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EVALUATION OF THE EXPOSURE OF WOOD INDUSTRY WORKERS TO ULTRAFINE PARTICLES IN THE CENTRAL REGION

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Abstract: Workplaces in an industrial environment encompass complex processes, in which new models of work organization and technologies are continuously introduced and are therefore exposed to different types of professional risks, which will affect the safety, health and well-being of workers, which will consequently determine the capacity for work. Study want evaluate the occupational exposure of workers in a timber industry to particles and atmospheric pollutants. Data collection consisted of two moments of investigation, firstly a questionnaire was applied to all workers in the timber industry under study, to analyze the symptomatology perceived by the same workers. The second moment consisted of the evaluation of the air quality parameters, resorting to the evaluation of atmospheric pollutants (CO_2, CO, VOC, inhalable particles, breathable particles, and ultrafine particles) and of meteorological variables Temperature and Relative Humidity.
In terms of average values, the air quality parameters, for the most part, were found significantly above the exposure limit values, and the paint booth was where, in general, the highest values were found. Concentrations were generally higher inside the industry than outside. For preventing exposure to ultrafine particles, also emphasizing the need to define limit values for occupational exposure to them.

Keywords: occupational exposure; symptomatology; particulate matter; atmospheric pollutants; exposure limit.

Introduction

Issues related to indoor air quality (IAQ) result from the interconnections between building materials and furniture, the activities carried out inside the building, the climate, and the occupants of the building. The Canadian Committee on Indoor Air Quality and Buildings states that a healthy indoor environment is one that contributes to productivity, comfort and a sense of health and well-being (COOHS, 2022).
In the European Union (EU), in 2020, 96% of the urban population was exposed to levels of fine particles above the reference value for health established by the World Health Organization. Exposure to fine particulate concentrations above the 2021 reference level resulted in 238 000 premature deaths in the EU (EEA, 2022)
In addition to affecting the incidence of disease and mortality, it is important to consider the loss of productivity at work and the additional economic burden, as well as the impact on agricultural crops and the damage caused to buildings and infrastructure (WHO, 2021).
People are exposed to air pollution in each microenvironment they live in, which is a function of the concentration of the pollutant and the time a person is exposed to it. Among the elements of risk assessment is exposure assessment, a process that involves assessing emissions, air pollution concentrations, population exposure, body burden, and doses of pollutants at the organ or cell level, as well as risks to the health. In some locations, concentrations of pollutants are low, but the overall contribution to exposure is high due to the longer time spent there, and even short periods spent in such locations result in high exposures (WHO, 2021).
Carbon monoxide (CO) is a colorless and odorless gas which, due to its high toxicity, makes it especially dangerous. Sources of CO can be diverse, including unvented oil heaters, gas heaters, leaky chimneys, gas ovens and water heaters, wood stoves, generators and other gas equipment, car exhaust and tobacco smoke (Seguel, 2017).
Carbon dioxide (CO2) is a colorless, tasteless, odorless and non-flammable gas that can accumulate in lower spaces, causing an oxygen deficiency. The concentration of CO2 inside buildings represents an indicator of indoor air quality, the ability to exchange air flow and sufficient air renewal in closed spaces (IPCS, 2006; Emmerich, 2001).

