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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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Citation: Moreira, F.M.; Ferreira, A.; Barros, N. Determination of Occupational Exposure to Ultrafine Particles in Different Sectors of Activity. *Safety* **2024**, *10*, 30. https://doi.org/10.3390/safety10010030

Academic Editor: Raphael Grzebieta

Received: 17 October 2023
Revised: 29 February 2024
Accepted: 5 March 2024
Published: 15 March 2024

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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_{10} (i.e., particles up to 10 μm in aerodynamic equivalent diameter), coarse particles or $PM_{2.5–10}$ (particles between 2.5 and 10 μm in aerodynamic equivalent diameter), and $PM_{2.5}$ 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 $PM_{2.5}/PM_{10}$. 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 $PM_{2.5}$ and NO_x. 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_{10}, $PM_{2.5}$, carbon dioxide (CO_2), 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^2, 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^2 and a ceiling height of 4 m. The space was divided into several rooms, each approximately 30 m^2 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^2 and 20 m^2, 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^2, and an administrative and waiting room of around 30 m^2. 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].

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 CO_2 T RH	0–500 ppm 0–5000 ppm 0–50 °C 5–95% RH
P-Trak Ultrafine Particle Counter—8525	UFPs	$0–5 \times 10^5$ PNC
Lighthouse, model 3016 IAQ	PM_{10} $PM_{2.5}$	$0–350\ mg \cdot cm^{-3}$ $0–350\ mg \cdot cm^{-3}$

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 PM10, PM2.5, CO, and CO_2. 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_2 (ppm/8 h)	1000	ACGIH—TLV
T (°C)	22	ILO
RH (%)	65	ILO
UFPs (PNC 24 h mean particles$\cdot cm^{-3}$)	<1000 Low 1001–9999 Medium >10,000 High	WHO
PM_{10} ($\mu g \cdot m^{-3}$/8 h)	10	ACGIH—TLV
$PM_{2.5}$ ($\mu g \cdot m^{-3}$/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_2 show significant differences. The indoor and outdoor CO values are similar, while the indoor/outdoor CO_2 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_{10} ($\mu g \cdot m^{-3}$)	Indoor	1926	0.0496	0.254
	Outdoor	1926	0.0153	0.004
$PM_{2.5}$ ($\mu g \cdot m^{-3}$)	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_2 (ppm)	Indoor	1926	553	239.075
	Outdoor	1926	351	21.784
UFPs (PNC—particles$\cdot cm^{-3}$)	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_{10} and $PM_{2.5}$ 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 $PM_{2.5}$ and 0.1% for PM_{10} are over the guideline limits (Table 5).

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

		Occurrence	Frequency (%)
$PM_{2.5}$	Above Limit	6	0.3
	Below limit	1920	99.7
	Total	1926	100.0
PM_{10}	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^{-3}) 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^{-3})	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^{-3}) 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-3) 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_2. 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_2 levels. Also in the carpentry workshop, sawing, which includes sanding, shows a strong positive correlation with PM_{10} and $PM_{2.5}$, 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_2	PM_{10}	$PM_{2.5}$	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_2, 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_{10}, $PM_{2.5}$, and CO_2 in the office [8,19].

In the school, the only correlation we found is in relation to the remaining particulate matter, PM_{10} and $PM_{2.5}$, 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_{10} and $PM_{2.5}$, most likely due to the movement of people. The strong positive correlation with CO_2 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_{10} 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_2, 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.

Author Contributions: F.M.M., A.F. and N.B. designed the study. F.M.M. designed the questionnaire, collected the data, and performed the statistical analysis. F.M.M., A.F. and N.B. prepared the original draft of the manuscript. F.M.M., A.F. and N.B. critically interpreted the results, reviewed the draft version, and approved the final manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Coimbra Heath School of the Polytechnic Institute of Coimbra.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Instituto Politécnico de Coimbra (protocol code 2021/128 and date of approval 15 November 2021).

Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors would like to thank all the professionals who participated in this work, in particular those who answered the questionnaire of this study. Special thanks are due to the researcher, Nelson Barros, and the FP-I3ID of the University, Fernando Pessoa, for their support.

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

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