Investigation of Indoor Noise Pollution Level and Air Quality of Furniture Manufacturers

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Indoor air quality has become a more prominent concern since the arrival of the COVID-19 pandemic. Manufacturing industries have always been prone to occupational health risks, which depend on the dynamics of the production shop floors. The furniture industry is one of these sectors with a unique work environment. Although a typical furniture manufacturing facility involves physical, chemical, and noise pollution-producing elements, this industry has been studied relatively less for indoor air quality and noise-related risks. This study investigated nine furniture manufacturing organizations' indoor air quality and noise pollution levels through comprehensive quantitative techniques. The results of the measurements were compared against reference values set by specific guidelines to explore the degree of occupational health risk associated with the World Health Organization's (WHO) suggested levels. Repetitive measurements from five pre-designated workstations were taken at each facility. The study's results indicated that organization size and department were significant factors for PM 2.5 and HCHO parameters, while only department type was substantial for noise exposure levels. However, across all departments and organization sizes, LAeq noise levels were below the safety threshold of 85 dB(A). Most organizations presented a lack of proper use of personal protective equipment and poor ventilation across shop floors.

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INTRODUCTION

The furniture industry is an essential sector with a worldwide economic contribution (Abu *et al*. 2019). The USA, China, Canada, and Italy lead the furniture industry globally (Pirc and Vlosky 2010). In addition, many local manufacturers in other Asian and European countries serve the furniture market. Türkiye is an essential player in the global furniture market, with an export value of more than 554 million USD annually (Çınar 2005; IMOS 2019). The country is a decisive force in regional industrial dynamics due to its forest product stocks and geo-strategic location between the East and West. Türkiye is an essential supplier of some tree species, such as pine, beech, and fir, which are used for furniture manufacturing (Coşkun 2019).

One of the most significant value-generating furniture manufacturer clusters in Türkiye is in the Bursa-Inegol region. The city is located on the historical Silk Road and has been famous for its furniture among traders using this route. In the last 15 to 20 years, in the Inegol Region, the number of small-, medium-, and large-scale enterprises has increased; today, there are around 587 furniture exporting companies (Araz and Yaşar 2020). Within Türkiye's furniture industry, beech, hornbeam, poplar, and pine are the most commonly utilized wood species for upholstered furniture manufacturing, while walnut, oak, and some other hardwood species are preferred for furniture items made of solid wood.

Furniture has always been a reflection of culture and lifestyle for societies. The furniture industry has been directly affected by many global and regional social and natural factors such as wars, population trends, natural disasters, technological improvements, pandemics, and, last but not least, resource scarcity. For instance, after the Second World War, there was a worldwide shortage in the supply of raw wood and wood-based materials, and the furniture industry had a difficult time, leading to the emergence of alternative furniture designs (Pirc and Vlosky 2010). Similarly, the COVID-19 pandemic started to shake the world in 2019 and directly affected the furniture industry's manufacturers and consumers (Ratnasingam *et al*. 2020). Due to the pandemic, people have been forced to adopt the home-office working model and started to spend more time at home. Therefore, the demand for furniture has increased out of the ordinary (Pirc Barčić *et al*. 2021). The increasing demand has caused furniture workers to work indoors over capacity for more extended hours, which has meant longer exposure to working environment conditions. The furniture industry produces semi-finished or finished products from wood by cutting, sanding, mowing, chipping, fibering, bonding, pressing, steaming, drying, and impregnation processes (Smardzewski 2015). During these processes, physical injuries and other occupational hygiene and health-threatening risks may occur due to exposure to dust, chemical gas, noise, vibration, and thermal discomfort. Additionally, indoor air quality risks have recently been more prominent and attention-grabbing due to the COVID-19 pandemic (Abouleish 2021; Tian *et al*. 2021).

Indoor air quality should include key aspects to provide a healthy and comfortable working environment (Persily 2015). These features are stated in Standard 62 of the American Society of Heating, Refrigerating, and Air-Conditioning (ASHRAE). Indoor air pollutants could be classified as gases and particulates (Batterman and Peng 1995). The well-known gas pollutants are CO, CO_2, formaldehyde, volatile organic components (VOC), O_3, NO_2, and SO_2. Particle matter (PM) is a tiny solid pollutant, usually originating from the external environment or dust generated during manufacturing processes (Alptekin and Çelebi 2015). Depending on emission sources and air conditions, particle matter's density and chemical compositions change. Because fine (PM 2.5) and coarse (PM 10) particles come from different sources and show different physical and chemical properties, PM 2.5/PM 10 ratios can provide important information about the source, formation, and effects of particles on human health (Bozkurt 2018). Past research revealed that dust exposure during wood processing mainly occurs at the sanding station, and it was reported that furniture dust negatively affects lung functions and causes serious diseases such as asthma (Mikkelsen *et al*. 2002; Jacobsen *et al*. 2008). A survey study conducted among 30 selected furniture factories in the Southeast Asian region showed that total inhalable dust particles were less than 10 µm in diameter, and their concentration was less than 25% by weight (Ratnasingam *et al*. 2010).

In addition to gases and particulates, noise is another occupational risk category that must be addressed. A few studies examined the effects of manufacturers and their facilities on occupational health, including safety, respiratory, and noise at various scales. Lie *et al.* (2016) reported a literature survey covering almost 700 articles and delved into roughly 200 of them to understand whether noise exposure results in a hearing decrease or loss among workers in terms of occupational health context (Lie *et al*. 2016). The study found that men tend to experience more hearing loss. On top of that, besides noise, some other factors, such as vibration and chemical substances, played essential roles in this concern. Bharwana *et al*. (2019) conducted a study with fifty workers of iron furniture manufacturers to understand occupational risks (Bharwana *et al*. 2019). The authors utilized a survey and reported high dust, heat, and noise exposure as notable hazards in small-scale manufacturers. Ntalos and Papadopoulos (2005) observed a similar trend of noise exposure in furniture manufacturing firms. The study found that all noise measurements were above 85 dB(A), which is considered unhealthy working conditions, particularly when exposed for more than 8 hours.

Considering more noise-specific studies, Malkin *et al*. (2005) performed a study in seven wood pallet production companies to assess noise exposure. The authors measured the noise levels and found that noise levels associated with machines and machine-related activities in each site were above 90 dB(A). Filipe *et al*. (2014) conducted a study in fourteen furniture factories to examine noise exposure in Brazil. The noise levels ranged around 50 dB(A) during 8-hr measurements. The study reported that measurements were above accepted noise levels of Brazilian regulations. Guarnaccia *et al*. (2013) performed an experimental study in wood production firms to understand single-source noise level exposure when the workers were in their working routine. The study found that various specific wood processing equipment, including band saws, circular saws, and nail guns, are responsible for high noise levels and concluded that mitigation policies should be taken for frequently utilized higher noise-level equipment.

Durcan and Burdurlu (2018) studied wood materials from a more specific perspective by evaluating the MDF made of Lombardy Poplar at various thicknesses ranging from 6 to 30 mm within a twenty-minute production time (Durcan and Burdurlu 2018). The study results showed that noise levels increased by up to 9 dB(A) with increasing levels of thickness. In a more recent study, Fidan *et al*. (2020) performed a study that examined noise levels only in lumber processing sections of forest product manufacturers (Fidan *et al*. 2020). The study was conducted in 17 work areas with a 5-second sequence of three-minute sampling. The measurements were analyzed and interpreted as some equipment, including a vertical wood band sawmill, were operating at higher noise levels than other machinery. The study suggested the adoption of protective precautions depending on the requirements of each case within manufacturing facilities. However, these past studies primarily focused on noise measurements of specific machinery and equipment in offices, stores, and shop floors and did not address the co-existence of other occupational health threats from a holistic perspective. Most of these studies also did not evaluate the situation comparatively for furniture companies of various scales. Furthermore, some past studies solely focused on shop-floor activities and ignored administrative offices and warehouses. In addition to comprehensive indoor air quality measurements, this study investigated ambiance noise levels through quantitative measurement techniques and compared them with reference values set by the World Health Organization to take a snapshot of the relatively less charted territory, furniture manufacturing facilities located in Inegol-Bursa.

The motivations behind this study were multifaceted, stemming from the increasing concern for occupational health within the manufacturing sector, particularly in settings prone to air pollutants and noise exposure such as the furniture manufacturing industry. This industry's unique intersection of chemical usage, wood dust generation, and machinery operation presents significant health risks, meriting a detailed investigation. A notable gap in the literature was identified: the lack of comprehensive research evaluating indoor air quality and noise pollution across different organizational scales within the furniture manufacturing sector. This gap was particularly pressing in the wake of the COVID-19 pandemic, which has heightened awareness around the importance of indoor air quality for public and occupational health and altered industrial work dynamics, potentially intensifying exposure to indoor pollutants. Furthermore, there existed a pressing need for data-driven recommendations to inform the development of targeted interventions and policies aimed at mitigating health risks in this industry.