Recent studies reveal physiological changes in the circulatory, cardiovascular, and nervous systems, including an increase in arterial pressure of CO_2 in the blood, an elevated blood pressure, an increase in heart rate and an increase in peripheral blood circulation at exposures in the range of 500 to 5000 ppm (Azuma, 2018).
In the various manufacturing processes, VOCs may be emitted in the form of gases, which are then inhaled, and the effects of this exposure are still unknown. Despite these unknowns, some of the adverse health effects include discomfort, irritation, respiratory symptoms, mutagenic and even carcinogenic effects (Rumchev, 2007).
The definition of particulate matter, presented by the World Health Organization (WHO), is that "it consists of a mixture of particles that can be solid, liquid or both suspended in the air and represent a mixture of complex organic and inorganic substances" (WHO, 2021).
Particles are defined by their diameter for air quality regulation purposes. The smaller the dimension, the more likely it is to penetrate the respiratory tract and the greater the negative effects it can cause (Kim, 2015; APA, 2021).
The furniture production sector has evolved progressively in Portugal, and much of this evolution is due to the continuous implementation of improvements in production processes, which has increased its responsiveness, and consequently productivity and competitiveness (Pinho, 2015).
This industry involves a great deal of mechanical work, which is used to manufacture furniture and flooring, among others. Dust created during the manufacturing process can settle on floors, walls, and work surfaces in production facilities, or even, for dust with significantly reduced particle sizes, remain suspended in the air, which compromises the health of workers and creates additional hazards in the workplace by limiting visibility and increasing the risk of fire (Pęedzik, 2021).
Based on the activities performed, the concentration and size of wood particles may vary. Considering the place of deposition, the particles can be defined as:

- Inhalable: With an aerodynamic diameter of less than 100 µm; enter the respiratory tract, reaching only the upper airways.
- Thoracic: With an aerodynamic diameter of less than 25 µm; they manage to go beyond the larynx, reaching the lungs and gas exchange regions of the lung.
- Breathable: With an aerodynamic diameter of less than 10 µm; are those most likely to reach and be deposited in the gas exchange region of the lung, namely the lung alveoli (US EPA, 2004).

Inhalable wood particles are deposited mainly in the nose, mouth, larynx, and pharynx, being strongly associated with nasal pathologies. Most attention has shifted to ultrafine particles (UFPs), as they have an aerodynamic diameter of less than 100 nm, giving them the ability to move to almost any organ, and although their role in the development of certain conditions is not yet known, it is recognized that their potential to harm health is great (Carvalho, 2022; Slezakova, 2019).
The health of people who are already vulnerable to air pollution can be adversely affected by short-term exposure (lasting one or more days) to these particles. These may suffer from coughing and chest tightness, as well as worsening respiratory complaints and temporary reductions in lung function. In most cases, the symptoms disappear along with the concentration of particles (Moreira,2024; Atlas, 2018).
Despite recognizing the enormous potential that UFP must compromise health, its behavior and exact role as a source is still unknown. Their point of entry into the body is usually through from the lungs, through inhalation, reaching the alveoli and being distributed throughout the body through the circulatory system. (Schraufnagel, 2020; Kwon, 2020).
More recent studies report the effects that UFPs have on the cardiovascular and respiratory system, exacerbating the effects of asthma, the immune system's ability to respond when exposed to allergens, and even damage to deoxyribonucleic acid (DNA) due to its ability to penetration at the intracellular level (Li, 2016).
PFUs can also cause systemic inflammation, endothelial dysfunction, and clotting disorders, and can travel to the brain and cause brain dysfunction. In addition, exposure of the fetus in utero to UFPs may increase the risk of low birth weight (Schraufnagel, 2020).

The challenges posed by UFP include scientific challenges, associated with the complex processes involved, the necessary instruments which, due to their characteristics, are quite expensive. Their small size also affects how airborne PFUs move, taking on different shapes compared to fine particles, moving in random patterns more like gases. Legislative challenges are also considered, due to the lack of support that supports the standardization of measurements and the understanding of the sources and consequent effects, indicating the need for specific regulation of the UFP (Cassee, 2019; IQAir, 2022).

As a general objective, this project proposes to study the impacts of occupational exposure to particles and atmospheric pollutants on the health of workers in a logging company.

The specific objectives of this investigation were:

- Qualitatively and quantitatively characterize occupational exposure to particulate matter and air pollutants (CO_2, CO, VOC, inhalable particles, breathable particles, and ultrafine particles).
- Describe the type of association between occupational exposure and the possible development of pathologies.
- Characterize the study population regarding respiratory and cardiovascular symptoms, among others.
- Evaluate the need for values stipulated by existing legislation and standardization.

Study design

Regarding the type of study, this was a descriptive observational type, with a cross-sectional timeline.

