sub>, temperature and RH should be monitored and controlled as they act as precursors to secondary UFP formation.

The main findings of the evaluations were:

- Sources of UFP are predominantly indoor.
- High levels of UFP were observed in all activities.
- Even activities without primary sources of UFP have high levels compared to WHO guidelines.
- Occupancy rate, temperature and relative humidity influence the formation of secondary UFP.
- Adequate room ventilation is crucial to improve UFP parameters.

It is therefore clear that the control of UFP is of utmost importance for human health and environmental well-being. However, reducing ultrafine particles is a challenge as conventional pollution control systems have difficulty filtering them effectively. Urgent

action is needed, such as enforcing standards and regulations to control pollution sources or adopting more efficient emission control technologies. Monitoring and control of ultrafine particles should not be underestimated and further comprehensive studies in this field are essential to address this pressing issue.

Objectively answering the initial questions of the study which essentially aimed at global status, health effects and risk assessment, we have that:

- What are the main risks associated with exposure to UFP?

The risks associated with UFP are primarily respiratory, cardiovascular, and central nervous system, however there is the possibility of particles lodging in other body tissues due to their small size, these damages differ depending on the toxicity of the UFP breathed in.

- Are there significant differences in UFP formation between activities?

There are significant differences in the generation of UFP, whether by primary or secondary formation. They are influenced by the other particles and substances present as well as the occupation and tasks performed.

- Can differences in UFP formation justify monitoring only some activities?

All tasks can potentially result in the formation of UFP, therefore it is important to evaluate and control all activities.

- What are the activities with the highest UFP formation?

Carpentry and Bakery, perhaps due to the primary formation of the particles, have higher UFP values, however we cannot say absolutely that this is the only cause.

These conclusions are relevant to what can be the study and enrichment of academic studies, if on the one hand the consequences for health are increasingly evident and substantiated, we cannot neglect the need for information and knowledge about the area. Given the inconstancy, impossibility and existence of UFP in all activities, there is clear evidence of the need to create rules and procedures in order to know the exposure of both workers and the general population and this study contributes in a valid and concrete way in this path. Being an academic study, it is still of high relevance for the scientific advancement on UFP and all the inherent problems.

It was able to prove the numerous health risks of exposure to UFP by researching and collecting valid and coherent peer-reviewed literature from the academic community. It also highlighted the lack of regulation and procedures for the assessment and monitoring of UFP.

Even so, this thesis has some limitations, the number of participants in the questionnaire could be larger and more representative, be broader in the companies and parameters evaluated and could represent a larger sampling fringe. These limitations, although they do not call into question the validity and applicability of the study, allow us to recognise what could be the future path to follow in this area.

It is expected that this study will be one of the drivers of new studies and knowledge on the topic at national and international level. It is also intended to be included in the reflections and discussions that arise for the creation of standards and regulations for the monitoring of UFP control.

Looking ahead, the researchers intend to conduct more area-specific assessments, evaluating the health impact on occupants, workers or users of the spaces. This approach will provide a deeper understanding of health effects and help to design effective strategies for the assessment and protection of UFP. It is intended to do more targeted studies, with higher correlation of parameters and on specific activities, enriching the studies in the area. Subsequently, it is intended to aggregate these same studies in order to correlate activities and possible patterns of UFP occurrences. These studies can be of great importance for the creation of control mechanisms for UFP. It is also intended to create strategies and protocols for the control of workers' health.

In summary, the numerous health risks of exposure to UFP were highlighted through the search and collection of valid and coherent peer-reviewed literature from the academic community. The lack of regulation and procedures for the assessment and control of UFP was also highlighted. Despite different origins or combinations, and despite some differences, all activities have UFP training. And this existence demonstrates the need to control all activities for the protection of workers.

In short, the control of UFP levels is essential to protect human health and the environment. Given the difficulties in filtering UFP through conventional pollution

control systems, more efficient emission control technologies need to be developed. Further research on UFP and their health effects is essential to inform regulatory measures and establish effective guidelines. The application of international methodologies and the establishment of guideline values can contribute significantly to reducing adverse health effects from exposure to UFP.

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**Appendix I -Results from SLR**

**Ultrafine particles: world characterization, occupational assessment and effects on human health.**

Authors	Title	Journal	Year
Borys RD,Lowenthal DH,Mitchell DL	The relationships among cloud microphysics, chemistry, and precipitation rate in cold mountain clouds	Atmospheric Environment	2000
Jones NC,Thornton CA,Mark D,Harrison RM	Indoor/outdoor relationships of particulate matter in domestic homes with roadside, urban and rural locations	Atmospheric Environment	2000
Suwa T,Hogg JC,Quinlan KB,Ohgami A,Vincent R, Van Eeden SF	Particulate air pollution induces progression of atherosclerosis	Journal of the American College of Cardiology	2002
Hussein T,Glytsos T,Ondráček J,Dohányosová P,Ždímal V,Hämeri K,Lazaridis M,Smolík J,Kulmala M	Particle size characterization and emission rates during indoor activities in a house	Atmospheric Environment	2006
Kwasny F,Madl P,Hofmann W	Correlation of Air Quality Data to Ultrafine Particles (UFP) Concentration and Size Distribution in Ambient Air	Atmosphere	2010
Knibbs LD,Morawska L	Traffic-related fine and ultrafine particle exposures of professional drivers and illness: An opportunity to better link exposure science and epidemiology to address an occupational hazard?	Environment International	2012
Knibbs LD,Morawska L	Traffic-related fine and ultrafine particle exposures of professional drivers and illness: An opportunity to better link exposure science and epidemiology to address an occupational hazard?	Environment International	2012
Shannahan	Manufactured and airborne nanoparticle	Inhalation	2012

**Ultrafine particles: world characterization, occupational assessment and effects on human health.**

JH,Kodavanti UP,Brown JM	cardiopulmonary interactions: A review of mechanisms and the possible contribution of mast cells	Toxicology	
Maciej Serda, Et all	Synteza i aktywność biologiczna nowych analogów tiosemikarbazonowych chelatorów żelaza	Uniwersytet śląski	2013
Geiss O,Bianchi I,Barrero-Moreno J	Lung-deposited surface area concentration measurements in selected occupational and non-occupational environments	Journal of Aerosol Science	2016
Kranjec N,Galičič A,Eržen I,Kukec A	The impact of ultrafine particles on daily counts of deaths from respiratory diseases in the Municipality of Ljubljana: A temporal variability study - Sanitarno Inženirstvo		2016
Li Y,Li P,Yu H,Bian Y	Recent advances (2010-2015) in studies of cerium oxide nanoparticles' health effects	Environmental Toxicology and Pharmacology	2016
Ragde SF,Jørgensen RB,Førelund S	Characterisation of Exposure to Ultrafine Particles from Surgical Smoke by Use of a Fast Mobility Particle Sizer	Annals of Occupational Hygiene	2016
Bourdrel T,Bind MA,Béjot Y,Morel O,Argacha JF	Cardiovascular effects of air pollution	Archives of Cardiovascular Diseases	2017
Eshleman EJ,LeBlanc M,Rokoff LB,Xu Y,Hu R,Lee K,Chuang GS,Adamkiewicz G,Hart JE	Occupational exposures and determinants of ultrafine particle concentrations during laser hair removal procedures	Environmental Health: A Global Access Science Source	2017
Fireman E,Edelheit R,Stark M,Shai AB	Differential pattern of deposition of nanoparticles in the airways of exposed	Journal of Nanoparticle	2017

**Ultrafine particles: world characterization, occupational assessment and effects on human health.**

	workers	Research	
Wang D,Guo H,He C	An investigation on particle emission from a new laser printer using an environmental chamber	Indoor and Built Environment	2017
Jordakieva G,Grabovac I,Valic E,Schmidt KE,Graff A,Schuster A,Hoffmann- Sommergruber K,Oberhuber C,Scheiner O,Goll A,Godnic-Cvar J	Occupational exposure to ultrafine particles in police officers: No evidence for adverse respiratory effects	Journal of Occupational Medicine and Toxicology	2018
Marcias G,Fostinelli J,Catalani S,Uras M,Sanna AM,Avataneo G,De Palma G,Fabbri D,Paganelli M,Lecca LI,Buonanno G,Campagna M	Composition of metallic elements and size distribution of fine and ultrafine particles in a steelmaking factory	International Journal of Environmental Research and Public Health	2018
Marcias G,Fostinelli J,Catalani S,Uras M,Sanna AM,Avataneo G,De Palma G,Fabbri D,Paganelli M,Lecca LI,Buonanno G,Campagna M	Composition of metallic elements and size distribution of fine and ultrafine particles in a steelmaking factory	International Journal of Environmental Research and Public Health	2018
Songmene V,Kouam J, Bahloul A	Effect of minimum quantity lubrication (MQL) on fine and ultrafine particle emission and distribution during polishing of granite	Measurement: Journal of the International Measurement	2018

**Ultrafine particles: world characterization, occupational assessment and effects on human health.**

		Confederation	
Manigrasso M, Protano C,Vitali M,Avino P	Where Do Ultrafine Particles and Nano-Sized Particles Come From?	Journal of Alzheimer's Disease	2019
Marcias G, et all.	Occupational fine/ultrafine particles and noise exposure in aircraft personnel operating in airport taxiway	Environments - MDPI	2019
Moreno T, Pacitto A, Fernández A, Amato F,Marco E, Grimalt J, Buonanno G, Querol X	Vehicle interior air quality conditions when travelling by taxi	Environmental Research	2019
Sanchez-Crespo A	Lung Scintigraphy in the Assessment of Aerosol Deposition and Clearance	Seminars in Nuclear Medicine	2019
Su WC,Chen Y,Xi J	A new approach to estimate ultrafine particle respiratory deposition	Inhalation Toxicology	2019
Schraufnagel DE	The health effects of ultrafine particles	Experimental and Molecular Medicine	2020
Su WC,Chen Y,Xi J	Estimation of the deposition of ultrafine 3D printing particles in human tracheobronchial airways	Journal of Aerosol Science	2020
Audignon-Durand S,Gramond C,Ducamp S,Manangama G,Garrigou A,Delva F,Brochard P,Lacourt A	Development of a Job-Exposure Matrix for Ultrafine Particle Exposure: The MatPUF JEM	Annals of Work Exposures and Health	2021
Boccuni F,Ferrante R,Tombolini F,Iavicoli S,Pelliccioni A	Relationship between indoor high frequency size distribution of ultrafine particles and their metrics in a university site	Sustainability (Switzerland)	2021
Boudjema J,Lima	Metal enriched quasi-ultrafine particles	NanoImpact	2021

**Ultrafine particles: world characterization, occupational assessment and effects on human health.**

B,Grare C,Alleman LY,Rousset D,Perdrix E,Achour D,Anthérieu S,Platel A,Nesslany F,Leroyer A,Nisse C,Lo Guidice JM,Garçon G	from stainless steel gas metal arc welding induced genetic and epigenetic alterations in BEAS-2B cells		
Hachem M,Saleh N,Bensefa-Colas L,Momas I	Determinants of ultrafine particles, black carbon, nitrogen dioxide, and carbon monoxide concentrations inside vehicles in the Paris area: PUF-TAXI study	Indoor Air	2021
Leso V,Ercolano ML,Mazzotta I,Romano M,Cannavacciuolo F,Iavicoli I	Three-Dimensional (3D) Printing: Implications for Risk Assessment and Management in Occupational Settings	Annals of Work Exposures and Health	2021
Pasquiou A,Pelluard F,Manangama G,Brochard P,Audignon S,Sentilhes L,Delva F	Occupational exposure to ultrafine particles and placental histopathological lesions: A retrospective study about 130 cases	International Journal of Environmental Research and Public Health	2021
Trechera P,Moreno T,Córdoba P,Moreno N,Zhuang X,Li B,Li J,Shangguan Y,Dominguez AO,Kelly F,Querol X	Comprehensive evaluation of potential coal mine dust emissions in an open-pit coal mine in Northwest China	International Journal of Coal Geology	2021
Marval J,Tronville P	Ultrafine particles: A review about their health effects, presence, generation, and measurement in indoor environments	Building and Environment	2022
Fonseca JA,Pereira MC,Slezáková K,de	Indoor ultrafine particles evaluation of pre-school environments		2013