Therefore, the objectives of this study were to 1) determine and compare indoor air quality and ambient noise levels of the small, medium, and large-scale organizations within the furniture industry and 2) identify and discuss the chronic indoor air pollution and noise-associated risks along with underlying factors of these risks from a holistic perspective in terms of occupational health and safety.

EXPERIMENTAL

The study methodology employed could be summarized in three phases: 1) the identification and selection of participating firms, 2) the determination of measurement parameters and measurement locations, and 3) data collection, processing, and reporting.

The selection of the participating firms, which were subjected to ambient air quality and noise level measurements, was completed systematically. A target population of 350 firms involving small-, medium-, and large-sized enterprises that meet the corresponding size classification criteria of the Ministry of Industry and Technology of the Republic of Türkiye were identified by using the membership database of the Association of Inegol Furniture Manufacturers (IMOS), a regional authority awarded with ECEI Bronze Label by European Secretariat in 2014. Micro-sized enterprises were excluded from the population, and the remaining population size was clustered into three size categories: small-, medium-, and large-sized enterprises. Then, three firms from each category were selected through a judgmental sampling procedure (Duignan 2016). A total of nine companies from all size categories were identified as main participants of the study, and nine more firms (three from each size category) were also selected and contacted as backup facilities or data sources, as illustrated in Fig. 1. Confidentiality and cooperation agreements were signed with all of the participating firms. Therefore, company names were not disclosed throughout the article. A site-visit schedule was created for data collection purposes, and each firm was visited on a separate weekday. The data were collected based on a pre-determined schedule involving different time intervals of regular business hours.

Numerous workstations within a furniture manufacturing plant are designed to perform various production activities, such as wood and panel cutting, edge banding, sanding, drilling, surface finishing, upholstery, assembly, and packaging. In addition to those shop-floor components, there would also be warehouses and administrative offices as essential parts of any production facility. Some critical physical and chemical hazards and ergonomic risks exist in such a work environment. These risks include but are not limited to dust and noise exposure, VOCs, improper lighting, lack of proper air circulation, heavy lifting, trip hazards, or the use of tools with significant vibration.

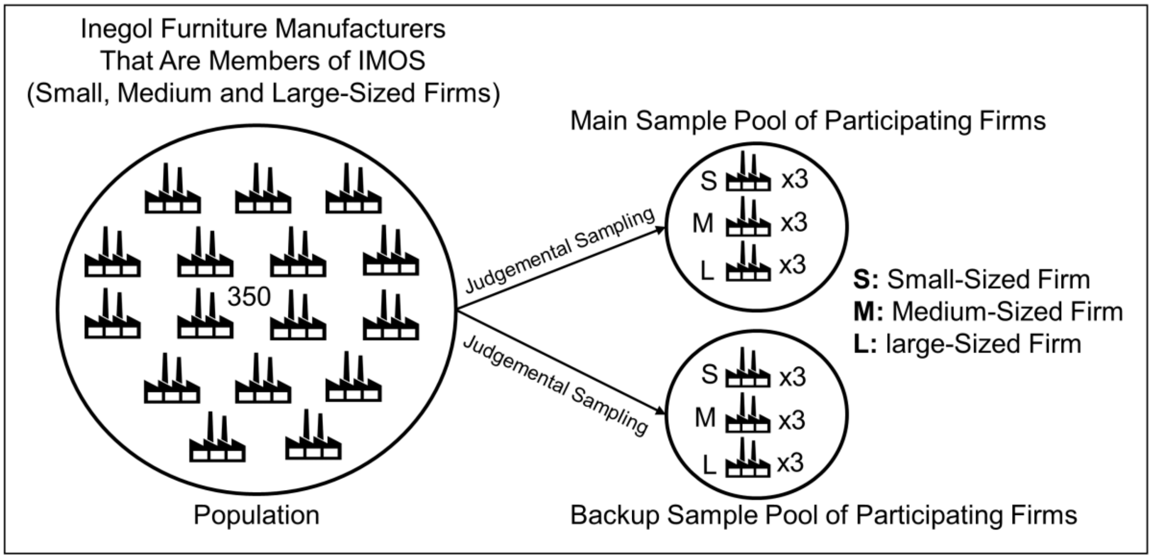

Fig. 1. Illustration of the sampling procedure followed in the study

Each workstation includes different characteristics as a function of varying machine configurations and job specifications, leading to various dust, VOC, CO_2 emission, and noise exposure levels. Therefore, selecting measurement locations was of critical importance for this study. To accurately designate the measurement locations within each facility, firms' process flow diagrams and facility layout plans were created in collaboration with professionals from the firms ahead of the site visits. Minitab Quality Companion was used to create process flow diagrams, while AutoCAD 2021 was used to draw facility layout plans. The researchers used these process flow diagrams and layout plans to discuss and select the measurement locations at each plant.

Three measurements from five pre-designated workstations (departments), namely, sanding/finishing, panel/part cutting, assembly/upholstery, administrative offices, and warehouses, were taken at each facility for ambient noise level and indoor air quality detection. In addition to shop floor functions of corporate buildings, as some other studies suggested, administrative offices, packaging areas, and warehouses were also included for a better understanding of the indoor air quality and noise hazard status of corporate facilities (Nezis *et al*. 2019; Strelyaeva *et al*. 2019; Mannan and Al-Ghamdi 2021).

Data were collected in a time-phased manner using 1-hour intervals for three repetitions, namely, 09:00-10:00, 11:00-12:00, and 14:00-15:00. The length of each measurement was ensured to be at least five minutes before being recorded as a valid data point. The sampling strategy was developed with an understanding that machinery in a furniture manufacturing setting does not operate continuously at full capacity; however, it is acknowledged that the noise levels during active machine operation are critical for assessing the risk of hearing damage. Therefore, time intervals and length of the sampling procedure were strategically designed for accurate assessment of the noise levels that workers might experience during their shifts, factoring in both the periods when machinery was actively processing materials and when it was idle between two consecutive parts at each station. As such, the noise level analysis took into consideration the variance in noise levels during different operational phases, including a comparative analysis of peak noise levels (LA_{max}) that occur during active processing periods. A total of 15 data points were collected for each parameter used for noise level detection. One hundred thirty-five data points were collected from nine facilities for each evaluation parameter. Noise level measurements were sampled according to BS EN 9612 and ISO 1997-2-2017 standards without interrupting regular work sequences using a PBX LXTI Class I sound level meter. For noise level measurement purposes, data for six key parameters were collected. LA_{eq} (A-weighted equivalent continuous sound level) was calculated by using Eq. 1 with a 5 dB(A) exchange rate, which meant that when the noise level was increased by 5 dBA, the amount of time a person could be exposed to a certain noise level to receive the same dose was cut in half (Fink 2017; The Engineering ToolBox 2004).

$$LA_{eq} = 10 \log \left[(1/T) \int (p_A / p_{ref})^2 \, dt \right] \quad (1)$$

In Eq. 1, LAeq is equivalent sound level (dB), T is time period (s), p_A is sound pressure (Pa, N/m^2), and p_{ref} is reference sound pressure (2x10^{-5} Pa, N/m2).

Other noise parameters measured were LA_{min} (instantaneous minimum sound level), and LA_{max} (instantaneous maximum sound level) with percentiles of LA10, LA50, and LA90. During the measurements, the sound level meter was set according to ISO criteria at least 150 cm clear from any potential barriers, such as walls and machinery in the designated measurement station. The device was also placed close to the active working area to capture noise levels realistically.

Indoor air quality measurements involved three particulate matter categories: total particles, PM 2.5 and PM10, formaldehyde emission (HCHO), and carbon dioxide (CO_2) level. Temtop M2000 2nd Air Quality Monitor was employed for indoor air quality measurements, and data collection was carried out with utmost care to ensure consistency and control for human-factor-driven variability. The measurement ranges of the device for the parameters mentioned above were 0 to 999 µg/m^3, 0 to 2 µg/m^3, and 0 to 5000 ppm, whereas the resolutions for the same parameters were 0.1 µg/m^3, 0.001 mg/m^3, and 1 ppm, respectively. Following the aforementioned ISO criteria, the device was held near the workers' noses and mouths to measure the designated workstation's air quality. The designated workstations' temperature and humidity levels were also measured and recorded to check for potential abnormalities. The same time intervals and sampling length as the noise level sampling procedure were also followed for the indoor air quality data collection phase. A total of 15 data points were collected for each parameter tracked for indoor air quality detection.