The occupational exposure of workers belonging to a wood industry located in the central region of Portugal was evaluated, in which the data collected in that same industry was subsequently processed.

Population and sample

The target population of the study consisted of 4 workers who performed their duties in the company in question, located in the central region of Portugal.

To integrate our study, the sample included, as inclusion criteria, workers who performed functions in the company, with continuous activity of 1 year. Locations that were not part of the production line, namely toilets and changing rooms, were excluded.

The applied sampling method was of the non-probabilistic type and as for the technique, this was for convenience.

As for the sample size, it consisted of 4 workers belonging to the company under study, who performed functions in the respective areas: production, assembly, and painting.

Instruments and data collection

The study was carried out in the academic year 2023, with data collection taking place in the month of May.

Data collection consisted of two stages of investigation, the first being the application of a questionnaire (Annex I) addressed to all workers in the timber industry under study, to analyze the symptoms perceived by the workers. The second moment consisted of the evaluation of air quality parameters, resorting to the evaluation of atmospheric pollutants (CO_2, CO, VOC, inhalable particles, breathable particles, and ultrafine particles) and meteorological variables Temperature (T°) and Relative Humidity (Hr) in 3 work areas inside the industry (production area, assembly area and painting area), in a total of 540 measurements, and outside a total of 60 measurements.

Measurements were taken over a period of 45 minutes per day in each work zone, for 4 days, with minute-to-minute sampling.

To carry out the measurements, important criteria were considered, such as the consideration of locations representative of the activities in question, placing the equipment in a central point of the space, at the level of the airways, also making a characterization of the location, and considering the operating periods of activities for measurement times (APA, 2009).

Portable real-time reading equipment was used for data collection. Regarding the parameters CO, VOC, CO_2, the Q-Track Plus equipment, brand TSI, model 8552/8554 with serial number 8554-01061006 was used. The Particles Counters equipment, brand Lighthouse Worldwide Solutions, model 3016 LAQ with serial number 110144012, was used to assess the concentrations of particulate matter, and the equipment P-Track Ultrafine Particle Counter, brand TSI, model 8525 with serial number 8525-11170007, which has a 95 isopropyl alcohol solution reagent%.
Regarding the exposure limit values, according to the Portuguese Standard (NP) 1796:2014, the established limit value of CO_2 is 5000 ppm, that of CO is 10 mg/m^3, VOC 0.1 mg/m^3, for inhalable particles 10.0 mg/m3 and for respirable particles 3.0 mg/m^3. According to Decree-Law n. º 243/86, of 20 August, the reference environmental conditions for temperature must oscillate between 18 and 22˚C, while for relative humidity, it must oscillate between 50 and 70% (NP 1796,2014; Decree-Law No. 243/86).
Given the lack of reference values for the concentration of particulate material, namely ultrafine particles, the analytical average values recorded between the interior and exterior of the industry were assumed as a reference point.

Statistical analysis

After the collection and subsequent treatment/analysis of the data obtained from the monitoring carried out, a statistical approach was taken, using all the information to create a database in specialized software (*IBM SPSS Statistics version 28.0*).
Descriptive statistics techniques were applied, namely frequency analysis (absolute and relative), calculation of measures of central tendency (simple arithmetic mean), measures of dispersion (standard deviation, amplitude, minimum and maximum value) and measures of tendency non-central (quantiles).
Inferential statistics techniques were also applied, resorting to an assessment of the assumptions, which can be framed in statistical tests of the parametric and non-parametric type. For this, a descriptive evaluation was necessary through the measures of kurtosis, by the Kurtosis statistic, and asymmetry, by the Skewness statistic. Finally, the normal distribution was also used as a measure for deciding on the choice of test.
In terms of hypothesis testing, *Kruskall-Wallis* tests, *Chi-square of independence*, *Wilcoxon Mann-Whitney*, *T-Student* for 1 sample and *Test of Covariance* were used.
Finally, regarding the extrapolation of the results to the population, we assumed a confidence level of 95% for a maximum random error of up to 5%.