**Ultrafine particles: world characterization, occupational assessment and effects on human health.**

Engenharia UP			
Cartieaux E,Rzepka MA,Cuny D	Mise au point: Qualité de l'air à l'intérieur des écoles	Archives de pédiatrie	2011
Wallace L,Howard-Reed C	Continuous Monitoring of Ultrafine, Fine, and Coarse Particles in a Residence for 18 Months	Journal of the Air & Waste Management Association	2002
Glantz SA	Air pollution as a cause of heart disease: Time for action	Journal of the American College of Cardiology	2002
Pietrojusti A,Magrini A	Engineered nanoparticles at the workplace: Current knowledge about workers' risk	Occupational Medicine	2014
Viitanen AK,Uuksulainen S,Koivisto AJ,Hämeri K,Kauppinen T	Workplace measurements of ultrafine particles-A literature review	Annals of Work Exposures and Health	2017
Zhao Y,Wang F,Zhao J	Size-Resolved Ultrafine Particle Deposition and Brownian Coagulation from Gasoline Vehicle Exhaust in an Environmental Test Chamber	Environmental Science and Technology	2015
Castro AH,Silva GM,Araújo RS	Qualidade Do Ar – Parâmetros De Controle E Efeitos Na Saúde Humana: Uma Breve Revisão	Holos	2014

**AppendixII– Internacional Survey**

# Characterisation of frequency and methodology for ultra fine particles assessment

This survey was created during the PhD. degree in Ecology and Environmental Health at University Fernando Pessoa, Porto, Portugal ([www.ufp.pt](http://www.ufp.pt)).

Research team:

- PhD. student Fernando Moreira MSc. ([fernando.moreira@estesc.ipc.pt](mailto:fernando.moreira@estesc.ipc.pt))
- Supervisor Professor Doctor Nelson Barros

This survey aims to characterise the different methods and frequency, to analyse and quantify indoor and occupational ultra fine particles, and takes 3 minutes to respond.

Data protection

The collection of personal data (email address is optional) serves the only purpose of allowing the option at the end of the survey to indicate whether they wish to receive study results information. No personal data will be published during survey evaluation or any other survey-related publications.

ELECTRONIC CONSENT

Clicking on the "Next" button below indicates that:

- you have read the above information
- you voluntarily agree to participate
- you are at least 18 years of age

---

\* Indica uma pergunta obrigatória

## Demographics

1. 1 - Age \*

*Marcar apenas uma oval.*

<25

26-35

36-45

46-55

>56

08/07/23, 19:01

Characterisation of frequency and methodology for ultra fine particles assessment

2. 2 - Gender \*

*Marcar apenas uma oval.*

- Male  
 Female  
 Other

3. 3 - Country \*

---

4. 4 - Professional area \*

---

5. 5 - Working In (tick all that apply) \*

*Marcar tudo o que for aplicável.*

- Education Institution (non hospital)  
 Hospital or Teaching Hospital  
 Research Centre  
 Regulator

6. 5 - Main Area of practice/research (tick all that apply) \*

*Marcar tudo o que for aplicável.*

- Occupational Health  
 Public Health  
 Environmental  
 Other

08/07/23, 19:01

Characterisation of frequency and methodology for ultra fine particles assessment

7. 6 - Do you have experience on the assessment of indoor ou occupational air quality? \*

*Marcar apenas uma oval.*

- Yes  
 Yes, some.  
 No

Ultra fine particles assessment national regulation

8. 7 - The assessment of indoor ultra fine particles exposure is performed in your country? \*

*Marcar apenas uma oval.*

- Yes  
 No  
 I don't know

9. 8 - The assessment of occupational ultra fine particles exposure is performed in your country? \*

*Marcar apenas uma oval.*

- Yes  
 No  
 I don't know

10. 9 - Your country have legislation about indoor ultra fine particles exposure? \*

*Marcar apenas uma oval.*

- Yes  
 No  
 I don't know

08/07/23, 19:01

Characterisation of frequency and methodology for ultra fine particles assessment

11. 10 - Your country have legislation about occupational ultra fine particles exposure? \*

*Marcar apenas uma oval.*

- Yes  
 No  
 I don't know

12. 10 - Do you use a method to assess ultra fine particles exposure? \*

*Marcar apenas uma oval.*

- Yes  
 No *Avançar para a pergunta 20*

Methodology for ultra fine particles assessment

13. 11 - The method use for ultra fine particles assessment is based on \*

*Marcar apenas uma oval.*

- Estimation considering the environment *Avançar para a pergunta 14*  
 Measurement with specific equipment *Avançar para a pergunta 15*

Estimation methodology

14. Please describe a summary of the methodology and guidelines used for the estimation of ultra fine particles assessment that you regular use \*

---

---

---

---

---

*Avançar para a pergunta 20*

08/07/23, 19:01

Characterisation of frequency and methodology for ultra fine particles assessment

Measurement methodology

15. Identify the equipment brand and model that you regular use for ultra fine particles assessment \*

---

16. The measurement occur during \*

*Marcar apenas uma oval.*

- 1 minute  
 2 to 4 minutes  
 5 to 10 minutes  
 11 to 15 minutes  
 More than 15 minutes

17. The measurement is repeat \*

*Marcar apenas uma oval.*

- Once  
 Two times  
 Tree time  
 More than tree times

18. The measurement is performed (tick all that apply) \*

*Marcar tudo o que for aplicável.*

- Before the occupation/activity  
 During the occupation/activity  
 After the occupation/activity



08/07/23, 19:01

Characterisation of frequency and methodology for ultra fine particles assessment

19. The equipment is positioning (tick all that apply) \*

*Marcar tudo o que for aplicável.*

- Without a specific position from the floor
- 1 meter from the floor
- 1.50 meters from the floor
- Point central area
- Near to the possible source

*Avançar para a pergunta 20*

Results dissemination

20. If you wish to receive information about the results of this study please write your email

\_\_\_\_\_

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Este conteúdo não foi criado nem aprovado pela Google.

Google Formulários

## Ultrafine particles: world characterization, occupational assessment and effects on human health.

08/07/23, 19:01

Characterisation of frequency and methodology for ultra fine particles assessment

**Appendix III – Ultrafine particles - formation, contamination and health effects –  
a literature review**

**ULTRAFINE PARTICLES - FORMATION,  
CONTAMINATION AND HEALTH EFFECTS  
– A LITERATURE REVIEW**

**Abstract** This reviews literature studies on indoor (workplace and residential) and outdoor sources of ultrafine particles. Information is provided on relevant emission factors, particle concentrations, sizes and compositions, and the health relevance of ultrafine particles and Particulate Matter is discussed. ultrafine particles are defined as particles with an aerodynamic diameter of less than 100 nm. Special attention is given to the fraction of particles deposited in the olfactory bulb after inhalation, as these particles can potentially reach the brain and their possible role in neurodegenerative diseases is an important topic in recent literature. They are thought to be one of the main contributors to the adverse health effects of particulate matter exposure. This is due to their extremely small size. Inhalation exposure to fine and ultrafine particles is associated with respiratory disease. However, little is known about the quality, thresholds and concentrations of these particles that cause adverse health effects. Exposure to UFP in the environment and in the workplace is known to cause adverse health effects. However, little is known about how these aerosols trigger the development of pathophysiological mechanisms in the body or how ultrafine particles behave in the lung after inhalation.

**Keywords** Ultrafine Particles; Air Quality; Occupational Health 1. Introduction

According to health guidelines, as the population grows, with 54% of the world's population currently living in urban areas, most residents live in cities with inadequate air quality. In fact, in the last two decades, several studies show that air pollution, especially in urban environments, has become a major concern (Capitão et al., 2018; Kwasny et al., 2010; Kwon et al., 2020).

In addition to poor outdoor air quality the top five environmental risks to public health is indoor air pollution, with pollutant levels inside buildings being two to five times higher than outdoors, and in extreme cases, being 100 times higher. Currently,

society spends much of its day indoors, in personal and occupational activities making these levels of contamination of great importance (Knibbs & Morawska, 2012; Nunes, 2018).

Indoor air pollution can be characterized by the presence of chemical, physical or biological pollutants in the indoor air of buildings, such as in schools, offices, homes and commercial and service buildings and also inside the means of transport (Marval & Tronville, 2022). The characterisation of indoor sources is much less defined. Buildings provide moderate but incomplete protection against outdoor UFP. The infiltration of outdoor UFP is quantified by the infiltration factor, which in turn depends on several parameters, such as building construction characteristics, air exchange mechanisms, outdoor meteorological conditions and indoor air circulation. (Bocconi et al., 2021). Other sources that contribute to increased indoor air pollution are outdoor air, smoke, cleaning activities, humidity, and proximity to main roads and industrial activities (Moreno et al., 2019).

Ultrafine particles (UFP) are generally defined as the fraction of particles with a diameter of less than 100nm and, due to their size, they manage to enter the bloodstream, causing several adverse effects on the health of the population, using inhalation as the main route of entry into the body (Marcias et al., 2019). Several epidemiological studies associate the presence of ultrafine particles in the atmosphere with total mortality, respiratory and cardiovascular causes, acute airway inflammation, compromised lung function, and increased asthma symptoms. These particles in the outdoor environment are formed through natural and anthropogenic sources that can enter the indoor environment through ventilation (Monteiro et al., 2018; Viitanen et al., 2017) and can enter the human body by inhalation, through the respiratory tract; by absorption, through the skin; by ingestion, through the mouth or a combination of these. It is very likely that inhalation is the most important route of human exposure to these particles. In this way, and due to their size and other characteristics, ultrafine particles can reach the alveolar region, giving rise to inflammatory processes in the lungs and subsequent cardiovascular morbidity and mortality (Jordakieva et al., 2018).

Bearing in mind that society spends a lot of time in closed spaces, it is important to monitor the air quality, as well as implement preventive measures, in order to safeguard human health (Bourdrel et al., 2017).

## **2. Materials and Methods**

A SLR was carried out in order to find, select, analyse and systematize information on Ultrafine Particles. This information was published in recent research papers focusing on UFP in the occupational environment and their impacts on human health. SLR are based on a replicable, scientific and transparent process that comprises a logical sequence (Snyder, 2019):

- Planning the review process;
- Carrying out the review;
- Elaboration and dissemination of the results obtained.

Through SLR, it is possible to synthesize knowledge about the topic that is intended to be deepened, identifying research trends, as well as the gaps that exist and ways to fill them.

In the first stage of this SLR, the planning of the review process was done by selecting the keywords and topics to be addressed. Using three online research databases: B-on, Science Direct and Web of Science were then consulted. According to the objective of the present study, keywords used were UFP Ultrafine Particles combined with Occupational Health and Health Effects. How studies focusing on Ultrafine Particles can include UFP. Selection criteria were: peer review, combination of keywords and year of publication of articles after 2002.