All data were digitally stored and processed in Microsoft Excel before transferring to Minitab 18 Statistical Analyses software for descriptive and inferential statistical analysis. Upon completion of descriptive statistics, the inferential statistical analysis, two-way ANOVA, and Tukey Pairwise Comparisons were carried out on the study parameters. The two-way ANOVA analysis used a stepwise regression procedure involving second-degree interaction terms of independent variables.

RESULTS AND DISCUSSION

Results of Descriptive Statistical Analyses

Both independent variables, organization size, and department, were checked against thirteen dependent variables (evaluation parameters). Sample size, mean, minimum, and maximum values, range and median values, and Q1 and Q3 values across each parameter were reported in Table 1 as part of descriptive statistical analyses.

Table 1. Results of Descriptive Statistical Analyses

Variable	N	Mean	Min.	Q1	Median	Q3	Max.	Range
PM 2.5	135	73.23	10.80	30.00	48.40	95.80	379.40	368.60
PM 10	135	640	4.00	47.00	81.00	152.00	70714	70710
Total Particles	135	14239	2023	6248	9922	18102	59198	57175
CO_2	135	486.90	313.00	412.00	443.00	497.00	1089.00	776.0
HCHO	135	0.2365	0.0010	0.0400	0.1010	0.3210	3.4440	3.4430
LA_{eq}	135	71.08	41.90	62.20	74.70	78.80	93.75	51.85
LA_{min}	135	62.21	33.30	51.60	64.00	74.70	85.00	51.70
LA_{max}	135	83.04	56.70	75.60	84.00	90.20	120.60	63.90
LA_{10}	135	69.03	38.55	60.50	69.28	79.03	89.30	50.75
LA_{50}	135	73.14	44.10	62.21	75.01	81.76	101.25	57.15
LA_{90}	135	55.81	28.49	44.80	52.90	69.90	83.60	55.11
Temperature	135	26.88	23.00	25.00	26.00	30.00	32.00	9.00
Humidity	135	0.47	0.34	0.42	0.47	0.50	0.64	0.30

The mean value for PM 2.5 was 73.2 µg/m^3, with min, max, and range values of 10.8, 379.4, and 368.6 µg/m^3, respectively. Minimum and maximum values across all measurements for the PM10 variable were 4 and 70714 µm, respectively, which yielded an extensive range value of 70,710 µm. Similarly, a wide range (57,175 counts/L) value was recorded for the total particle variable with minimum and maximum values of 2023 and 59198 counts/L, respectively. As another indicator of indoor air quality, CO_2 levels for different organization sizes and departments were measured. A mean value of 487 ppm was calculated based on 135 data points. The highest concentration of CO_2 was measured to be 1089 ppm, whereas the lowest concentration level was 313 ppm. Another critical indicator of indoor air quality for furniture manufacturers is HCHO levels within the work environment. As presented in Table 1, the mean HCHO value was around 0.236 µg/m^3 with minimum and maximum values of 0.0010 and 3.44 µg/m^3, respectively.

Within the scope of noise level indicators, the mean LA_{eq} value across all data points was 71.1 dB(A). The minimum LA_{eq} value was 41.9 dB(A), while the median and maximum values for this variable were 74.7 dB(A) and 93.8 dB(A), respectively. The mean, minimum, maximum, and range values for the LA_{min} variable were 62.2, 33.3, 64.0, and 85.0 dB(A), respectively. On the other hand, a mean value of 83.0 dB(A) was recorded for the LA_{max} category. The minimum, median, and maximum values for this evaluation category were 56.7, 84.0, and 120.6 dB(A), respectively, as shown in Table 1.

Results of Inferential Statistical Analyses

The results of the inferential statistics showed that both organization size and department were statistically significant at the 95% confidence level in the means of PM 2.5 particles with p-values of 0.003 and <0.0001, respectively. Within the general linear model of PM 2.5 versus organization size and department, the interaction term of the independent variables was not significant at the same confidence level and had a p-value of 0.074, as shown in Table 2.

Table 2. Results of Two-Way ANOVA Analysis for PM 2.5 Observations versus Organization Size and Department

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Organization Size	2	41297	20648	6.14	0.003
Department	4	131115	32779	9.75	<0.0001
Organization Size*Department	8	49720	6215	1.85	0.074
Error	120	403377	3361		
Total	134	625510			

Tukey groupings of the size sub-groups indicated that small and mid-sized organizations had similar PM 2.5 levels, and the mean values of these size categories were not statistically different. In contrast, the large-sized organizations' subgroup had a much lower mean value and was grouped in a different category, as given in Fig. 2A. Based on the Tukey groupings of sub-groups of the department type variable, sanding/finishing department and administrative offices were placed in the same group, while panel/part cutting, assembly/upholstery and warehouse departments were grouped. However, some departments were not statistically differentiated from each other. For instance, administrative offices were not statistically different from panel/part-cutting departments, and assembly/upholstery departments were not statistically different from warehouses, as shown in Fig. 2B.

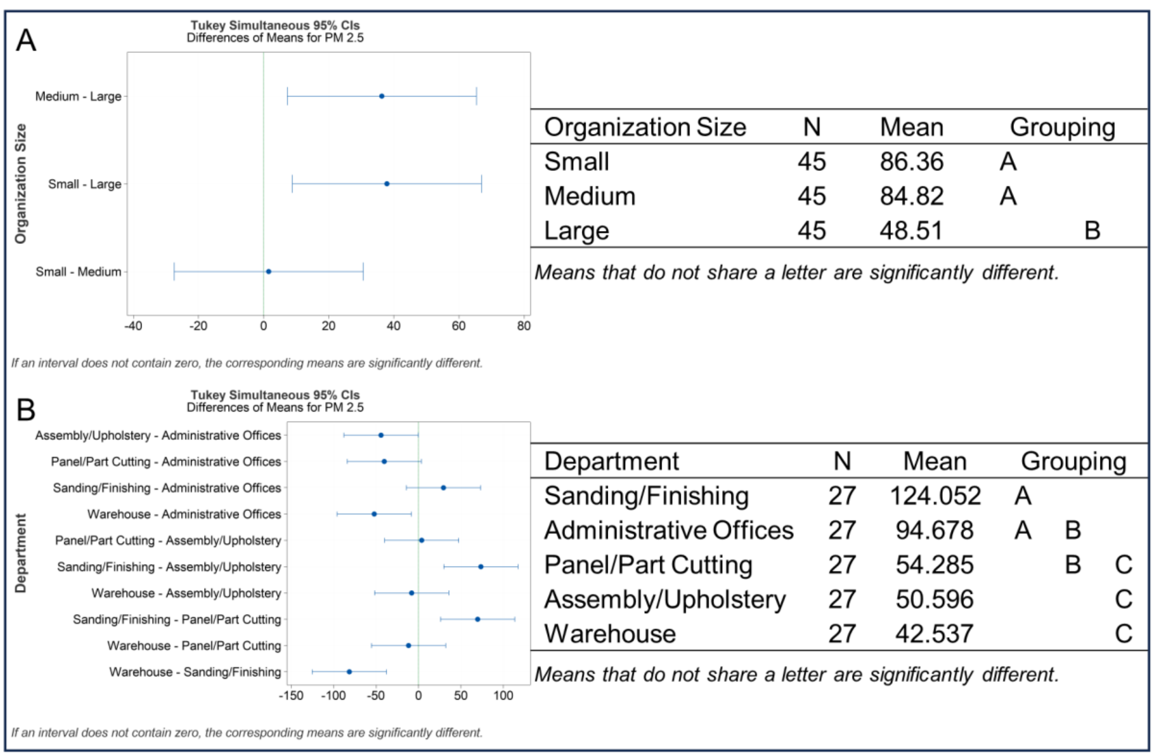

Fig. 2. Tukey groupings of the PM 2.5 sub-group means for organization size (A) and department (B)

According to the general linear model of HCHO versus organization size and department variables, both independent variables and their first-degree interaction term were statistically significant at the 95% confidence level with p-values of 0.002, <0.0001, and 0.003, respectively, as presented in Table 3.

Table 3. Results of Two-Way ANOVA Analysis for HCHO Observations versus Organization Size and Department.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Organization Size	2	2.039	1.0197	6.51	0.002
Department	4	6.927	1.7317	11.06	<0.0001
Organization Size*Department	8	3.915	0.4894	3.13	0.003
Error	120	18.793	0.1566		
Total	134	31.674			

As shown in Fig. 3A, within the sub-groups of the organization size variable, medium- and large-sized organizations were grouped in the same category with much lower mean values (0.1619 and 0.1377) than that (0.4097) of the small-sized organizations. Within the scope of Tukey groupings of HCHO mean values across different departments, all departments but the sanding/finishing department were grouped under the same category, as given in Fig. 3B.