Results

Based on the application of pre-defined data collection instruments, we proceeded to evaluate the different workstations in relation to the different exposure limit values for $C0_2$ and VOCs. CO values are not represented in the table since no values were found within the industry. This assessment was then carried out to determine whether the exposure limit value for the worker had been exceeded, values which are shown in Table 1:

Table 1*. Average concentrations of CO_2, VOC, Respirable Particles, and Inhalable Particles in the different evaluated work zones*

		Production (n=180)	**Assembly (n=180)**	**Painting (n=180)**
$C0_2$ (VLE=5000ppm)	M (DP)	452.03 (53.111)	427.91 (54.169)	**457.17 (54.397)**
	[Min; Max]	[391;665]	[387;653]	[387;707]
	Mean difference	-4547,967	-4572,089	-4542,833
	p-value	0.0	0.0	0.0
VOC (LEV = 0.1 mg/m3)	M (DP)	0.0 (0.0)	0.0 (0.0)	**12.22 (13.251)**
	[Min; Max]	[0.0;0.0]	[0.0;0.0]	[0.0;64.58]
	Mean difference	-	-	**12.112**
	p-value	-	-	<0.001
Breathable particles (LEV = 3.0 mg/m3)	M (DP)	4,001 (4,781)	6,342 (15,642)	**29,029 (65,848)**
	[Min; Max]	[0.0;31.29]	[0.0;91.45]	[0.0;220.59]
	Mean difference	1.00	3,342	**5.303**
	p-value	0.003	0.002	<0.001
Inhalable particles (LEV = 10.0 mg/m3)	M (DP)	16,796 (31,645)	**25,713 (69,582)**	21,682 (45,323)
	[Min; Max]	[0.01;260.33]	[0.0;370.33]	[0.0;141.11]
	Mean difference	6,796	**15.713**	11,682
	p-value	0.002	0.001	<0.001

Test: t-Student for 1 sample; M – Average; SD – Standard Deviation; Min. - Minimum; Max.- Maximum; ELV - Exposure Limit Value

According to the results shown in Table 1 and using the t-Student test for 1 sample, it was found that the average CO_2 values in all stations were lower than the exposure limit value, with the highest average values verified in the "Painting" zone (457.17 ± 54.397), which is significantly below the limit ($p<0.001$).
In terms of VOCs, these showed significant values far above the exposure limit value (12.22 ± 13.251), namely in the "Painting" area, which is also the only place where values were measured.
Regarding respirable particles, it appears that the mean values are significantly above the exposure limit value, with the highest values found in the "Painting" zone (29.029 ±65.848).
Finally, about inhalable particles, it is again verified that the mean values are significantly above the exposure limit value, with the highest values recorded in the "Assembly" zone (25.713 ± 69.582).
Next, we evaluated the average concentrations of CO_2, Respirable Particles, Inhalable Particles, Ultrafine Particles and VOCs, values represented in table 2:

Table 2. *Average concentrations of CO_2, Temperature, Relative Humidity, Breathable Particles, Inhalable Particles, Ultrafine Particles and VOC in the different work zones.*

Work Zone		**Production (n=180)**	**Assembly (n=180)**	**Painting (n=180)**	**p-value**
CO_2	M (DP)	452.03 (53.111)	427.91 (54.169)	**457.17 (54.397)**	<0.001
	[Min; Max]	[391;665]	[387;653]	[387;707]	
Temperature	M (DP)	19,848 (1,162)	19,240 (1,048)	**20.192 (1.217)**	<0.001
	[Min; Max]	[17.5;22.3]	[17.5;21.1]	[17.8;22.5]	
Relative humidity	M (DP)	**54,096 (11,937)**	53,717 (15,305)	43.912 (5.606)	<0.001
	[Min; Max]	[39.8;76.0]	[40.8;82.8]	[37.4;58.3]	
Breathable particles	M (DP)	4,001 (4,781)	6,342 (15,642)	**29,028 (65,848)**	<0.001
	[Min; Max]	[0.0;31.29]	[0.0;91.45]	[0.0;220.49]	
Inhalable particles	M (DP)	16,796 (31,645)	**25,713 (69,582)**	21,682 (45,323)	<0.001
	[Min; Max]	[0.01;260.33]	[0.0;370.33]	[0.0;141.11]	
Ultrafine particles	M (DP)	**17953.17 (25400.717)**	11796.06 (9404.573)	13047.84 (7030.412)	<0.001
	[Min; Max]	[3390;194000]	[1500;33200]	[6210;47316]	
VOC	M (DP)	0.0 (0.0)	0.0 (0.0)	**12,218 (13,251)**	<0.001
	[Min; Max]	[0.0;0.0]	[0.0;0.0]	[0.0;64.58]	