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology is a set of guidelines that aims to improve the quality and transparency of systematic reviews and meta-analyses in the scientific literature. It is a widely used tool to ensure consistency and improve the presentation of systematic reviews, making it easier for readers to assess the validity and reliability of the results.

The main steps of the PRISMA methodology are (Page et al., 2021):

1. Protocol Development: Defining a detailed protocol before starting the systematic review is essential. The protocol should include the eligibility criteria of the studies, search strategy, data extraction and analysis.
  2. Search Identification: Describe the search sources used, such as databases, online libraries, and other means of identifying relevant studies.
  3. Selection Criteria: Specify the inclusion and exclusion criteria of the studies, such as the type of study, target population, intervention or exposure, outcomes and publication period.
  4. Selection Process: Detail the strategy for selecting studies, including the initial screening process based on titles and abstracts and the full assessment of relevant articles.
  5. Data Extraction: Explain how data will be extracted from the selected studies, including information on participants, interventions, outcomes, methodology and results.
  6. Assessment of Risk of Bias: Describe the approach to assessing the risk of bias in individual studies as well as the overall quality of the evidence.
  7. Synthesis of Results: Present the results of the studies included in the review clearly and objectively, using tables, graphs and meta-analyses to combine the quantitative data.
  8. Appraisal of the Quality of the Evidence: Consider the overall quality of the evidence and provide an assessment of the servitude (degree of confidence) in the outcome estimates.
-

9. Discussion and Conclusions: Interpret the results, highlighting clinical or practical implications and providing recommendations for future research.

PRISMA also recommend that authors report the sources of funding for the review, any potential conflicts of interest, any acknowledgements, and a complete list of references (Page et al., 2021).

We therefore turned to three scientific search engines:

B-On - The Online Knowledge Library (b-on) is an initiative that offers unlimited, permanent access to the full texts of thousands of scientific journals and eBooks online from renowned content providers. Through nationally negotiated subscriptions, it provides access to higher education and research institutions, enabling them to enjoy a vast range of scientific information. Launched in March 2004, b-on already had a large collection of scientific publications available at that time and has since become a reference in access to international scientific information. ([www.b-on.pt](http://www.b-on.pt) in 09/10/2022).

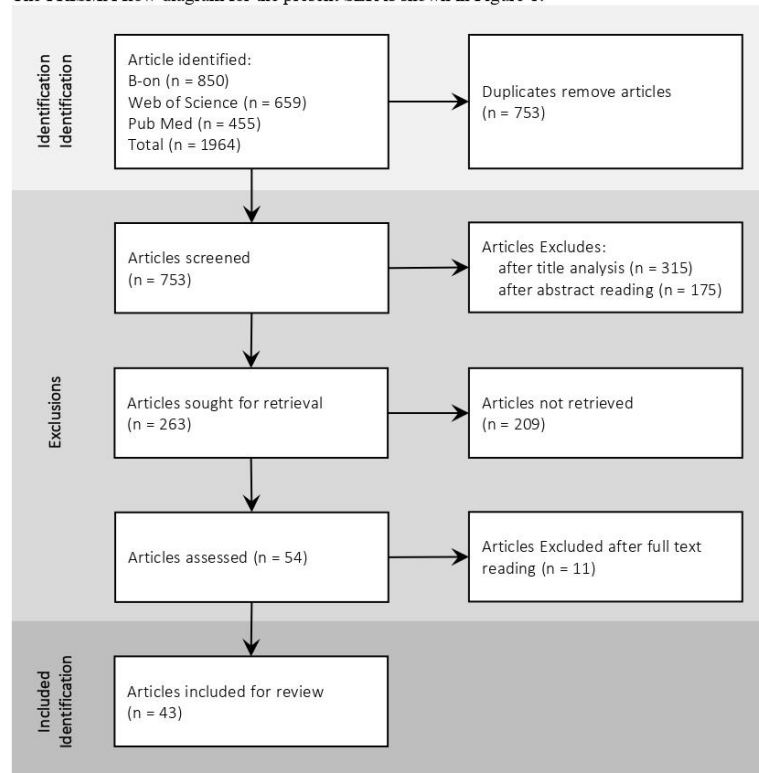
Pub-Med - PubMed is one of the largest and most important bibliographic databases specialising in scientific publications in the biomedical and life sciences fields. Maintained by the National Center for Biotechnology Information, a part of the US National Institutes of Health, the platform has become a key resource for researchers, health professionals, students and others interested in finding relevant information related to medical, biological and health topics. Since 1994, PubMed has established itself as an essential source for health professionals, scientists, students and anyone seeking to keep up to date with the latest research and advances in the biomedical and life sciences fields. (<https://pubmed.ncbi.nlm.nih.gov> in 09/10/2022).

The Web of Science (formerly known as Web of Knowledge) is a website that provides subscription-based access to multiple databases that provide comprehensive citation data for many different academic disciplines. It was originally produced by the Institute for Scientific Information (ISI) and is currently maintained by Clarivate Analytics. Web of Science is described as a unifying research tool that allows the user to acquire, analyse and disseminate database information in a timely manner. This is realised due to the creation of a common vocabulary, called ontology, for varied search terms and varied data. In addition, search terms generate related information across categories. Acceptable Web of Science content is determined by an evaluation and selection process based on the following criteria: impact, influence, timeliness, peer review, and geographic representation (Boccuni et al., 2021). Web of Science employs several search and analysis capabilities. First, citation indexing is employed, which is enhanced by the ability to search for results across disciplines. The influence, impact, history and methodology of an idea can be followed from the first instance, notice or reference to the present day. This technology points to a deficiency of the keyword-only search method. ([www.webofscience.com](http://www.webofscience.com) in 10/10/2022).

The bibliographic databases were searched in November and December 2022. The keywords used: Health Effects, Ultrafine Particles and Occupational Health. A

total of 1964 records were found, reduced to 668 articles after removing duplicates. The first screening of articles was derived from 753 articles after removing duplicate records. The first screening of articles was derived from a title, excluding those that did not specifically focus on Ultrafine Particles from a title analysis, then those that did not fit with occupational health effects and later with health effects were excluded. This stage reduced the sample to 263 articles. The abstracts were then read and at this stage the sample was reduced to 43 articles, of which 28 were used by the author.

The PRISMA flow diagram for the present SLR is shown in Figure 1.



**Figure 1** – PRISMA flow diagram for the present SLR.

For the SLR textual analysis, we also used the application IRaMuTeq - Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires. This is a free tool for the analysis of textual and questionnaire data. It has been developed in R, a programming language widely used for statistical analysis and data visualization. Was used as a tool to provide text analysis of keywords and abstracts. It is based on Software R and the python programming language and was developed in 2009 by Pierre Ratinaud(Snyder, 2019).

The IRAMUTEQ application is particularly useful for researchers, social scientists and students who want to extract meaningful information from large textual datasets, such as interviews, open-ended survey responses, social media texts, and others. The tool allows qualitative and quantitative analysis to be carried out in a systematic and efficient manner. IRAMUTEQ is a powerful text analysis tool that provides valuable insights for researchers who want to explore and understand qualitative and quantitative data in an integrated way. It is a useful option for studies in social sciences, psychology, communication, cultural studies and other fields that involve the analysis of textual data (Snyder, 2019).

### 3. Results and Discussion

The analysis using the IRaMuTeq software allowed the verification of some relevant data, namely, the similarity between abstracts, the frequency of themes and words used. As expected, the most recurrent words, as we can see in Figure 2, are Particles, with 180 repetitions, 137 repetitions for exposure, concentration, UFP, Ultrafine Study, high, occupational and air. The main words referred by the software are related to the formation, was emission, environmental, aerosol, smoke, outdoor, pollutant. Other references are related with the effects, are reference to level, health, deposition, cardiovascular. This are the major evidence of words used.





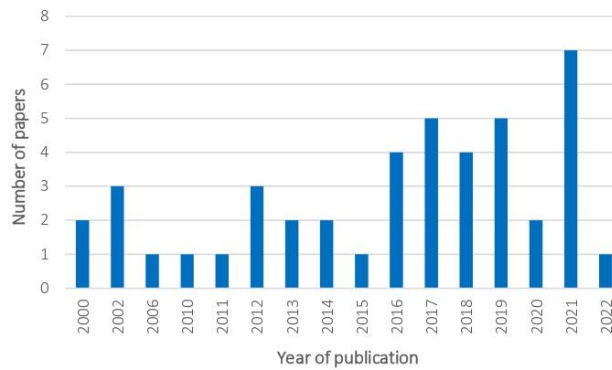


Figure 4 – Count publication year.

If we analyse Figure 4, we can see the distribution of the year of publication. The largest number of articles, seven, were published in 2021. Most articles were published between 2016 and 2019, with fewer articles published in 2020. This probably explains the even greater interest in the subject of theme.

These are the focus articles found in the bibliographic research consulted after these schematic analyses we have a close lecture of the texts can improve knowledge above the peculiarities, differences between IAQ and Occupational Exposure, and the generation of the UFP.

### 3.1 Ultrafine particles peculiarities and health effects

Particles the same size as UFP may be introduced purposely to benefit from their unique nanoscale capabilities, in addition to being released accidentally as a result of the chemical and physical changes that materials go through. They are known as nanomaterials and nanoparticles in this situation. Nanomaterials are defined as "Any form of a material that is composed of discrete functional parts, many of which have one or more dimensions of the order of 100 nm or less" and "A discrete entity which has three dimensions of the order of 100 nm," respectively (Commission, 2005).

The production of ultrafine particles in the atmosphere involves several steps. The new process of ultrafine particle formation may produce such particles. It involves the creation and formation molecular clusters and the ensuing expansion of such clusters to bigger sizes. Recognizing the initial stages of atmospheric aerosol formation requires an in-depth knowledge of neutral and charged the gaseous components, chemical makeup, and cluster densities involved in their development and creation(Ferreira et al., 2024; Marval & Tronville, 2022).

The essential feature of UFP is their rapid evolution, especially in their smaller fractions <20 nm. These particles move in diffusion-based motions via concentration gradients, so in situations with a high concentration number near emission sources, UFP easily collide with adjacent particles to coagulate into particles larger or settle on available surfaces. Moreover, particle growth mainly occurs due to the coagulation and condensation of Semi-Volatile Organic Compounds (SVOC) on the particle surface. Consequently, UFP have very short atmospheric lifetimes, generally on the order of a few hours, and their concentrations decrease rapidly (Kwon et al., 2020).

Understanding the first stages of formation of particles and aerosols requires knowledge of their formation process, as well as the cluster of physicochemical composition and aerosols. The first step of formation is nucleation with stable nuclei, of very small size, less than 2 nm, therefore very difficult to detect with the instruments used in current assessments. Thus, gaseous components such as Volatile Organic Compounds (VOC), and SVOC, interact with each other to form new nuclei or else they condensed with existing nuclei (Marval & Tronville, 2022).

The next process is coagulation, which we can define as the creation of a new particle resulting from the collision between two. These newly formed particles, an ultrafine particle, in the case of solid particles we call agglomeration and the resulting particles we determine as agglomerates (Zhao et al., 2015).

Exposure to particulate matter has been pointed out by experts as a possibility for the development of various diseases, from changes in lung function, inflammation of the upper respiratory tract, increased allergic reactions, vascular thrombosis, changes in heart rate, brain inflammation, are pathologies identified in recent studies. These are consistent with exposure to particulate matter, which is fine or ultrafine, except for the cerebral ones which are more consistent in brain pathologies (Glantz, 2002).