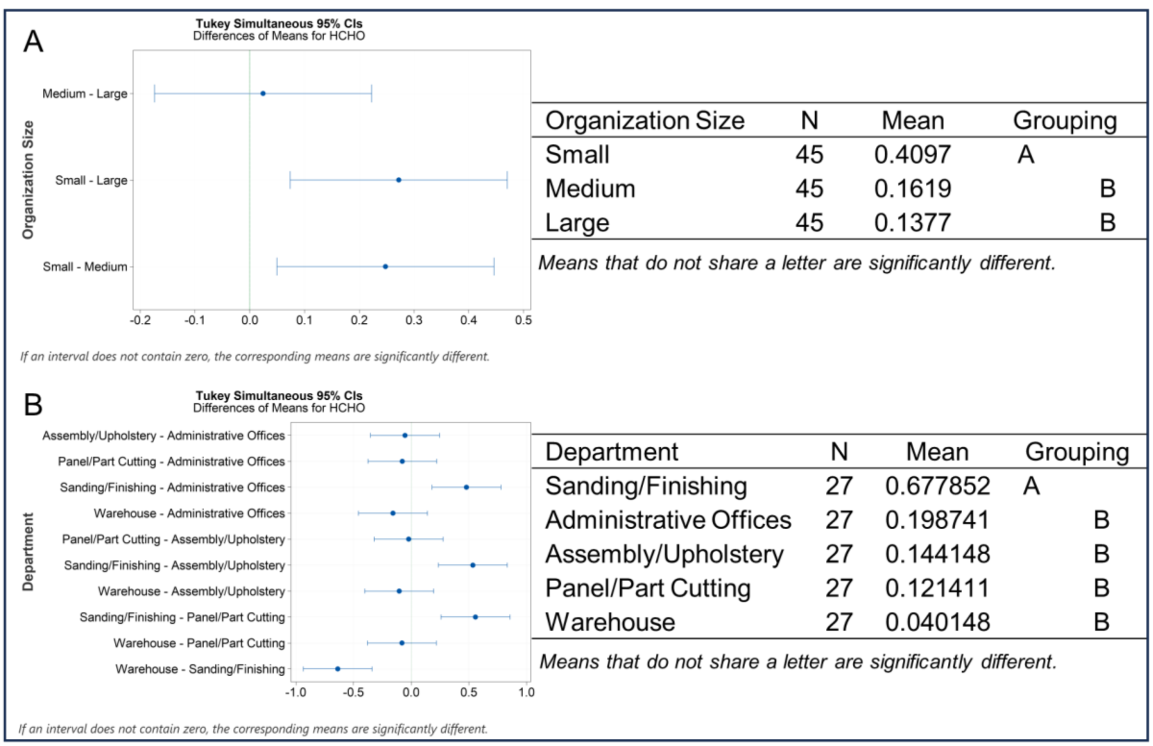

Fig. 3. Tukey groupings of the HCHO sub-group means for organization size (A) and department (B)

Two-way ANOVA results of LA_{eq} versus organization size and department type yielded interesting findings; mean LA_{eq} values across all organization sizes were not statistically different at the 95% confidence level, with a p-value of 0.077. Department type was found to be statistically significant with a p-value of <0.0001. The first-degree interaction term of the independent variables was also not statistically significant even though it was kept in the model by the stepwise regression procedure, as given in Table 4.

Table 4. Results of Two-Way ANOVA Analysis for LA_{eq} Observations versus Organization Size and Department.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Organization Size	2	137.7	68.87	2.61	0.077
Department	4	12266.3	3066.58	116.37	<0.0001
Organization Size*Department	8	381.1	47.64	1.81	0.082
Error	120	3162.3	26.35		
Total	134	15947.5			

When Tukey groupings of the LA_{eq} means of sub-groups belonging to organization size and department type variables were compared, as illustrated in Fig. 4A and 4B, all organization sizes were under the same category, while department types were under three distinct categories. LA_{eq} mean values of panel/part cutting and sanding/finishing departments shared the same group, while administrative offices and warehouse departments were placed in another group. As shown in Fig. 4B, the assembly/upholstery department was individually grouped into another category.

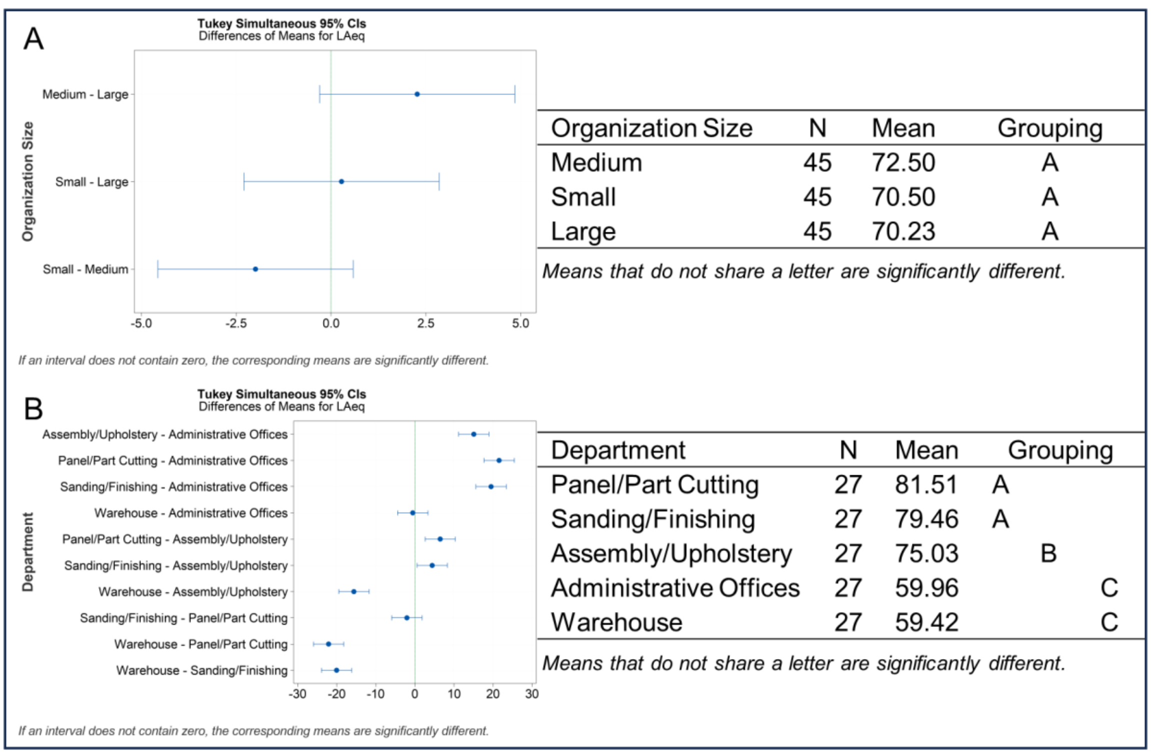

Fig. 4. Tukey groupings of the LA_{eq} sub-group means for organization size (A) and department (B)

Linear models constructed for variance analysis of other parameters, namely, total particles, PM10, LA_{min}, LA_{max}, LA_{10}, LA_{50}, and CO_2, did not have strong enough R-square and adjusted R-square values (<0.3) when checked against organization size and department variables. Therefore, no interpretation of inferential statistics was carried out for those parameters. PM 2.5, HCHO, and LA_{eq} were considered critical parameters and more detailly evaluated and discussed based on spatial patterns.