Test: Kruskall-Wallis. M – Average; SD – Standard Deviation; Min. - Minimum; Max.- Maximum

Through the analysis of Chart 2, it was possible to verify that all pollutants and atmospheric particles showed significant differences ($p< 0.05$).

About the CO_2 pollutant, it was found that the “Assembly” zone had lower average values compared to the “Painting” zone ($d\bar{x}= 29.26ppm$) and “Production” zone ($d\bar{x}= 24.12ppm$).

Regarding the Temperature parameter, the “Assembly” zone revealed lower average values compared to the “Painting” zone ($d\bar{x}$= 0.952 ºC) and the “Production” zone ($d\bar{x}$= 0.608 °C).

Regarding the Relative Humidity parameter, the “Painting” zone presented lower average values compared to the “Production” zone ($d\bar{x}$= 10.184 %) and the “Assembly” zone ($d\bar{x}$= 0.379 %).

As for Breathable Particles, it was found that the average value was lower in the “Production” zone compared to the “Painting” zone ($d\bar{x}$= 25.027 mg/m3) and the “Assembly” zone ($d\bar{x}$= 2.341 mg/m3).

Analyzing the Inhalable Particles, it was found that the average value was lower in the “Production” zone compared to the “Assembly” zone ($d\bar{x}$= 8.917 mg/m3) and the “Painting” zone ($d\bar{x}$= 4.886 mg/m3).

Regarding Ultrafine Particles, the average value was lower in the “Assembly” zone compared to the “Production” zone ($d\bar{x}= 6157.11ppm$) and the “Painting” zone ($d\bar{x}= 1251.78ppm$).

Finally, regarding VOCs, it was found that the “Pintura” area was the only one where values were found compared to the other locations.

Subsequently, it was intended to verify whether there were exceedances of the legally established reference value for the thermal comfort parameters in the indoor air of the wood industry, whose values are shown in Table 3:

Table 3. *Average concentrations of Temperature and Relative Humidity in the different work zones*

		Work Zone							
		Production		**Assembly**		**Painting**		**Total**	
		n	%	n	%	n	%	n	%
Temperature (a)	≤17.99° C	3	10	23	76.7	4	13.3	30	5.6
	[18-22] °C	176	35.6	157	31.8	**161**	**32.6**	494	91.5
	>22.00° C	1	6.3	0	0.0	15	93.8	16	3.0
	Total	180	33.3	180	33.3	180	33.3	540	100.0
Humidity (b)	≤49.99%	95	25.0	135	35.5	**150**	**39.5**	380	70.4
	[50-70] %	44	59.5	0	0.0	30	40.5	74	13.7
	>70.00%	41	47.7	**45**	**52.3**	0	0.0	86	15.9
	Total	180	33.3	180	33.3	180	33.3	540	100.0

Caption: (a)(b) Chi-Square Test: $\chi2$ = 52.994/97.015; p<0.001/ p<0.001; n = number of samples; Temperature≤17.99°C= Temperature less than or equal to 17.99ºC; [18 – 22] ºC = Temperature between 18 and 22ºC; >22ºC = Temperature above 22ºC; Humidity≤49.99%= Humidity less than or equal to 49.99%; [50-70] = Humidity between 50 and 70%; >70%= Humidity above 70%

Regarding the Temperature parameter, it was observed that of the 3 zones evaluated, in a total of 540 evaluations carried out, 46 (8.52%) had a temperature outside the legally established range [18-22ºC]. Therefore, the work zones classified as "Assembly" and "Painting" had a greater number of cases in which the temperature was outside the legally established range.