Mass-based measurement of UFP using current technologies is challenging due to the extremely low mass of UFP. However, to demonstrate compliance with regulatory requirements, measurements of particle number or areal concentrations alone are not sufficient because mass balance is not stored or reported in any of the units alone (Viitanen et al., 2017).

Exposure to UFP can reduce vascular reactivity and significantly reduce venous nitric oxide (NO) concentrations. The impact of these delayed and cumulative effects of UFP pollution is also debatable; the cumulative effects of high levels of UFP over 5 days are stronger than the health effects that appear shortly after exposure. This exposure is associated with a decrease in the electrical activity of the heart, which can lead to myocardial infarction (Kranjec et al., 2016). Long-term exposure studies have investigated the cardiovascular effects of air pollution after annual variations in pollutant concentration, most studies have extrapolated the level of individual exposure to air pollution, in taking into account background concentrations of pollutants or exposure to road traffic in the home (Bourdrel et al., 2017).

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The pro-inflammatory effects caused by exposure to UFP, through the oxidative stress response and with the formation of Reactive Oxygen Species (ROS), stimulate the progression of atherosclerosis and the precipitation of the cardiovascular response acute, which involves all responses from increased blood pressure to myocardial infarction and heart attack. In addition to the effect on the development of respiratory and cardiovascular diseases, UFP have other effects on human health, such as increasing levels of neutrophil biomarkers of inflammation. In patients with chronic respiratory diseases, exposure to UFP may induce a white blood cell (monocyte) immune response. UFP can modify the structure of Deoxyribonucleic acid (DNA). The contradictory effects of UFP stem, in part, from increased oxidative stress in tissues and their subsequent impairment of alveolar macrophage phagocytic capacity and phagocytic activity (Kranjec et al., 2016).

After entering the respiratory system, UFP is potentially translocated to the heart, liver and brain within minutes of being inhaled. Instead, larger particles are usually detected only in lung tissue and less likely in blood. We can conclude that UFP could reach the brain by entering directly through the olfactory bulb. Several studies have found a direct correlation between exposure to the ultrafine fraction and permanent DNA damage, as cells are subjected to systemic oxidative stress (Marval & Tronville, 2022).

### **3.2 Occupational vs. Indoor human exposure to the ultrafine fraction**

UFP are widely distributed in both indoor and outdoor environments, hence the proper indicator of their presence is their numerical concentration. Due to their size being similar to those of cellular structures, these particles may have an effect on targets inside of cells. They can also be disseminated through the blood circulation to peripheral organs thanks to their small size, which enables them to enter the respiratory system and do so with high efficiency all the way to the alveolar region. These particles surface area is a significant physical characteristic with potential health implications. Due to its capacity to absorb harmful compounds and transport them into the body, this parameter is significant (Manigrasso et al., 2019).

Almost any type of indoor activity produces a considerable amount of UFP. Thus, and according to the review of the literature, it can be said that combustion, electrical heating and cleaning are the main generators of UFP, at the level of IAQ. They also demonstrated that internal particle events are intermittent and highly variable, requiring the uninterrupted use of instruments for their characterization (Marval & Tronville, 2022).

In working environments, UFP are generated in processes involving high temperatures, in combustion, and in mechanical processes involving massive energies. Typical examples of this are respectively welding, motors and grinding. Other indoor sources in the workplace are, for example, the kitchen, office supplies and building materials. The formation and dynamics of interior UFP are described and generally occur through the nucleation of vaporized compounds or as primary particles from combustion sources. Additionally, apart from the work environment, UFP are formed from both natural and anthropogenic sources (Viitanen et al., 2017).

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UFP from external sources can enter the working environment through ventilation, which in turn influences the overall exposure load of workers. In general, exposure levels in the workplace can be higher than exposure levels in the environment and therefore the risk for some groups of workers can be higher than the average risk for the general public. In recent years in particular, the emerging industry around electrical vehicles has drawn attention to worker exposure to ultrafine sized particles. Workers can be exposed different types of UFP: engineered nanoparticles; incidental engineered nanoparticles have been measured in several workplace studies. Articles have been written on the subject (Suwa et al., 2002).

### **3.3 Generation of ultrafine particles**

In residential and commercial buildings, almost all activities are a potential source of UFP. Several studies have analysed UFP generation from everyday activities such as cooking, smoking, lighting candles, cleaning, spraying, ironing, electrical heating, vacuuming, digital and 3D printing. When assessing the UFP generation associated with a given event, in addition to the particle number concentration, it is necessary to assess the time required to reach the highest particle concentration and the time required to return, again to the background particle concentration. These parameters are essential to understand the behaviour of the particles generated by the event and to assess the dose correlated to such exposure to UFP (Marval & Tronville, 2022; Schraufnagel, 2020).

To find the initial concentration of background particles, the time required is much longer, ranging from a few tens of minutes to a few hours. The decrease in concentration follows an exponential law. Moreover, it turned out that the lower the ventilation rate, the longer the particle decay time, as expected. Particles generated by smoke seem to have the longest decay time, with values of several hours. To find the initial concentration of background particles, the time required is much longer, ranging from a few tens of minutes to a few hours. The decrease in concentration follows an exponential law. Moreover, it turned out that the lower the ventilation rate, the longer the particle decay time, as expected. Particles generated by smoke seem to have the longest decay time, with values of several hours (Wallace & Howard-Reed, 2002).

In order to establish a baseline for the background concentration, various studies have measured an average particle number concentration in microenvironments with limited human activity and no combustion activity, internal particles are highly dependent on transport dynamics and those become external. Some researchers have concluded that the ratio of internal to external particle size distribution is constant under all conditions, whether for ultrafine or larger fractions of PM. Lower infiltration values were found for ultrafine and coarse particles than for fine particles. In the case of the ultrafine fraction, this behaviour is explained by both the removal efficiency of the building's air conditioning system and deposition by Brownian diffusion (Suwa et al., 2002).

For coarse particles, such behaviour is explained by gravitational sedimentation. Deposition rates (both theoretical and experimental) in several studies were compared, concluding that indoor particle deposition depends on particle size and other site-specific conditions. Therefore, when indoor particle generation is low, human exposure to PM can be predicted by knowing the outdoor aerosol and ventilation characteristics of the building (Jordakieva et al., 2018; Monteiro et al., 2018).

On the other hand, in buildings with high indoor particle generation (e.g., restaurants), the average indoor/outdoor UFP ratio can be around 5, with peaks reaching ratio values of 14. This behavior is also typical of poorly ventilated homes (Hussein et al., 2006). Almost any type of indoor activity produces a considerable amount of UFP. Several studies have concluded that combustion, electrical heating and cleaning are the main generators of UFP. They also demonstrated that internal particle events are intermittent and highly variable, requiring the uninterrupted use of instruments for their characterization (Marval & Tronville, 2022).

Therefore, in buildings with a significant generation of indoor UFP, the particle size distribution and the internal composition are very different from the external ones. Indoor generated UFP is responsible for 50% to 80% of total indoor UFP (Wallace & Howard-Reed, 2002).

As many activities produce UFP in high concentrations, future studies on exposure and its impact on health should take a broader approach. Examining only emissions caused by traffic or other external sources leaves a critical part of the health impact unaddressed (Moreira et al., 2024).

Zhao et al. (2015) found that people are exposed to very high levels of UFP during working hours, with concentrations 550 times higher than natural levels. A study of non-smoking women in Asia found a direct link between lung cancer and occupational activities that produced UFP. It was also found that the longer the exposure time, the greater the risk of developing lung cancer (Bourdrel et al., 2017).

#### **4. Conclusions**

This document analyses literature studies on the sources of ultrafine particles that occur indoors (in the workplace and in residential areas) and outdoors. Information is provided on the relevant emission factors, particle concentrations, sizes and compositions, and the health relevance of UFP is discussed. Particular attention is paid to the proportion of particles that deposit in the olfactory bulb after inhalation, as these particles can potentially reach the brain and their possible role in neurodegenerative diseases is an important topic in recent literature. UFPs are thought to be one of the main factors contributing to the adverse health effects of exposure to PM, due to their extremely small size. The formation of PFUs can occur in various ways, mainly through natural and anthropogenic processes. These processes result in a complex dynamic of formation, growth and transformation of ultrafine particles.

These processes dictate a relatively unstable cycle and lifespan for UFP. These particularities lead to profound difficulties in monitoring UFP. This limitation greatly limits the perception of air quality and has significant impacts on human health. Inhalation exposure to fine and ultrafine particles is associated with respiratory diseases. However, little is known about the quality, thresholds and concentration of these particles that cause adverse health effects. Exposure to UFP in the environment and workplace is known to have adverse effects on health. However, little is known about how these aerosols trigger the development of pathophysiological mechanisms in the body or how ultrafine particles behave in the lungs after inhalation. The development of aerosols from different sources that can be labelled with a wide variety of radionuclides compatible with clinical gamma camera systems opens up the possibility of using lung scintigraphy images to study these causes in detail. Lung scintigraphy (planar or SPECT) allows regional mapping of aerosol deposition in the lung and dynamic assessment of particle clearance and translocation from healthy and affected human lungs. In this article, we will present the unique characteristics of lung scintigraphy in the study of aerosol clearance in humans. UFP are defined as particles with an aerodynamic diameter of less than 100 nm. The authors can therefore conclude that it is of the utmost importance to carry out more in-depth studies and to draw up monitoring procedures as well as regulations and legal limits for exposure to UFP.

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**Appendix IV – Comprehensive Global Study: Monitoring and Assessment of  
Ultrafine Particle Exposure**

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## **Comprehensive Global Study: Monitoring and Assessment of Ultrafine Particle Exposure**

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**Abstract** Several studies point to IAQ as a significant health problem. This dilemma is the proliferation of ultrafine particles (UFP), defined as particles with a diameter less than 100 nm, capable of penetrating the bloodstream and eliciting adverse health outcomes. Given the apparent absence of universal regulatory standards for UFP control worldwide, this comprehensive study endeavours to elucidate the diverse methodologies and strategies employed internationally for the monitoring and mitigation of UFP. As a first step, an exhaustive review was carried out with the aim of establishing the contemporary panorama of UFP research. To find out about global practices in evaluation by UFP researchers, a survey was carried out using a meticulously designed questionnaire. These responses provided valuable insights into the international community of UFP practitioners, encompassing their preferred measurement methodologies and the utilization of guideline values, where applicable, thereby offering a holistic portrayal of global trends in UFP control and investigation. A predominant finding was the absence of specific methodologies for UFP measurement, coupled with the lack of national standards addressing this critical issue. These findings underscore the urgent need for regulatory interventions aimed at standardizing assessment protocols and establishing guideline values to safeguard human health.

**Keywords** Ultrafine Particles; Air Quality; Occupational Health; UFP; Worldwide survey

## 1. Introduction

Particulate matter (PM) is a mixture of solid or liquid airborne particles of different sizes and compositions containing a variety of constituents such as dust, dirt, soot, pollen or small metal and plastic particles, smoke and liquid droplets, some of which may be toxic and classified as pollutant (Ferreira et al., 2024; F. M. Moreira et al., 2024).

Particle size is important because it affects how aerosols interact with their environment. Smaller particles can stay in the air longer, travel further and penetrate deeper into the lungs. Larger particles, on the other hand, are more likely to fall out of the atmosphere quickly and are less likely to reach the lungs. In addition, the size of particles can affect how they interact with other components of the environment, such as water vapor, sunlight and other pollutants. Particle size can also affect how aerosols interact with other particles, such as how they agglomerate to form larger particles. All of these factors can have a significant impact on air quality and public health (Marval & Tronville, 2022).