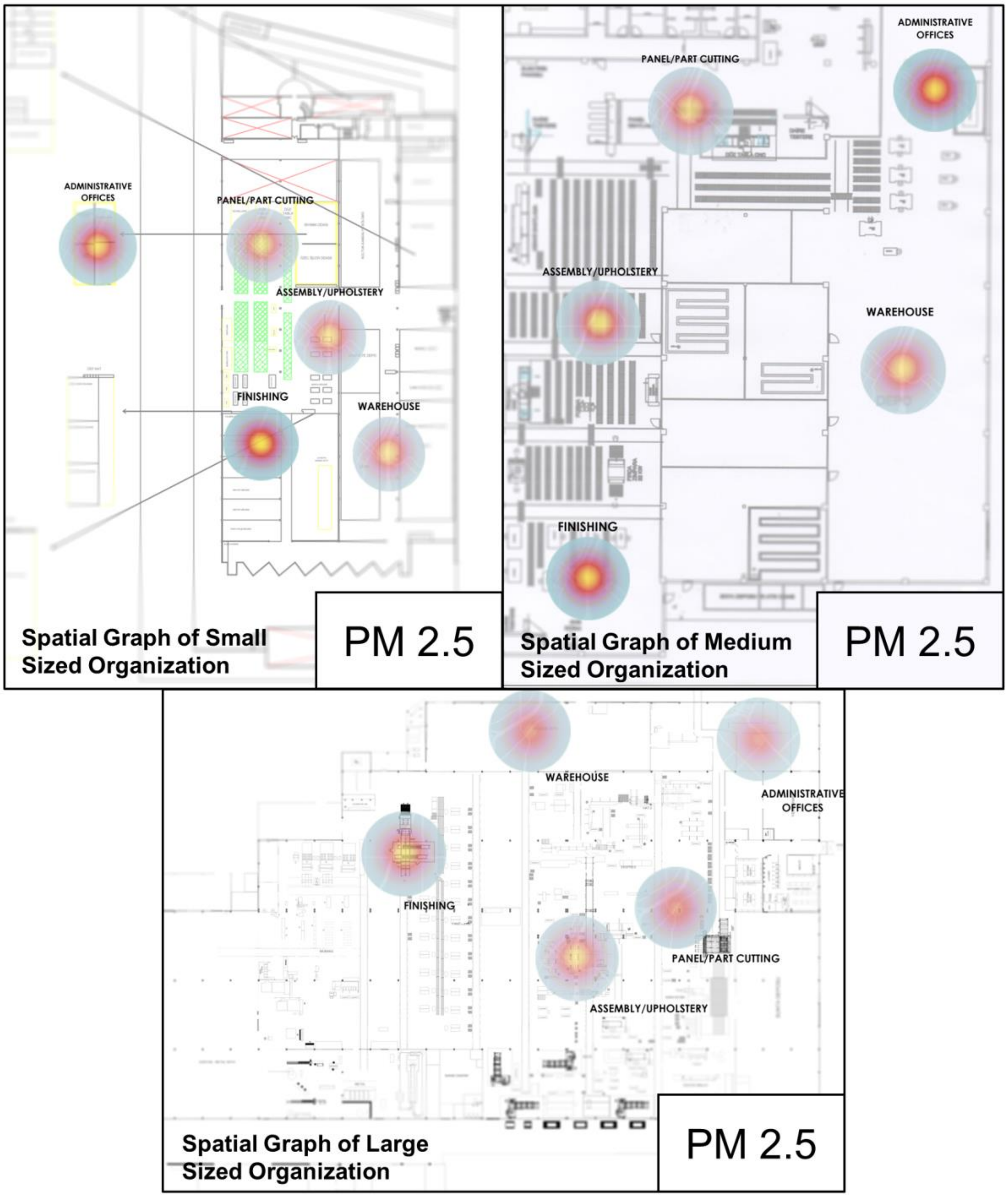

Fig. 5. Spatial layout illustration of average PM 2.5 for organizations

Spatial Patterns of Critical Parameters

A unique pattern emerged when looking at the spatial distribution of critical parameters, namely PM 2.5, HCHO, and LA_{eq}, within the large, medium, and small firms across different departments. Color-coded (darker colors mean higher levels of concentration or emission) critical pattern measurements were also illustrated on representative facility layout maps of small, medium, and large-sized organizations. These are presented in Figs. 5, 7, and 9.

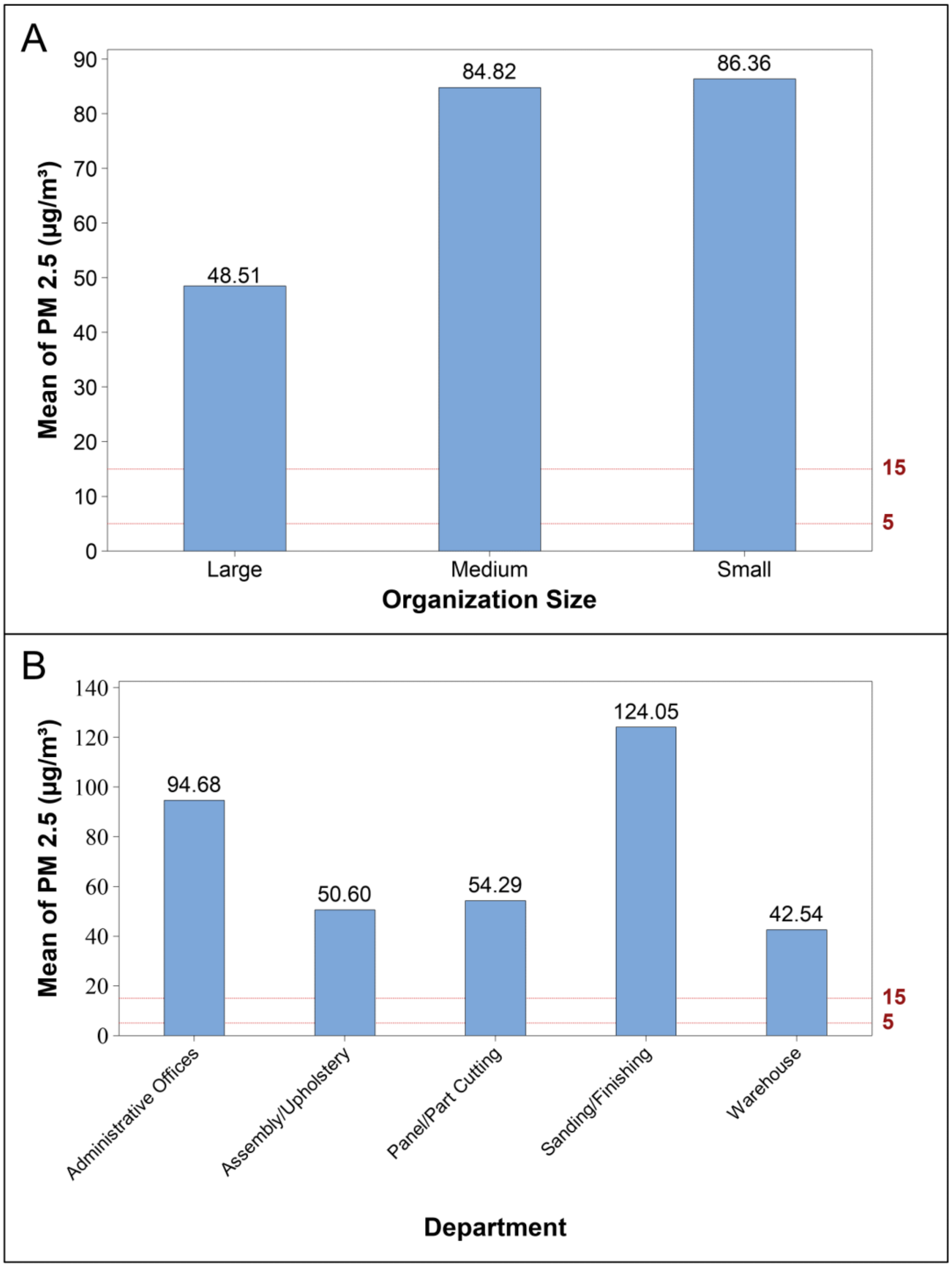

Fig. 6. PM 2.5 sub-group means for organization size (A) and department (B)

The average PM 2.5 values of the subgroups followed a unique pattern with some interesting findings when checked for organization size and department variables, as illustrated in Fig. 5. PM 2.5 values were also checked against the World Health Organization (WHO) guidelines (WHO 2010). According to these guidelines, there was no difference between the hazardous nature of particulate matter from indoor and outdoor sources. WHO highlights that the annual average concentration of PM 2.5 should not exceed 5 µg/m^3, while 24-hour average exposures should not exceed 15 µg/m^3 for more than 3 to 4 days per year. Among the measurements carried out for this study, the lowest average level of PM 2.5 concentration, 48.5 µg/m^3, was measured in large-scale organizations and increased by the decreasing organization size, as shown in Fig. 6A. The average PM 2.5 value for large-scale organizations was more than three times higher than the safety threshold of 15 µg/m^3.