Regarding the Relative Humidity parameter, it was observed that of the 3 areas evaluated, in a total of 540 specific evaluations carried out, 466 specific evaluations (86.3%) presented humidity outside the legally established range [50-70%]. Therefore, the work zones classified as "Painting" and "Assembly" showed a greater number of cases in which the humidity was outside the legally established range.

Subsequently, it was intended to evaluate the relationship between the concentrations of Respirable Particles, Inhalable Particles and Ultrafine Particles with indoor air and outdoor air, whose values are shown in Table 4:

Table 4. *Concentrations of Respirable Particulates, Inhalable Particulates and Ultrafine Particulates in indoor and outdoor air.*

	Local	**No**	**Average**	**Standard deviation**	**p-value**
Breathable particles	Inside	540	**13.124**	40,699	<0.001
	Outside	60	0.886	0.494	
Inhalable particles	Inside	540	**21,397**	51,341	<0.001
	Outside	60	1.201	0.701	
Ultrafine particles	inside	540	14265.69	16344.035	<0.001
	Outside	60	**19373.33**	5434,693	

Test: Wilcoxon-Mann-Whitney; N - Number of measurements; Z= -6.606/-6.524/-7.105

Through the analysis of Table 4, and using the Wilcoxon Mann-Whitney test, it was verified that the average concentration in each of the evaluated atmospheric parameters registered significant differences depending on the place where the measurements were carried out (indoor and outdoor).
The values registered were higher for Respirable Particles and Inhalable Particles inside the industry compared to outside it ($d\bar{x}$= 12.238 mg/m3 for Respirable Particles and$d\bar{x}$= 20.196 mg/m3 for Inhalable Particles), while for Ultrafine Particles the values outside the industry were higher compared to inside it ($d\bar{x}$= 5107.64ppm).
Next, it was intended to evaluate the relationship between the number of Breathable Particles, Inhalable Particles and Ultrafine Particles between the various work zones, whose values are presented in Table 5:

Table 5. *Association between number of Breathable Particles, Inhalable Particles and Ultrafine Particles with different work zones.*

Work zone			**N Breathable Particles**	**N Ultrafine particles**	**N Inhalable Particles**
Production	N Breathable Particles	Pearson correlation	1	0.478	**0.918**
		p-value	-	<0.001	<0.001
	N Ultrafine particles	Pearson correlation	**0.478**	1	0.638
		p-value	<0.001	-	<0.001
	N Inhalable Particles	Pearson correlation	0.918	**0.638**	1
		p-value	<0.001	<0.001	-
Assembly	N Breathable Particles	Pearson correlation	1	-1,187	**0.994**
		p-value	-	0.012	<0.001
	N Ultrafine particles	Pearson correlation	**-0.187**	1	-0.184
		p-value	0.012	-	0.013
	N Inhalable Particles	Pearson correlation	0.994	**-0.184**	1
		p-value	<0.001	0.013	-
Painting	N Breathable Particles	Pearson correlation	1	**0.071**	**0.997**
		p-value	-	0.346	<0.001
	N Ultrafine particles	Pearson correlation	0.071	1	0.080
		p-value	0.346	-	0.285
	N Inhalable Particles	Pearson correlation	0.997	**0.080**	1
		p-value	<0.001	0.285	-

- General characterization of the sample

For the collection of data for the present investigation, a wood furniture production industry, located in the central region of Portugal, was selected. The collections were carried out at the company's workstations where the 4 employees, all male, performed their duties.