Either  $PM_{2.5}$  or  $PM_{10}$  also includes the fraction below 100 nm (i.e. ultrafine particles) but, in fact, Ultrafine Particles (UFP) is a minor contributor to the total mass concentration of indoor and outdoor aerosols (Marval & Tronville, 2022). For this reason, the concentration of UFP is defined as the particle number concentration (i.e. the number of particles in a given volume of air), as the mass concentration is too low to be measured reliably and effectively. There are two main aspects that differentiate UFP from larger airborne particles ( $PM_{2.5}/PM_{10}$ ) in terms of toxicology: differences in inhalation deposition (local dose) and differences in intrinsic toxicity due to physicochemical properties. Notably, associations between UFP exposure and health effects have been observed independent of other air pollution measures such as  $PM_{2.5}$  and  $NO_x$ . It is interesting to note that some UFP can translocate from the lungs to the circulatory system and other organs, while the larger PM are retained in the lungs (Casseo et al., 2019).

Ultrafine particles refer to extremely small solid or liquid particles that have a diameter in the nanometre range, usually below 100 nanometres. Because of this they have a large surface area compared to their mass, resulting in a greater interaction with the surrounding environment, making them highly reactive. This increases their potential for transport and toxicity (F. Moreira et al., 2021). UFP have a greater tendency to agglomerate, and form aggregates due to the forces of attraction between them. Because of their small size and ability to remain suspended in the air for prolonged periods, ultrafine particles are more likely to be inhaled and carried by the human body. This can lead to health and toxicity concerns (Boudjema et al., 2021; Jordakieva et al., 2018; Marval & Tronville, 2022; Sousa et al., 2021).

One of the most important anthropogenic sources of UFP is combustion of gases and pollutants. This includes primary emissions from industrial plants, vehicles and machines that use biomass or fossil fuels. Vehicle emissions, including non-exhaust emissions, are a major source of UFP in urban areas (Manigrasso et al., 2019). This process occurs when the concentration of precursor gases reaches a critical level and favourable environmental conditions, such as low temperature and high humidity, are present (Verma et al., 2009). On the other hand, looking to buildings air quality, any type of indoor activity can produce a large amount of UFP

(Jones et al., 2000). Several studies have identified sources of UFP in dwelling indoor air from activities such as cooking, smoking, burning candles, cleaning, using a spray, ironing, electric heating, vacuum cleaning and printing (Marval & Tronville, 2022; Su et al., 2019; Wallace & Howard-Reed, 2002).

Studies have shown that UFP causes systemic inflammation and coagulation changes that predispose to ischemic cardiovascular disease, circulating polymorphonuclear leukocytes, platelets, fibrinogen, plasma viscosity and other markers. UFP promotes endothelial dysfunction, vascular inflammation, and atherosclerosis. Previous studies have attributed this effect primarily to  $PM_{2.5}$ , but a growing number of studies show that UFP plays an important role in virtually all of these factors. In fact, most studies show a much broader effect, as UFP also causes increased heart rate variability, loss of sympathetic vagal balance and altered inflammatory and haemostatic functions in exposed humans (Schraufnagel, 2020).

There published work on the effects on the brain or nerves, as well as on the mechanisms by which UFP affects the brain and its development. Translocated UFP can be found in the brain after inhalation. UFP inhaled through the nose can reach the brain via the olfactory nerves. After exposure to UFP aerosols, brain uptake is greatest in the olfactory bulb, even seven days after exposure. In an animal inhalation study, up to 20% of UFP deposited on the olfactory mucosa reached the olfactory bulb. This route, which may bypass the blood-brain barrier, may be even more direct in humans. UFP not only translocate and directly damages nervous tissue, but also affects autonomic function. (Suwa et al., 2002).

Nevertheless, there is already considerable evidence of the toxicological effects of UFP. However, at an early stage, evidence from epidemiological studies was insufficient to establish guidelines, although now an increasing number of studies does support the need to establish reference guidelines (WHO, 2021).

On the other hand, the European Commission has already set out its intentions to monitoring and control the UFPs levels regarding indoor air quality in the Directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe, published on 26 October 2022 (European Parliament and Council, 2022) and WHO has also expressed concern about UFP, suggesting distinguish between low ( $< 1000 \text{ particles.cm}^{-3}$ , 24 hour mean) and high Particle Number Concentration (PNC) ( $>10\,000 \text{ particles.cm}^{-3}$ , 24 hour mean or  $20\,000 \text{ particles.cm}^{-3}$ , 1 hour) to guide decisions on priorities for emission control of UFP sources [3]. Safe Work Australia and the British Standard Institute have also provided some references and concern to UFP control (Pietroiusti & Magrini, 2014).

There seems to be a huge information gap on UFP on such common aspects as who, when and why monitors this pollutant, what means and methods they use and, finally, whether there is a guideline reference value. Based on our literature review, ISO 16000-34:2018 is the only document that provides us with a method for all the PM measurements, including UFP.

The Technical Specification CEN/TS 16976 was developed by the European Committee for Standardization (CEN) as an initial effort to standardize the continuous measurement of particle number concentration in ambient air, marking a crucial step toward harmonization in this field (Bustin et al., 2019).

Afterwards, a worldwide survey based on a questionnaire was distributed to the international scientific community. The results of that questionnaire are interpreted and discussed in this manuscript.

## 2. Materials and Methods

In order to elaborate the questionnaire presented in this work, bibliographic research was carried out in the scope of UFP, which allowed the identification of the measuring methods generally used and their gaps, as well as the knowledge of the existence, or not, of regulations in this subject.

Subsequently, a questionnaire was created in English using Google forms. To test the level of understanding and intent of the survey, ensuring its reliability, a pilot questionnaire was carried out and presented to three native English speakers and five native speakers of other languages. The pilot test included fields for comments, which were carefully analysed and considered in the review of the structure and functioning of the questionnaire. After evaluation, the questionnaire was revised and sent through the International Federation for Environmental Health (IFEH), the Portuguese Society for Environmental Health (SPSA) and other international contacts national and continental associations, such as Sociedad Española de Salud Ambiental (SESA), Association Santé Environnement France (ASEF), European Federation of Environmental Health (EFEH). These sent the questionnaire to their members who voluntarily agreed to respond.

Monitoring of indoor air pollutants and particulate matter in particular, can be done in an occupational or non-occupational setting. For this reason the questionnaire was designed taking into account this difference and questions were asked orientated to these two realities. The questionnaire was divided into 6 sections. The first section was a presentation of the questionnaire and explanation of the research. Next (section 2) was the socio-demographic characterization. In this section we asked for age, sex, country, place of work and main area of practice or research, where we had the possibility to the inquiry give their contributes in open answers, as well as whether they had experience in air quality assessment, both in indoor air quality and occupational health. In section 3, we asked about national regulations on the assessment of ultrafine particles. The questions focused on the type of UFP assessment carried out in the respondent's country, if in a non-occupational context (IAQ assessment of buildings) and/or if in an occupational health context and if there was legislation/standards for such assessment. In section 4 we only asked which method was used for the assessment of ultrafine particles, whether it was based on estimation or whether specific equipment was used. If it is by estimate, it goes to section 5; if it is by utilisation of equipment, to section 6. In section 5 only a summary of the regularly used methodology and the guidelines used for the estimation of ultrafine particles is requested. Section 6, asked about the methodology followed, the equipment used (brand and model) and measurement methodologies, i.e., duration of the sampling (1 minute; 2 to 4 minutes; 5 to 10 minutes; 11 to 15 minutes; more than 15 minutes); Number of repetitions (one, two, three, or more than 3); When is performed (before, during or after the occupation/activity) and the equipment position (without a specific position from the floor; 1 meter from the floor; 1.50 meters from the floor; in a point central area; near to the possible pollutants source).

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### 3. Results and Discussion

The questionnaire was administered to 250 organizations in 20 countries, resulting in 51 valid responses from 16 countries. A low number of responses. The researchers believe that this is due to the low level of knowledge on the subject - UFP. The results made it possible to ascertain which professions/trainings monitor/study ultrafine particles, as well as the objectives and means used (equipment and measurement methodologies applied).

The highest frequency of occurrences is in the age group 36-45 and 46-55 years, with 31.4% and 29.4% respectively. On the other hand, about 26% of the frequency is below 36 years and about 14% above 56 years.

With regard to gender, the distribution of technicians involved in this type of measurement is relatively balanced, with around 54% women and 46% men.

Concerning the participants' countries of origin, responses were obtained from 16 countries on five continents (Figure 1).

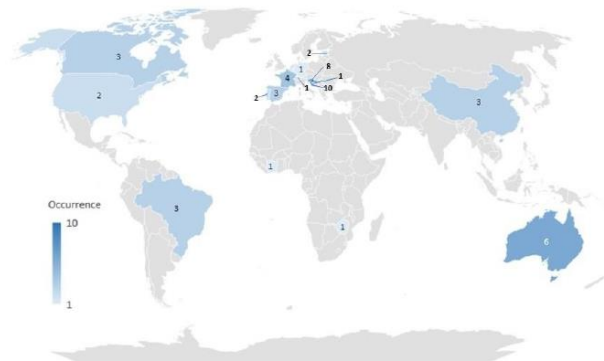


Figure 1– Countries of origin of the questionnaire participants

Over 60% are Europeans, about 16% are from American countries (which include Canada, Brazil and USA), 12% from Australia, 6% from China and 4% are from Africa. The country with the largest participation was Croatia (10 participants) and three countries had only one participation each (Belgium, Bosnia and Herzegovina and Zimbabwe).

With regard to professional affiliation, three closed options were included: Occupational safety, environmental health and academia and research. However, respondents also had the possibility to answer in an open-ended way according to

their actual professional area, which justifies the spreading of responses across other areas.

The largest proportion, almost half (43.1%), is from the environment and health sector, followed by the academic and research sector (27.5%). The remaining participants are from the occupational safety, research, biomedicine and medicine sector.

Concerning to participants workplace, they mainly work at education sector (41.2%) and regulators, with about 20% of the participants. The remaining participants work in research centres and other locations, which may indicate that UFP is being assessed, not only for research, but in routine measurements in worker protection.

There is a large convergence in the domains of work of the respondents, mostly oriented towards public and environmental health, being lower for those who answered working in the area of occupational health. These values are similar to what would be expected, since the vast majority of the studies found are in the field of indoor and outdoor air quality, which is effectively studied by public health and environmental health (Manigrasso et al., 2019; Morales Betancourt et al., 2017).

Participants were also asked if they had experience in measuring UFP. More often, 37.3%, stated that they had no experience of measuring UFP, while 33.3% reported having some experience. A slightly smaller proportion (29.4%) reported having experience. As a new area of intervention, these values are not surprising and are in line with studies that point to the lack of studies and the need for more and better studies in different countries worldwide (Boccuni et al., 2021; Kirešová et al., 2023; WHO, 2021).

We also asked if they realise the assessment by equipment or estimation. All of the participants said they use equipment's for measure UFP.

When participants were asked whether they knew if UFP monitoring is carried out in their country for buildings IAQ assessment, it was found that, 70.6% said yes, 25.5% said they did not know and only 3.9% said no (Table 1).

Table 1 – UFP monitoring objectives in the collected responses.