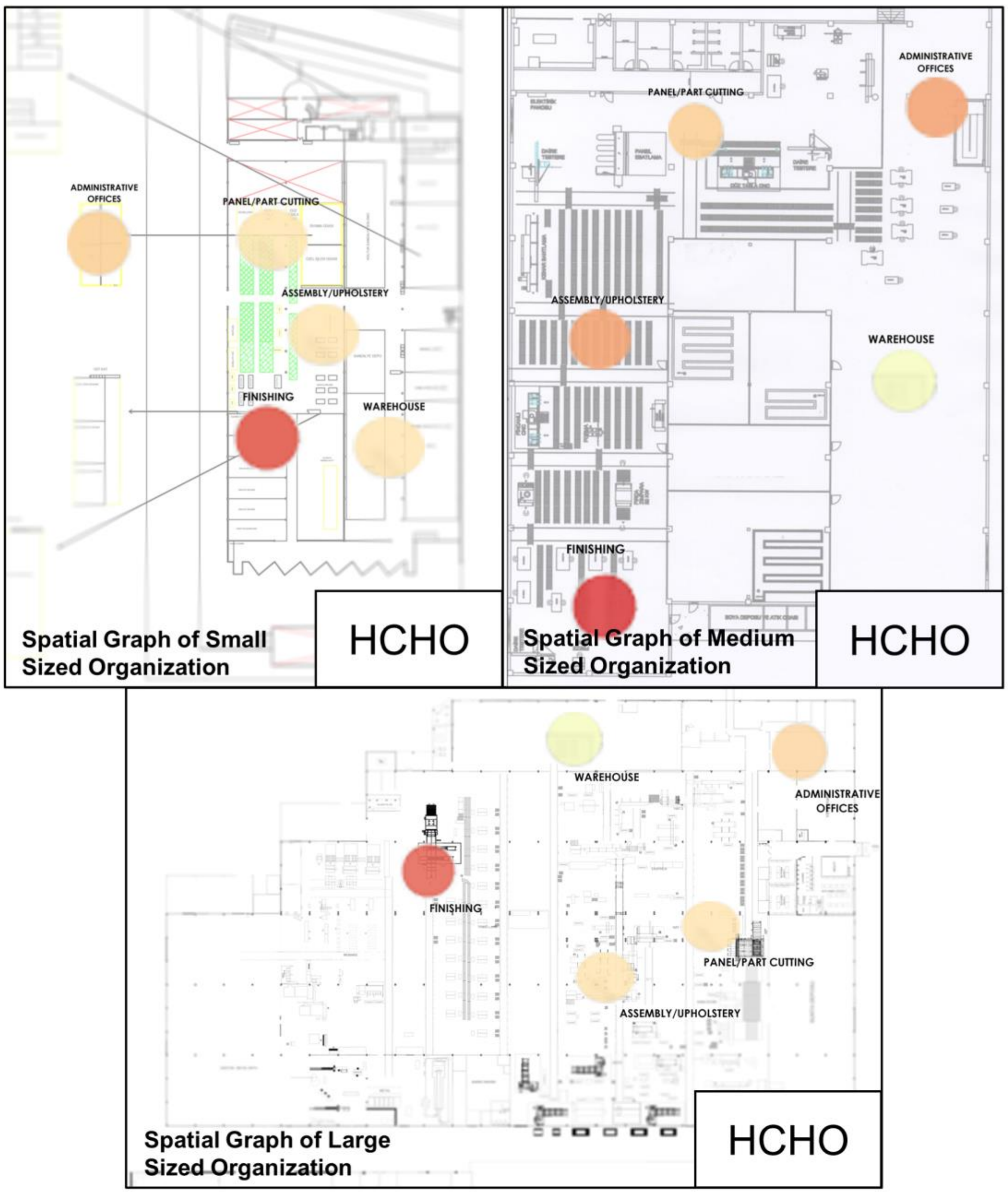

Fig. 7. Spatial layout illustration of average HCHO for organizations

The picture was much bleaker for medium- and small-sized enterprises, since their average PM 2.5 concentration levels were almost six times higher than the WHO safety threshold. Based on the department-wise comparisons, even though the finishing department included the highest PM 2.5 levels in all firm sizes, surprisingly, the administrative offices of the firms had the second highest mean PM 2.5 value, 94.7 µg/m^3. The firms' warehouse and assembly/upholstery departments had the lowest PM 2.5 concentration levels, with values of 42.5 and 50.6, respectively, as shown in Fig. 6B. However, even these concentration levels were much higher than safe and reasonable levels. Even though the authors noticed HVAC systems in most facilities, such high levels of PM 2.5 concentration across all organization sizes and departments could be due to poor, inadequate, and insufficient air circulation.

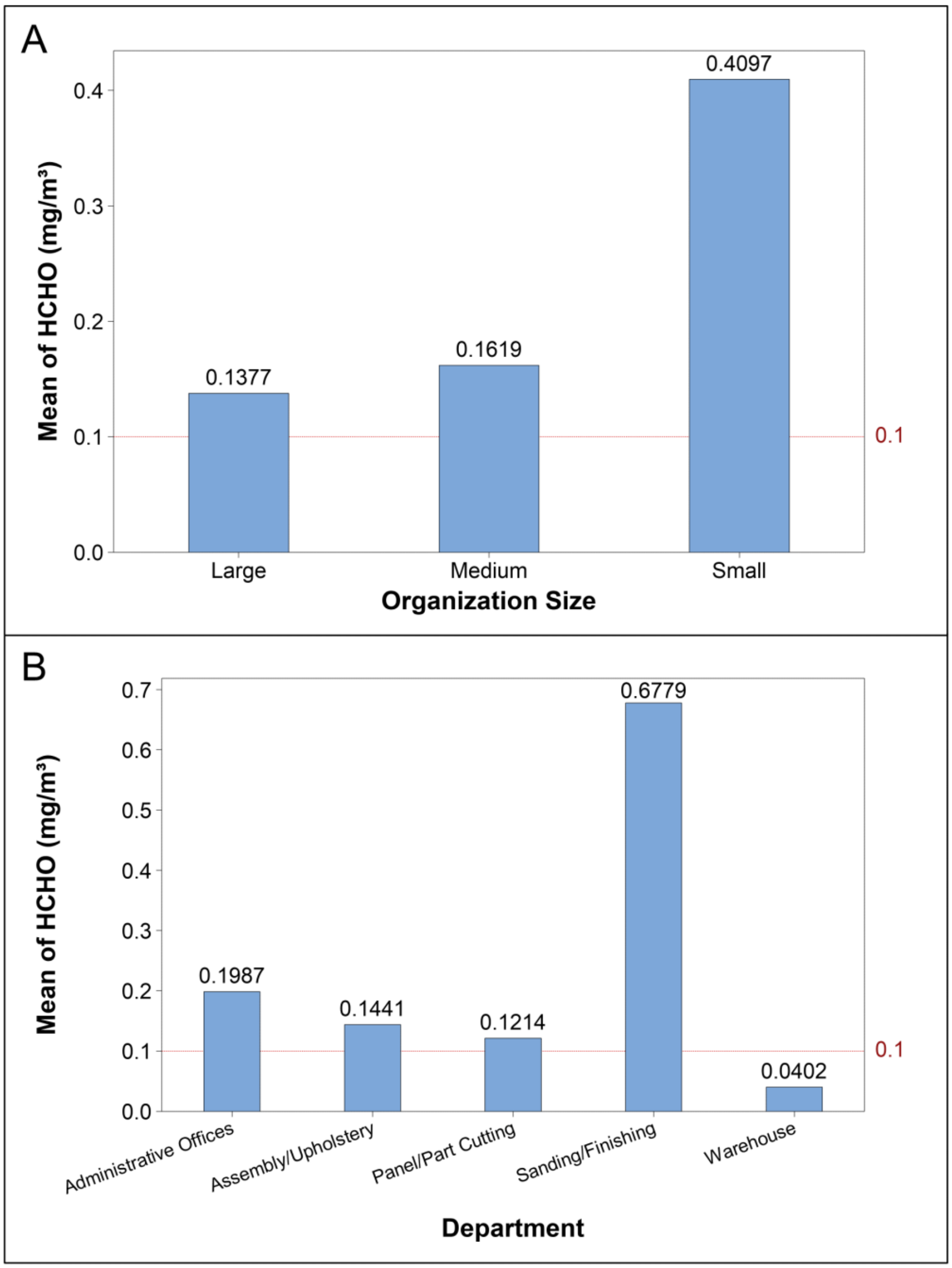

Fig. 8. HCHO sub-group means for organization size (A) and department (B)

As shown in Figs. 7 and 8A, HCHO concentration levels followed a similar pattern with the PM 2.5 parameter. Across all firm sizes, the HCHO concentration level was found to be the highest in the small-sized firms, with an average value of 0.410 µg/m^3, which is approximately four times higher than the short-term exposure (30 minutes) safety threshold of 0.10 µg/m^3 defined by the World Health Organization (WHO 2010). Only slight differences were observed between medium and large-scale firms, with average concentration levels of 0.138 and 0.162 µg/m^3. However, these levels were also above the safety threshold defined by the WHO guidelines. The over-clustered shop floor, high work-in-process inventories, and poor/insufficient ventilation could explain small-sized firms' high HCHO concentration levels. On the other hand, as shown in Fig. 8B, department-wise comparison also yielded interesting outcomes. Sanding/finishing departments had the highest level of HCHO concentration, approximately seven times higher than the safe level, with a value of 0.678 µg/m^3. Sanding/finishing departments were followed by administrative offices (0.199 µg/m^3), assembly/upholstery (0.144 µg/m^3), panel/part cutting (0.121 µg/m^3), and warehouse (0.040 µg/m^3) departments.