The production station has the tasks of sanding the parts, cutting, maintenance, among others. The paint booth was the place where the parts that would later be used in the assembly station were painted. The assembly station would be the last step, where the parts are fixed to obtain the final product, which will be sent to the customer.
The population that participated in the study consisted of 4 workers, all male (100%), with an approximate mean age of 55.3 ± 15.54 years.
About working hours, 2 of the 4 workers (50% of respondents) worked an average of 7 hours a day, and 2 workers (50% of respondents) worked an average of 8 hours a day. In terms of educational qualifications, the 4 workers had completed “Basic Education”.
Regarding the time they worked at the company under study, the individuals worked for an average of 35.5 ± 17.45 years, with a minimum time of 20 years and a maximum of 60 years. Regarding working hours/day, an average of 7.5 ± 0.58 hours was recorded.
Regarding the use of Personal Protective Equipment (PPE), all workers stated that they always used them. However, workers indicated lack of use of certain types of PPE, such as protective glasses and visor (25%), ear protectors (25%) and respiratory protection mask (25%). Most workers did not wear safety boots (75%).
Regarding the improvement of symptoms when they go abroad, workers do not point out any changes in symptoms, a response that was also unanimously verified when asked if the manifestation of symptoms differed according to the season of the year. Finally, regarding smoking habits, 2 workers (50% of respondents) revealed to be active smokers

Discussion

After analyzing the average values of CO_2 concentration, it was found that, in all workstations, the values were below the ELV, 5000ppm. This result was expected, given the existence of extraction systems, as well as the great natural ventilation existing in the place under study.
The workstation that presented the highest levels of CO_2 was the “Painting” area, which is to be expected, given the reduced space that this place presents, and being the one that is furthest from the entry point of natural ventilation. Even so and given that the company itself is small, the number of workers is low, and as a rule, workers do not work simultaneously in each area, the values obtained are not worrying, and are significantly below the limit value. of exposure.
About CO, its presence was only verified in outer space, and in this location the parameter was also below the ELV, 10 mg/m3. Although there are heating sources inside, the existence of extraction systems and strong ventilation inside the industry contributed to this result, and in all measurements the windows and doors were open.
Regarding the Temperature parameter, most average values (91.48%) were within the legally established temperature range [18-22] ºC. Although the measurements were taken in the month of May, which is characteristic of higher temperatures, the fact that the measurements were taken in the morning (9h-12h), and that this space is heavily ventilated, contributed to the values obtained.
Regarding the Relative Humidity parameter, the results were quite different, with a wide range of values being verified, most of which are below the legally established range [50-70%]. As previously mentioned, the industry has a strong renewal of the air, in its interior, in which the windows and doors are open during the execution of the works, which contributed to the values obtained.
According to the Canadian Center for Occupational Health and Safety, relative humidity outside the parameters considered acceptable, in this case low, can cause discomfort to occupants. In this case, it would be important to review whether the ventilation system used will be the best for the space in question. It would also be important to consider the need to reorganize the space, namely the location of the equipment and the way in which the stations were divided, for more efficient ventilation (Moreira,2024; CCOHS, 2004).
About VOCs, these showed significant values well above the exposure limit value (12.22 ± 13.251), namely in the “Pintura” area, which is also the only place where values were measured. Obtaining these values and given that the measurements were made with the paint booth exhaust in operation, may be associated with incorrect

exhaustion, or clogging of the exhaust filters. Given the various sources of VOCs, such as the use of products such as solvents, paints, adhesives, and cleaning products, among others, it would be expected that the "Painting" area would have the highest values.

Some of the measures that should be adopted are the replacement of exhaust filters and the correct storage of solvents, paints and paint thinners, in a dedicated room equipped with local exhaustion, where they are well closed when not in use. (CCOHS, 2004). It will be relevant to pay attention to the purchase of water-based substitutes, which are starting to have more and more prominence in the market.

In general, exposure levels in the workplace tend to be higher than those of environmental exposure, and therefore the risk for some groups of workers may be higher than the average risk for the general population (Hämeri, 2009).

Regarding the UFP, the average values, comparing the different work zones, were higher in the “Production” zone. When the concentration between the exterior and interior environment was evaluated, these were higher on the exterior. This may indicate a possible contamination from the outside to the inside, given that the “Production” area, which registered the highest values, was close to the access point to the interior, and this structure could be introducing external contaminants.