		Occurrence	Frequency (%)
Buildings IAQ	No	2	3.9
	Yes	36	70.6
	I don't know	13	25.5

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	Total	51	100.0
	No	4	7.8
	Yes	25	49.0
Occupational (indoor)	I don't know	22	43.1
	Total	51	100.0

Regarding occupational indoor assessment, in Table 2 can be observed that there is less reference to measurements being taken, with only 49% of the respondents saying yes. A very similar number, 43.1%, say do not know and an insignificant number, 7.8%, say that this type of measurement is not carried out. In fact, from the literature review, the studies and assessments published about UFP are in very specific areas, such as during laser hair removal procedures (Eshleman et al., 2017), steel industry, police officers (Jordakieva et al., 2018), taxi drivers (Moreno et al., 2019) or occupational exposure to particulate UFP in metal additive manufacturing (Sousa et al., 2021).

Table 2 – National Legislation and standards in UFP.

		Occurrence	Frequency (%)
	No	12	23.5
	Yes	23	45.1
Buildings IAQ	I don't know	16	31.4
	Total	51	100.0
	No	8	15.7
	Yes	25	49.0
Occupational (indoor)	I don't know	18	35.3
	Total	51	100.0

On the other hand, in the questionnaire there is a higher number of answers that refer to the IAQ assessment in buildings. We believe that this can be justified by the growing interest in this area of research in recent years, in particular after the COVID 19 pandemic.

From all the answers to the questions asked on this matter, one gets the idea of uncertainty on the part of those who are making the UFP measurements about the reason/objective for the measurement.

When we asked the participants about the existence of standards and legislation in the control and monitoring of UFPs, some mentioned their existence (Table 2).

In fact, 45.1% of respondents for buildings IAQ assessments and 49% for occupational assessments confirmed the existence of legislation or legal standards in their country. Only 23.5% of respondents for buildings IAQ assessments and 15.7% for occupational assessments, respectively, stated that there was no standard or legislation applicable to UFP in their country. It should be noted that about 1/3 of the respondents did not know whether or not there were standards or legislation in their country. These figures contradict the previous literature review conducted in this work where no references to legal standards for the assessment or control of UFP were identified, either for indoor air quality assessment or occupational health control.

Nevertheless, as mentioned earlier, concern about UFP has already led the Guideline Development Group from World Health Organization to establish best practice limits (WHO, 2021) and the European Parliament and the Council to propose an obligation to measure UFP in their Directive on ambient air quality and cleaner air for Europe, published on 26 October 2022 (European Parliament and Council, 2022).

From these responses, we begin to realize that there may be some confusion between measurements of UFP and those of buildings IAQ assessments or occupational exposure to PM<sub>2.5</sub> or PM<sub>10</sub> particulates. Particularly, only in recent years, emerging industry has drawn attention to worker exposure to ultrafine particles. These have been measured in several workplace studies and several review articles have been written on the subject [23, 22]. Safe Work Australia proposes to include standards aggregates and agglomerates with a size >100nm, leaving the threshold undefined. In this guidelines UFP are categorized into different risk groups, which may vary from organization to organization. In the British Standard Institute's approach, four groups provide a basis for categorizing nanomaterials, but without defined values (Pietrojusti & Magrini, 2014). In fact, workers are exposed to UFP in a variety of work environments, but this exposure is not currently regulated as a separate part of the usual occupational exposure limits (Viitanen et al., 2017).

When asked whether they use a legally established methodology for UFP measurements, only 23.5% said yes and 76.5% answered no (Table 3).

Table 3 – Legally established methodology for UFP measurements

	Occurrence	Frequency (%)
No	39	76.5
Yes	12	23.5
Total	51	100.0

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When the participants were asked about the duration of the measurements and the routine of the procedures, we obtained some relevant results. Of the 51 participants, only twelve (24%) mentioned the existence of a routine in the measurements. The vast majority (76.5%), did not know or did not answer on this subject. Given these data, apparently UFP is not routinely measured for occupational health or for indoor air quality control purposes in buildings (Table 4).

Table 4 – Measure time and routine in UFP assessments

		Occurrence	Frequency (%)
Measure Time	1 min	2	3.9
	5 to 10 min	6	11.8
	more than 15 min	4	7.8
	doesn't know or doesn't answer	39	76.5
Measure routine (number of measures made in each point)	one	3	5.9
	three	3	5.9
	More than three	6	11.8
	doesn't know or doesn't answer	39	76.5

Considering the equipment mentioned, only 14 (27,5%) of the participants reveal the equipment they use to perform the quantification of UFP. Table 5 shows the equipment used by the responders of the survey.

Table 5 – Equipment used by the responders of the survey in their assessments.

	Occur- rence	Frequency (%)
GRIMM	2	3.9
Laser Particle Sensor PM2008-API PM2008-API	5	9.8
FLUKE 985 particle counter	2	3.9
TSI counter	4	7.8
not known	1	2.0
Total	14	27.5

It was possible to verify the variability of the equipment used, some accurate and advanced, such as the Laser Particle Sensor PM 2008-API, whose cutting-edge technology allows the sample characterization by size (5 particles) or the TSI UFPs Counter, specifically designed for occupational hygiene (4 participants), or the Grim which later allows an evaluation with quantification in the laboratory. However, two of the participants reported using the FLUKE 985, designed for PM2.5 and PM10 assessment and not applicable to UFP measurement. Again, we believe that this confusion may be related to the fact that there is no specific regulation or legislation defining UFPs.

## 5. Conclusions

The added value of implementing this survey is a global understanding of how UFP are being evaluated in different institutions around the world. In fact, information was obtained from 20 different countries in five continents making this survey, to the best of the authors' knowledge, the most extensive work done on this subject.

The following conclusions could be drawn:

- This study sheds light on the current landscape of ultrafine particle (UFP) monitoring and regulation, revealing significant gaps and challenges. Despite the growing recognition of UFP's potential health impacts, particularly in indoor environments and occupational settings, there appears to be a lack of clear guidelines and standardized methodologies for their assessment. The survey conducted among professionals in various countries indicates a notable uncertainty regarding UFP measurement objectives, methodologies, and regulatory frameworks.
- Key findings suggest that while there is some awareness and engagement in UFP monitoring, especially in building indoor air quality assessments,

a substantial portion of respondents lack experience or clear understanding of UFP measurement practices. Moreover, the absence of standardized methods and legislation specific to UFP monitoring poses a considerable challenge in ensuring accurate and consistent assessments across different contexts.

- The discrepancy between reported UFP monitoring practices and the absence of established regulations underscores the need for concerted efforts to develop comprehensive guidelines and standards. Such initiatives would not only facilitate more reliable and comparable UFP assessments but also help mitigate potential health risks associated with exposure to these particles. Furthermore, enhanced collaboration among international organizations, regulatory bodies, and research communities is essential to address the complex challenges surrounding UFP monitoring and regulation effectively.

Overall, this study underscores the urgency of prioritizing UFP monitoring and regulation, given their significant implications for public health and environmental quality. By bridging the existing gaps in knowledge and practices, policy-makers and stakeholders can better protect individuals and communities from the adverse effects of UFP exposure, ultimately contributing to improved air quality and human well-being.

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**Appendix V – Determination of Occupational Exposure to  
Ultrafine Particles in Different Sectors of Activity**



Article

# Determination of Occupational Exposure to Ultrafine Particles in Different Sectors of Activity

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**Abstract:** The primary sources of ultrafine particulate matter are linked to human activity. Certain particulate emissions, particularly those of a finer nature, can significantly impact human health, making them one of the most concerning pollutants. Ultrafine particles (UFPs), which have a diameter of less than 100 nm, are of particular concern due to their impact on human health and the difficulty in controlling them. The concentration of ultrafine particles (UFPs) in the workplace is a growing concern and is classified as an emerging risk. Workers may be exposed to UFPs through inhalation, skin absorption, ingestion, or a combination of these routes. This study aims to determine the levels of UFP exposure among workers in environments with varying direct particle emission patterns. Measurements were conducted to compare the results with the levels recommended by the WHO. The study monitored industrial workplaces with direct particulate matter emissions, such as a carpentry workshop and a bakery, as well as social sector sites without or almost without direct particle emissions, such as a school and a health clinic. One conclusion drawn from this study is that all tasks and occupations are susceptible to high levels of UFPs, exceeding WHO recommended values in virtually all monitored environments. Therefore, monitoring and controlling UFPs is crucial. Further in-depth studies on this subject are also necessary.

**Keywords:** ultrafine particles (UFPs); occupational health; air quality



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## 1. Introduction

Over time, man has found polluted air to be harmful to health and well-being. Indoor air can be contaminated by several emissions of different contaminants, thus becoming an increasing environmental concern [1].

Today, we spend around 90% of our lives inside places such as offices, homes, schools, vehicles, aeroplanes, and other spaces. Consequently, the way that these environments are designed and used has a profound impact on the health of their occupants [2].

Exposure to air pollutants is associated with several effects on human health. Studies indicate that such effects have been present since the beginning of the last century, with increases in morbidity and mortality rates being detected after short episodes with high levels of air pollutants [3–5].

Particulate matter or airborne aerosols are pollutants composed of a complex mixture of solid and liquid particles in a gas. Particulate matter (PM) varies in size and composition depending on its source and formation [6].

PM particles are classified based on their size and formation mechanism as either primary or secondary. Primary particles originate from direct emission sources, both natural and anthropogenic. In contrast, secondary particles are formed in the atmosphere through chemical and photochemical reactions or physical processes involving primary particles. The chemical composition of the particles is determined by the emission process,

which is caused by the different possibilities of chemical combinations [7]. These particles are PM<sub>10</sub> (i.e., particles up to 10 µm in aerodynamic equivalent diameter), coarse particles or PM<sub>2.5-10</sub> (particles between 2.5 and 10 µm in aerodynamic equivalent diameter), and PM<sub>2.5</sub> or fine particles (particles up to 2.5 µm in aerodynamic equivalent diameter) [8].

One of the main sources of particulate matter are anthropogenic, which refers to sources of pollutants that have the potential to release particulate matter into the air and which are related to characteristics or activities typically associated human activity [9]. These sources may vary depending on the context, but can be important sources of emissions, such as from fuel combustion and other anthropogenic activities that emit different forms of particulate matter. Many industrial activities, such as metallurgy, foundry, cementing, and materials processing, can generate large amounts of particulate matter during their processes [10]. Construction and demolition activities also generate particulate matter in the air, especially when excavating soil, handling particulate materials, cutting, and using heavy equipment [11].

The problem of occupational UFP exposure is receiving increasing attention, and is seen as an emerging risk.

Ultrafine particles are extremely small solid or liquid particles, typically less than 100 nm in diameter. These particles are so small that they can be compared to the size of individual molecules, making them significantly smaller than other forms of particulate matter. Because of this tiny size, they have a remarkably large surface area relative to their mass, resulting in extensive interactions with the surrounding environment, making them highly reactive. This increases their transport potential and toxicity. In addition, ultrafine particles tend to aggregate and form clusters due to the attractive forces between them. This agglomeration significantly affects their properties and behaviour in different environments, such as liquids or the atmosphere. Because of their small size and ability to remain suspended in the air for long periods, these ultrafine particles are more likely to be inhaled and transported within the human body. This raises health and toxicity concerns [5,10,12,13].

Ultrafine particles are also a minor contributor to the total mass concentration of indoor and outdoor aerosols [5]. Due to the limited detectability and reliability issues of mass concentration, the focus on UFPs is on particle number concentration, which refers to the number of particles present in a given volume of air.

Human exposure routes to UFPs may include inhalation via the respiratory tract, absorption via the skin, ingestion via the mouth, or combinations of these routes [14].