Such elevated HCHO levels of sanding/finishing departments could be due to the VOCs originating from (1) furniture paints and (2) adhesives used in wood-based panels. These VOCs could be released into the air due to spraying and abrasion of wood-based materials during the finishing and sanding processes, respectively. According to the WHO, prolonged exposure above the safety threshold could cause adverse health effects, including sensory irritation and cancer (WHO 2010). Unexpectedly elevated HCHO levels in the administrative offices could be due to personal care and hygiene products such as colognes, deodorants, hand sanitizers, air refreshers, *etc*. The authors observed that across all organization sizes and departments, there was a significant lack of respiratory system protective equipment use. Apparently, the existence of posted warning signs to wear PPEs on the shop floors was not sufficient to convince the workforce to take action to avoid particles- and HCHO-related risks.

Last but not least, noise parameters (LA_{eq}) are also imperative to highlight spatial patterns. Average noise (LA_{eq}) levels of large-, medium- and small-sized organizations were observed to be below the safety threshold of 75 dB(A) for industrial areas defined by the World Health Organization (WHO 2002), with values of 70.2, 72.5, and 70.5 dB(A), respectively, as presented in Fig. 9 and Fig. 10A. The WHO's recommended noise level threshold is 75 dB(A) for industrial areas and 70 dB(A) for commercial areas for daytime noise levels (WHO 2002).

Departmental noise levels reveal a different spatial pattern when compared to the HCHO results. All firms' panel/part-cutting departments had the highest average noise levels with a value of 81.5 dB(A), which was the department with the closest average LA_{eq} value to the safety threshold of 85 dB(A) set by the guidelines, as shown in Fig. 10B. Sanding/finishing departments of the firms followed panel/part cutting departments with an average LA_{eq} level of 79.5 dB(A). In all firms, the quietest departments were the warehouses and administrative offices, with average values of 59.4 dB(A) and 60.0 dB(A), respectively. The absence of sound-producing machinery could explain the relative quietness in these departments.

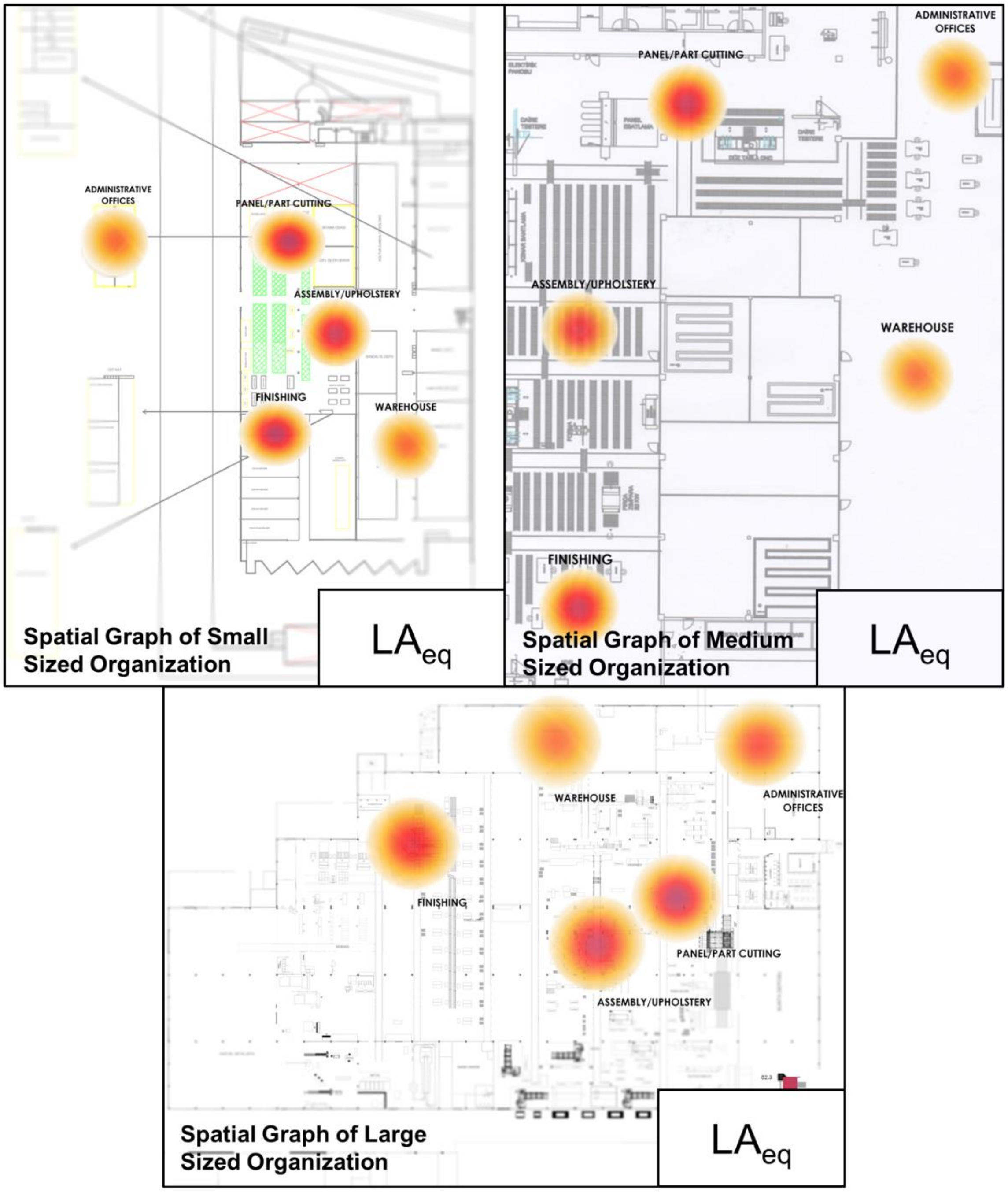

Fig. 9. Spatial layout illustration of average LA_{eq} for organizations

All machinery-intense departments clustered slightly below the safety threshold regarding noise exposure comparison results. Based on the researchers' observations and the WHO guidelines, even though an extreme lack of use of ear-protecting personal protective equipment (PPEs) was present within all organization sizes across all departments, employees of these organizations were not at the significant risk of occupational noise exposure-related health problems.