Some of the measures that should be taken are to identify the sources of the UFP, to establish measures that aim to eliminate or reduce these sources. To avoid possible external contaminants, the use of extraction systems located as close as possible to the source should be considered (Marval & Tronville, 2022).

About respirable particles, the average values (29.029 ± 65.848) they were significantly above the exposure limit value (3 mg/m^3). The values were higher in the “Painting” zone, which raises questions, as with VOCs, about possible incorrect exhaust, or clogging of exhaust filters.

At the level of inhalable particles, the average values (25,713 ± 69,582) were also significantly above the exposure limit value (10mg/m^3). In this parameter, the place that recorded higher values was “Assembly”.

What could also justify the presence of such high values for these parameters could be the meteorology, because according to (Santos, 2017), periods of precipitation can contribute to the dissolution of contaminants, thus reducing their concentrations in the air. Unlike this scenario, and we can only consider the Temperature and Relative Humidity parameter, the record that was verified may have contributed to the greater presence of pollutants.

About the association between UFP, inhalable particles and respirable particles, the results indicated different levels of association between variables in different work zones. In the “Production” zone, there are positive correlations between the different variables. In the “Assembly” zone, there are positive and negative correlations, which indicates a greater complexity in the relationships. In the “Painting” zone, except for the positive correlation between the number of respirable and inhalable particles, the correlations were not statistically significant.

The positive correlation between inhalable particles and respirable particles can be explained with the measurement equipment used, as according to (Malings, 2018), a failure in the efficiency of counting for each particle size range can compromise its measurement range. This means that, with an increase in the number of respirable particles, it is expected that the number of inhalable particles will also increase, since the device may consider, when measuring, a certain range of particle size, being this within the respirable particles or inhalable, as part of the second, and vice versa.

In relation to the positive correlation found in the “Production” zone between UFP and inhalable particles (0.638), and the former with breathable particles (0.478), this could be due to the formation of secondary pollutants inside. There is still a lack of knowledge regarding the association between UFP and other pollutants in indoor environments. The infiltration of outdoor photo-oxidants into indoor environments, and the very interaction between VOCs indoors, can trigger new particle formation processes, which could be a source of increased UFP (Morawska, 2019).

Conclusions

The importance of studying the occupational exposure of these pollutants in the wood industry is related to the exposure of these workers to different types of professional risks. Often motivated by production needs, it is common for workers to change temporary roles, which leads to their exposure to different types of contaminants. Based on the results obtained, we realize that, except for the values of $C0_2$, CO, Temperature, and ultrafine particles, and for the latter there are no exposure limit values, the remaining values are significantly above the exposure limit values, and concentrations are higher inside the industry compared to outside. That said, specific measures are needed to improve the quality of the front air for each work zone.

It is essential that workers, and management themselves, are made aware of the importance of using PPE, to prevent and preserve their health. Attention should be paid to frequent and adequate cleaning of spaces, mainly to prevent the accumulation of dust on surfaces, machines, furniture, and equipment. It is also important, in addition to having ventilation and air extraction systems, that they are properly maintained, and for that it is essential to carry out frequent monitoring, to be able to identify situations that may become harmful, and even dangerous for its workers.

In terms of limitations found throughout the study, the first was undoubtedly the lack of information that was in accordance with the industry under study, and all the studies found were related to the combustion of wood. Another limitation felt was the lack of legislation regarding the exposure limit values for UFP, as well as not having evaluated the parameters at different times of the day, to understand how the variables behave in the absence of activities. Another limitation was the lack of evaluations with different meteorological variables, to see if there are changes in values in different seasons. It would also have been pertinent to apply the questionnaire to a company with a larger number of workers, to have a more credible sample.

Current guidelines only limit the major fractions of PM2.5 and PM10, and current studies have increasingly supported the distinct behaviors that UFPs have from major fractions in the human body (Marval & Tronville, 2022). For this, there is a lack of epidemiological studies that study human exposure and bring together matrices that support the formation of guidelines for acceptable exposure levels, so that there is a standardization of methods, which will undoubtedly have to change in the future, with the growing concern for with this theme.

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