In fact, the most important route of human exposure to UFPs is inhalation. Via this route, and due to their size and other characteristics, UFPs may reach the alveolar region and behave similarly to fine particles, giving rise to inflammatory processes in the lungs and subsequent cardiovascular morbidity and mortality [15].

Several epidemiological studies have shown that dust in the workplace is a risk factor for workers exposed to it, and that it can cause pathologies and affect the quality of life of workers [4].

UFPs have different toxicological properties compared to larger airborne particles such as PM<sub>2.5</sub>/PM<sub>10</sub>. These differences are mainly due to differences in inhalation deposition (local dose) and intrinsic toxicity related to their physicochemical properties. Remarkably, health effects associated with exposure to UFPs have been observed independently of other air pollution measures such as PM<sub>2.5</sub> and NO<sub>x</sub>. Interestingly, certain UFPs, unlike larger PM particles, may move from the respiratory system to the cardiovascular system and other organs [16].

The main question we want to answer is the levels of UFPs that workers are exposed to in environments with different direct particle emission patterns.

For this purpose, the main questions we want to answer are:

- What are the levels of UFPs in traditionally particulate-polluted sites?
- Are UFPs also present at sites where PM emissions are low or non-existent?

- What is the relationship between the presence of UFPs and other pollutants such as PM<sub>10</sub>, PM<sub>2.5</sub>, carbon dioxide (CO<sub>2</sub>), and carbon monoxide (CO)?
- What is the relationship between the levels of UFPs and other parameters, such as temperature (T) and relative humidity (RH)?
- How do the values measured indoors relate to the values observed outdoors?

In order to investigate these matters, the study involved monitoring industrial workplaces with PM emissions, such as a carpentry workshop and a bakery, as well as at social sector sites without or almost without direct PM emissions, such as a school and a health clinic.

## 2. Materials and Methods

The study was observational, descriptive, analytical, and cross-sectional.

Non-probabilistic sampling was used to monitor environmental parameters and pollutants at four sites: two industrial (a carpentry workshop and a bakery) and two entities in the social sector (a school and a health clinic). The industrial sites were chosen for their high PM emissions, while the other two sites had low or no direct PM emissions.

The carpentry workshop in this study was an open space facility measuring approximately 500 m<sup>2</sup>, and constructed of masonry with a ceiling height of 5 m. Natural ventilation was present, with local extraction available when using wood cutting and sanding machines. The only existing control was local extraction for wood powder. Monitoring was carried out at several points representative of the work areas: painting, sawing (including sanding), and assembly.

The bakery was an industrial facility producing goods for sale in stores. It had a total area of 200 m<sup>2</sup> and a ceiling height of 4 m. The space was divided into several rooms, each approximately 30 m<sup>2</sup> in size. The rooms were constructed using metal sandwich panel walls to facilitate hygiene and cleaning. The only method of controlling pollutants and temperature was through forced ventilation. Various measurement points were defined to characterize the different areas, including manufacturing, production, dispatch, warehouse, and office.

This study focused on verifying the occupational conditions in the workplace, specifically work offices and workrooms where workers typically spend extended periods of time. The workrooms and offices measured approximately 40 m<sup>2</sup> and 20 m<sup>2</sup>, respectively, with a ceiling height of 3.5 m. The construction was made of masonry and covered with paint, with natural ventilation. No control system was applied during the measurements. The windows were kept closed throughout the duration of the study to ensure consistency.

The health clinic comprised three laboratories, each measuring approximately 10 m<sup>2</sup>, and an administrative and waiting room of around 30 m<sup>2</sup>. The laboratory walls were covered in ceramic and stainless steel, while the reception area was painted masonry. The laboratories were equipped with air conditioning featuring air recirculation and HEPA filters, while the reception area benefited from natural ventilation. During the measurements, the windows were kept closed to ensure accuracy.

The measurements were conducted between 2022 and early 2023, comprising multiple collection time points and a total of 1926 measurements at workplaces, including an outdoor control site. The assessments were conducted during normal facility operation and working hours to ensure that the sample was representative of occupational exposure to pollutants. The equipment was aimed at a central area within the measurement areas. Fifteen-minute measurements were taken at various times throughout the day to characterise daily exposure. Average values were then calculated and adjusted to standard values to assess exposure levels.

According to WHO recommendations, for the measurements, the equipment was placed at a central point in the space, about 1.5 m from the floor, at a height closest to the occupant's airways, at least 1 m from sources of particulate matter and at least 1 m from walls [17].

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For the analytical collection of the parameters evaluated, specific portable equipment for real-time reading was used (Table 1).

Table 1. Monitoring equipment.

Equipment	Pollutant	Equipment Range
TSI Q-Track Plus	CO	0–500 ppm
	CO <sub>2</sub>	0–5000 ppm
	T	0–50 °C
	RH	5–95% RH
P-Trak Ultrafine Particle Counter—8525	UFPs	0–5 × 10 <sup>5</sup> PNC
Lighthouse, model 3016 IAQ	PM <sub>10</sub>	0–350 mg·cm <sup>-3</sup>
	PM <sub>2.5</sub>	0–350 mg·cm <sup>-3</sup>

The data collected during the study were statistically treated using Statistical Package for Social Sciences (IBM SPSS) software version 28.0 for Windows. A 95% confidence level and a random error of less than or equal to 5% were taken into account for the estimation of statistical inference.

A normality test was conducted and the data were found to follow a normal distribution. This allowed for the use of a linear correlation test for data analysis.

Pearson’s correlation, also known as linear correlation, was performed in the statistical tests. It is a statistical measure that quantifies the linear relationship between two continuous variables. This correlation is represented by the Pearson correlation coefficient (*r*), whose value ranges between −1 and 1.

The reference values used to discuss the results are based on the American Conference of Governmental Industrial Hygienists—Threshold Limit Values (ACGIH—TLV) for PM<sub>10</sub>, PM<sub>2.5</sub>, CO, and CO<sub>2</sub>. These buildings were assessed from an occupational health perspective.

The provision of occupational health and safety measures to protect health workers is also fundamental to well-functioning and resilient health systems, quality of care, and the maintenance of a productive health workforce. The WHO works to protect the health and safety of health workers, including developing norms and standards for the prevention of occupational hazards in the health sector [18]. In the case of UFPs, given the absence of guidelines, the values suggested by the WHO for prioritising the control of UFP-emitting sources were used as reference values (Table 2) [9,15].

Table 2. Guidelines/recommended concentrations.

Pollutant	Limit/Recommended Values	Standard/Recommendation
CO (ppm/8 h)	30	ACGIH—TLV ACGIH—TLV (The American Conference of Governmental Industrial Hygienists—Threshold Limit Value)
CO <sub>2</sub> (ppm/8 h)	1000	ACGIH—TLV
T (°C)	22	ILO
RH (%)	65	ILO
UFPs (PNC 24 h mean particles·cm <sup>-3</sup> )	<1000 Low 1001–9999 Medium >10,000 High	WHO
PM <sub>10</sub> (µg·m <sup>-3</sup> /8 h)	10	ACGIH—TLV
PM <sub>2.5</sub> (µg·m <sup>-3</sup> /8 h)	3	ACGIH—TLV

PNC—Particle number concentration—WHO 2021. ILO—International Labour Organization. ACGIH—TLV—The American Conference of Governmental Industrial Hygienists—Threshold Limit Value.

### 3. Results and Discussion

Table 3 presents the number of evaluations conducted at various sampling points. A total of 1926 measurements were taken.

Table 3. Total of measures performed per workplace.

Workplace	Number of Evaluation Points	Frequency (%)
Carpentry Workshop	630	32.7
Bakery	1170	60.8
School	63	3.3
Health Clinic	63	3.3
Total	1926	100.0

The number of collections was determined based on the evaluation area, as well as the number of tasks and workplaces to be assessed. This explains the difference in the number of assessments. Out of a total of 1926 measurements, 58.1% were taken in the bakery, 35.7% in the carpentry workshop, and 3.3% each in the school and health clinic. The language used is clear, concise, and objective, with a formal register and precise word choice. The sentence structure is simple and the information flows logically, with causal connections between statements. The text is free from grammatical errors, spelling mistakes, and punctuation errors. No changes in content were made as per the instructions.

Table 4 presents the results of indoor and outdoor measurements. The concentrations observed indoors suggest the presence of significant indoor sources of the pollutants. The outdoor air does not appear to contribute to the degradation of indoor air, as the pollutant values are lower in the outside environment. Therefore, we can conclude that higher ventilation levels could lead to an important contribution by outdoor air to the improvement of indoor air quality. The values for CO and CO<sub>2</sub> show significant differences. The indoor and outdoor CO values are similar, while the indoor/outdoor CO<sub>2</sub> values have greater differences, likely due to contamination by occupants.

Table 4. Comparison of indoor and outdoor concentration levels.

Pollutants	Indoor/Outdoor	N	Mean	Std. Deviation
PM <sub>10</sub> (µg·m <sup>-3</sup> )	Indoor	1926	0.0496	0.254
	Outdoor	1926	0.0153	0.004
PM <sub>2.5</sub> (µg·m <sup>-3</sup> )	Indoor	1926	0.3760	1.003
	Outdoor	1926	0.0887	0.413
CO (ppm)	Indoor	1926	2.0	0.210
	Outdoor	1926	1.9	0.091
CO <sub>2</sub> (ppm)	Indoor	1926	553	239.075
	Outdoor	1926	351	21.784
UFPs (PNC—particles·cm <sup>-3</sup> )	Indoor	1926	24,487	27,216.882
	Outdoor	1926	2513	2709.181

PNC—particle number concentration—WHO 2021.

The next step was to check compliance with the PM<sub>10</sub> and PM<sub>2.5</sub> standards according to the ACGIH—TLV guidelines. The figures found are somewhat interesting, as they are almost all within the guideline limits, probably due to the collective protection systems (in the carpentry extraction located at dust-producing workstations and forced ventilation in the bakery). In fact, only 0.3% of the values for PM<sub>2.5</sub> and 0.1% for PM<sub>10</sub> are over the guideline limits (Table 5).

**Table 5.** Comparison of observed PM values with guideline values.

		Occurrence	Frequency (%)
PM <sub>2.5</sub>	Above Limit	6	0.3
	Below limit	1920	99.7
	Total	1926	100.0
PM <sub>10</sub>	Above Limit	2	0.1
	Below limit	1924	99.9
	Total	1926	100.0

Upon checking the UFP values against WHO recommendations for 24 h mean PNC (particles·cm<sup>-3</sup>) levels, it appears that the recorded values are not favourable for the workers. More than half of the UFP measurements (53.4%, 1028 occurrences) are medium values, while the remaining 46.6% (898 measurements) exceed the WHO recommendations for PNC 24 h mean. The results suggest that individuals exposed to ultrafine particles (UFPs) in their occupational environment may experience higher exposure levels compared to the background concentration (refer to Table 6). This implies that certain occupational activities or environments may have higher exposure to UFPs [5,17,19,20].

**Table 6.** Observed UFP levels and WHO recommendations.

	WHO PNC Recommended Value (24 h Mean)	Occurrence	Frequency (%)
UFPs (PNC (particles·cm <sup>-3</sup> ))	1001–9999—Medium	1028	53.4
	>10,000—High	898	46.6
	Total	1926	100.0

We then looked at UFP levels by workplace in line with WHO recommendations. As expected, the carpentry workshop had the highest frequency of high values of 65.4%, followed by the bakery of 38.6%. In the school and health clinic, the values are similar although the lowest values are, as expected, in the school where offices and workrooms were monitored (Table 7). In the following results, we will look at how the generation of UFPs can be verified in the different locations.

**Table 7.** Results in different sectors compared with WHO recommendations.

	WHO PNC (Particles·cm <sup>-3</sup> ) Recommended Value (24 h Mean)	Occurrence	Frequency (%)
Carpentry Workshop	1001–9999—Medium	218	34.6
	>10,000—High	412	65.4
	Total	630	100.0
Bakery	1001–9999—Medium	718	61.4
	>10,000—High	452	38.6
	Total	1170	100.0
School	1001–9999—Medium	52	82.5
	>10,000—High	11	17.5
	Total	63	100.0
Health Clinic	1001–9999—Medium	40	63.5
	>10,000—High	23	36.5
	Total	63	100.0

These values are in line with the literature presented, as a carpentry workshop is a primary source of UFPs due to the tasks involved [3,5,21]. As mentioned before, UFPs

can be emitted directly from anthropogenic sources or combustion, or even more frequently in chemical reactions and dynamic processes such as nucleation, condensation, and coagulation. These cases can be the origin of the UFPs found in this assessment [6,21–24].

Now analysing the workplaces in more detail, Table 8 shows the results of the measurements taken in the various sectors of each workplace.

**Table 8.** Average of all measures per assessment (24 h), maximum and minimum PNC (particles.cm<sup>-3</sup>) of UFPs by workplace and activities.

		Average	Minimum	Maximum
Carpentry Workshop	Paint	42,612	3331	140,883
	Sawing	45,711	8115	153,566
	Assembly	8313	1799	48,426
Bakery	Manufacture	48,580	22,308	139,233
	Production	36,209	16,356	86,846
	Dispatch	5578	2882	9964
	Warehouse	5038	2410	10,138
	Office	3107	1092	5036
School	Offices	2970	1574	70,730
	Workrooms	5298	1467	87,653
Health Clinic	Reception	4776	2397	12,384
	Laboratory	22,698	1315	114,248

To verify the exposure levels, we calculated the adjusted mean values of the measurement points and identified the minimum and maximum values recorded for the UFPs. It can be confirmed that the highest average and maximum values align with what was expected based on the literature regarding the sources that generate UFPs. The carpentry industry typically produces particles during sawing and painting tasks. It is important to note that this information is based on objective data from primary sources. The values for particle generation are in line with WHO average values, with assembly tasks producing lower levels [15,22,25]. In the bakery, the production area stands out (average 36,209; maximum 86,846) and even higher than for manufacturing (average 48,580) agreeing with the literature that refers to industrial and combustion activities as generating UFPs [15,19,26,27]. As expected, the school, lacking primary sources of UFPs, has average exposure levels. It is predictable that the highest levels would occur in industries where UFPs are more likely to be generated or released, such as manufacturing, construction, and mining. Work processes that involve activities such as cutting, grinding, burning, or the use of certain chemicals may generate ultrafine particles (UFPs) as byproducts. This can lead to higher exposure of workers in these environments. It is important to note that UFPs can have negative health effects on workers, making it crucial to implement proper safety measures [5,7,19,28]. Contrary to initial expectations, the laboratories of the health clinic have very high values.

Finally, to better understand what is influencing the UFPs, we checked Pearson's correlation between the pollutants assessed, including UFPs, per assessment site (Table 9).

In this analysis, we were able to verify a number of correlations, some of which were expected, but others were completely unexpected. In the carpentry workshop, as expected, there is a strong positive correlation between CO and UFPs, as well as between RH and UFPs. These results can probably be explained by the presence of combustion sources and humidity in the air, which favour the secondary formation of UFPs. On the other hand, and less expected, there is a strong negative correlation between UFPs and T. Here, some of the studies that talk about the formation of UFPs, associate T with the agglutination of particles that can make them no longer long in the spectrum of ultrafine particles. [11,21,29,30]. Another strongly negative correlation is that between UFPs and CO<sub>2</sub>. As expected, this can be strongly influenced by the ventilation that takes place after painting by aerating the room; this air renewal can favour the improvement of UFPs and CO<sub>2</sub> levels. Also in the carpentry workshop, sawing, which includes sanding, shows a strong positive correlation

with PM<sub>10</sub> and PM<sub>2.5</sub>, in line with the direct formation of UFPs. In assembly, this correlation is exactly the opposite, i.e., strongly negative, probably due to the lack of direct formation of UFPs. There is no wood decomposition in this zone [7,12,19,31].

Table 9. Correlations between UFPs and other pollutants.

			CO	CO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	RH	T
Carpentry Workshop	Paint	r	0.819 **	−0.702 **	−0.020	0.030	0.860 **	−0.895 **
		Sig. (2-tailed)	0.000	0.000	0.750	0.710	0.000	0.000
		N	210	210	210	210	210	210
	Sawing	r	−0.050	0.010	0.524 **	0.718 **	0.026	−0.004
		Sig. (2-tailed)	0.480	0.900	0.000	0.000	0.708	0.957
		N	210	210	210	210	210	210
Assembly	r	−0.090	−0.060	−0.292 **	−0.530 **	0.049	−0.029	
	Sig. (2-tailed)	0.190	0.430	0.000	0.000	0.480	0.678	
	N	210	210	210	210	210	210	
Bakery	Manufacture	r	0.100	0.788 **	−0.140	0.050	0.192 *	0.491 **
		Sig. (2-tailed)	0.230	0.000	0.100	0.520	0.019	0.00
		N	150	150	150	150	150	150
	Production	r	0.050	0.524 **	0.783 **	0.100	−0.075	0.824 **
		Sig. (2-tailed)	0.410	0.000	0.000	0.080	0.198	0.00
		N	300	300	300	300	300	300
	Dispatch	r	−0.210 **	0.321 **	0.010	0.386 **	0.413 **	−0.084
		Sig. (2-tailed)	0.010	0.000	0.880	0.000	0.000	0.304
		N	150	150	150	150	150	150
	Warehouse	r	0.889 **	−0.162 **	−0.564 **	−0.645 **	−0.641 **	−0.303 **
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.00
		N	300	300	300	300	300	300
Office	r	0.533 **	−0.251 **	−0.731 **	−0.722 **	0.049	−0.005	
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.420	0.938	
	N	270	270	270	270	270	270	
School	Offices	r	0.120	0.160	−0.090	−0.060	0.217	0.100
		Sig. (2-tailed)	0.550	0.440	0.640	0.770	0.276	0.621
		N	27	27	27	27	27	27
	Services	r	0.020	−0.290	0.586 **	0.781 **	0.109	−0.226
		Sig. (2-tailed)	0.920	0.080	0.000	0.000	0.526	0.185
		N	36	36	36	36	36	36
Health Clinic	Reception	r	−0.130	0.320	0.618 **	0.739 **	0.073	−0.037
		Sig. (2-tailed)	0.430	0.050	0.000	0.000	0.672	0.832
		N	36	36	36	36	36	36
	Laboratory	r	−0.030	0.750 **	0.445 *	0.26	−0.004	0.016
		Sig. (2-tailed)	0.860	0.000	0.020	0.190	0.985	0.936
		N	27	27	27	27	27	27

Test: Pearson Correlation. \*\*. Correlation is significant at the 0.01 level (2-tailed). \*. Correlation is significant at the 0.05 level (2-tailed).

In the bakery, as expected, the greatest influence is from CO<sub>2</sub>, which in areas with a higher number of workers increases the UFPs. These strongly positive correlations may be due to a greater formation of these particles as well as the tasks performed allowing greater permanence or elevation of these in the air. Interestingly, in manufacturing and production there is also a strong positive correlation with T. It is localised with relatively high temperature, but with very large gradients, which may induce the presence of gaseous and other precursors for the formation of ultrafine particles by condensation of vapours or by favouring chemical reactions [3,6,24,26,32]. On the other hand, RH has a significant effect in the shipping area and less so in the production area. Again, this may be due to

favouring condensation or secondary formation of UFPs [33]. An unexpected influence is that of CO in the warehouse and office, which can only be explained by the contamination of the room, since it is closer to the oven area. This low occupancy is reflected in negative correlations with all other pollutants. In reality, this occupation is concentrated in the unloading of materials and the loading of raw materials into the production area, three to four times a day for short periods of time. The same reasoning applies to PM<sub>10</sub>, PM<sub>2.5</sub>, and CO<sub>2</sub> in the office [8,19].

In the school, the only correlation we found is in relation to the remaining particulate matter, PM<sub>10</sub> and PM<sub>2.5</sub>, in the workrooms, which may be due to the movement of materials or people and the agitation of particulate matter that causes the occurrence of it in the air. As expected, at the beginning of the study, the UFP values are not very relevant in this activity [1,5].

In the health clinic, in the reception area, as in the school, the only positive correlation is with PM<sub>10</sub> and PM<sub>2.5</sub>, most likely due to the movement of people. The strong positive correlation with CO<sub>2</sub> was not expected in the laboratories. This must be due to the density of occupation of the space and the greater constraints on ventilation, avoiding contamination, for reasons of safety of the samples and results. The less significant correlation with PM<sub>10</sub> may be due to the presence and operation of equipment for the tasks.

#### 4. Conclusions

The processed assessments enabled us to observe the relationship between UFPs and commonly monitored parameters. A significant conclusion drawn from this study is that UFP levels are very high according to WHO values, while almost all other evaluated pollutants are within reference limits. The consulted studies confirm a positive correlation between the presence of UFPs and secondary formation. This correlation is observed in cases where UFPs are generated by dust or the combustion of materials. Additionally, in some cases, RH can also favour the appearance of UFPs.

The cross-sectional study comparing companies that generate UFPs with those that do not has highlighted the need to control them in all locations.

UFP levels increase in carpentry and painting tasks due to dust production, combustion, and humidity leading to the secondary formation of UFPs. However, UFP levels decrease with temperature due to particle agglomeration.

The bakery achieved the expected manufacturing and production results, with primary and secondary particle generations corresponding to expectations. However, unexpected contamination was found in the office and warehouse. Dispatch operations can benefit from improved UFP levels through ventilation.

Surprisingly, workrooms in the school had high levels of UFPs, which was unexpected.

The study's main finding was the high levels of UFPs present in the health clinic, particularly in the laboratories. This is due to poor ventilation and occupation, which increases the risk of contamination.

The study also suggests that indoor sources are the primary cause of pollutants, as outdoor values are consistently lower.

It is important to note that while primary sources of UFPs are related, they are not the only source of the problem. Many of our assessments emphasise the importance of controlling sources of PM that favour the formation of UFPs.

Additionally, it is important to control other factors such as CO, CO<sub>2</sub>, temperature, and relative humidity as they are precursors to the formation of secondary UFPs.

Key findings:

- Sources of UFPs are indoors.
  - All activities have high UFP levels.
  - Activities without primary sources of UFPs also have high levels compared to WHO guidelines.
  - Occupancy rate, temperature, and relative humidity are precursors of secondary UFP formation.
-

- Ventilation of rooms is of paramount importance to improve UFP parameters.

It is crucial to recognise the significance of controlling UFPs for both human health and the environment. Due to their small size, with diameters of less than 0.1 mm, they can penetrate deep into the lungs and bloodstream, posing a serious health risk. Reducing UFPs is challenging as they are not easily filtered out by conventional pollution control systems. There is an urgent need for standards and regulatory measures to control polluting sources or utilise more efficient emission control technologies. The importance of monitoring and controlling UFPs should not be underestimated. Further and more in-depth studies on this subject are also necessary. In the future, the research team intends to continue evaluating UFPs and carrying out further research into their health effects.

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