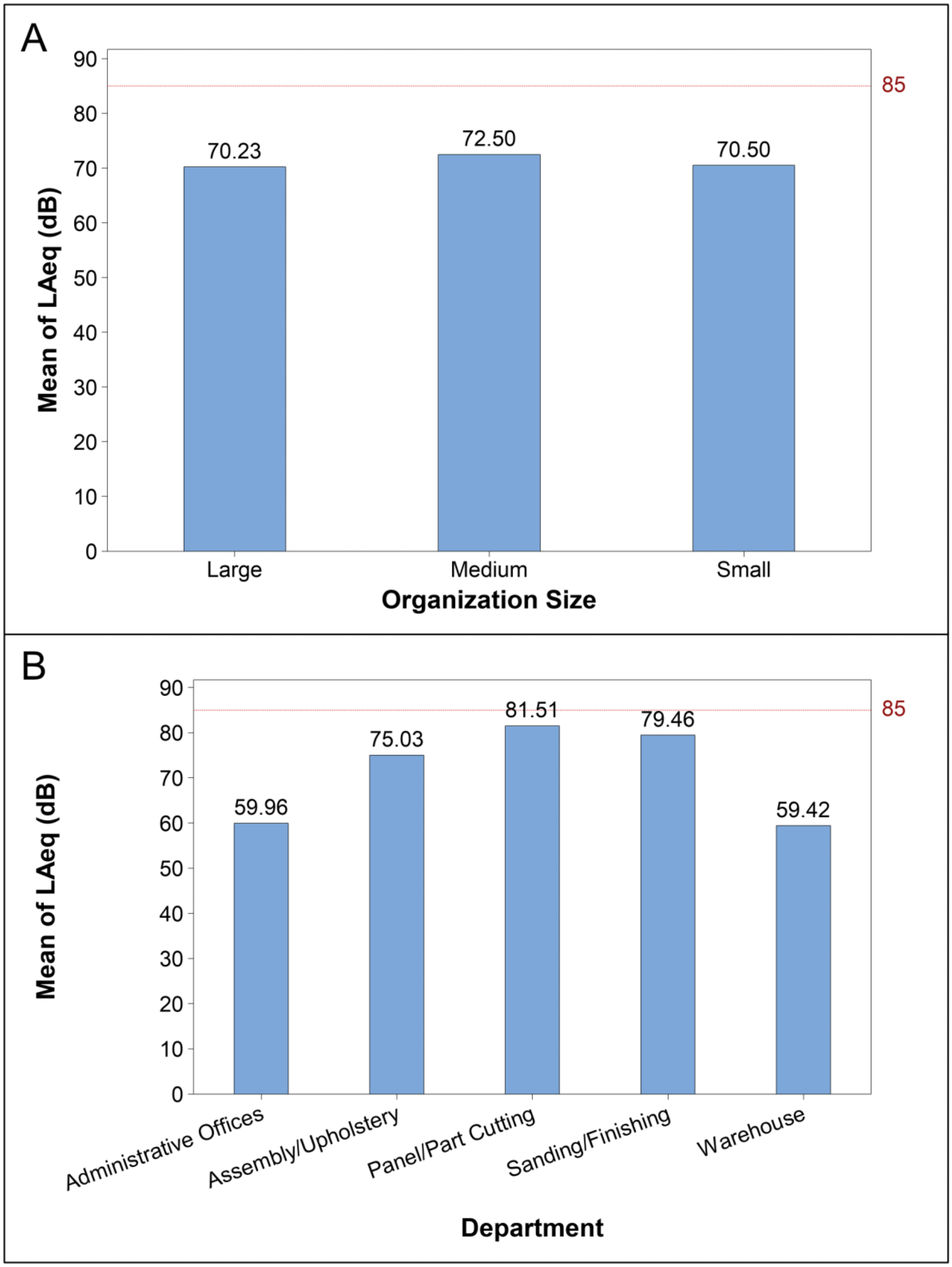

Fig. 10. LA_{eq} sub-group means for organization size (A) and department (B)

Discussion

The Turkish furniture industry is a major contributor to the Turkish economy. It employs over 1 million people and generates billions of dollars in annual revenue. However, the industry has also been criticized for its poor indoor air quality and noise exposure conditions. This study documented that indoor air pollution is a more significant problem than noise exposure.

A past study conducted by Teixeira *et al*. (2018) found that indoor air quality in furniture factories is significantly threatened by high concentrations of small particles (<10 microns) (Teixeira *et al*. 2018). On the other hand, another past study documented that particulate matter observations in furniture manufacturing facilities were below the safety threshold of 15 mg/m^3 (Whitehead *et al*. 1981). Concurrent with the findings of Teixeira *et al*. (2018) and in contrast with the results of Whitehead *et al*. (1981), the present study found that PM 2.5 levels in furniture manufacturing facilities were at alarming levels regardless of department and organization size. Turkish furniture manufacturers' average PM 2.5 levels exceeded the acceptable level of 15 µg/m^3 by three to ten times across various departments. A past study revealed that dust exposure during wood processing mainly occurs at the sanding station (Mikkelsen *et al*. 2002). Whitehead *et al*. (1981) also reported that sanding operations had the highest measured dust levels, along with furniture assembly and finish-milling (detailed woodworking). This study also observed the highest concentration of PM 2.5 within organizations' sanding/finishing departments. PM is a type of air pollutant that can cause various health problems. According to the authorities, short-term exposure to PM 2.5 could cause eye, nose, and throat irritation, coughing, wheezing, and difficulty breathing. Long-term exposure to PM 2.5 could cause heart disease, stroke, lung cancer, chronic obstructive pulmonary disease (COPD), and premature death (Saini *et al.* 2022; US EPA 2023).

Fidan *et al*. (2020) found that noise levels in the forest products industry could be significantly higher than the acceptable limits depending on the machinery (Fidan *et al*. 2020). Ntalos and Papadopoulos (2005) observed a similar trend of noise exposure in furniture manufacturing firms (Ntalos and Papadopoulos 2005). The study found that all noise measurements were above 85 dB(A). However, the findings of this study were somehow contradictory to those of the above-mentioned past studies. Average LA_{eq} levels of small, medium, and large organizations across all departments were below the safety threshold of 85 dB(A). Panel/Part Cutting and Sanding/Finishing departments slightly approximated the safety threshold with respective values of 81.5 and 79.5 dB(A). However, such findings should not be interpreted as meaning that there is no need for improved working conditions and preventive actions within the Turkish furniture industry.

On the other hand, Vaizoglu *et al*. (2005) found that the average indoor HCHO level in furniture manufacturing facilities was between 0.02 and 2.22 ppm, which was significantly above the safe limit set by the World Health Organization. The study also found that the HCHO levels in furniture manufacturing facilities varied depending on the type of manufactured furniture and the energy preferred energy source for heating. The highest HCHO levels were found within the painting/finishing departments of furniture manufacturing facilities due to the composition of coatings, according to a fact sheet published by The Robert-Sauvé Research Institute for Occupational Health and Safety (IRSST) (Goyer *et al*. 2006; IRSST 2006). On the other hand, composite materials such as particle board, MDF, and OSB would consist of formaldehyde-containing resins. During the site visits, it was observed that particleboard and MDF materials were being used in furniture manufacturing activities across all participating firms.

Furthermore, only the organizations' warehouses were safe with respect to the means of HCHO levels. Even the Administrative Offices across all organization sizes had hazardous HCHO levels. The high HCHO levels in the Turkish furniture industry are a cause for concern. Small-sized organizations suffered the most from high HCHO concentration. According to the Occupational Safety and Health Administration (OSHA), formaldehyde is a known carcinogen and can cause various health problems, including respiratory irritation, headaches, and nausea (OSHA 2011, Soltanpour *et al*. 2022). Therefore, the workers in furniture manufacturing facilities could be at an increased risk of developing these health problems.

The findings of previous studies highlighted the need for improved indoor air quality and noise control measures in the furniture industry. Therefore, members of the Turkish furniture industry should focus on improving the physical conditions of the workplace to tackle indoor air quality and noise exposure hazards, while the Turkish government should take action to regulate indoor air pollution and noise exposure in furniture factories. The Turkish government and furniture manufacturers can take the below-identified steps to improve indoor air quality and noise control in furniture factories.

- The government can regulate the use of hazardous chemicals in furniture manufacturing. For example, the Turkish government could require furniture manufacturers to install air purifiers and noise control devices in their factories.
- The government could regularly inspect furniture manufacturing facilities to ensure indoor air quality and noise levels are within safe limits.
- Regulations should involve strict enforcement and supervision of the use of appropriate PPE to protect against exposure to airborne pollutants and hazardous noise levels, enhancing worker safety and health outcomes.
- Furniture manufacturers could provide workers with personal protective equipment, such as respirators and earmuffs.
- Furniture manufacturers could train employees to properly use personal protective equipment (PPE) to protect themselves from indoor air pollution and noise exposure.
- Furniture manufacturers can develop and implement policies and procedures to reduce indoor air pollution and noise exposure in their factories. For example, driven by advancements in machine design, processing technologies, and materials science, the use of low-noise saw blades, the optimization of cutting parameters to minimize noise and particle emissions, and the use of enclosures and barriers to reduce noise and particle propagation could be promoted. Similarly, innovations in material science could lead to the development of composite materials and coatings that absorb or dampen vibrations and release less fine harmful particles, contributing to lower noise and air polluting agent levels.
- Furniture manufacturers could prefer formaldehyde-free adhesives and other environmentally friendly materials whenever possible and avoid using paints and varnishes that contain harmful chemicals.

While interpreting and filtering key outcomes of any scientific study, readers should also consider the study assumptions upon which the study was constructed. Several key assumptions also underpinned this study. Firstly, the authors presupposed a degree of homogeneity in the manufacturing processes and work environments across the studied facilities, allowing for meaningful comparisons despite the inherent variability in specific practices and technologies. The environmental conditions within each facility were assumed to be relatively stable throughout the measurement periods, attributing observed variations in pollutant and noise levels to organizational characteristics and departmental functions rather than external environmental factors. Additionally, the authors operated under the assumption that the facilities were generally compliant with existing safety standards and regulations related to indoor air quality and noise exposure. This assumption is critical for assessing the adequacy of current regulations and identifying areas necessitating further intervention. Finally, despite the authors' observations indicating a lack of proper usage of personal protective equipment (PPE), it was assumed that correct and consistent use of PPE could significantly mitigate the risks associated with exposure to harmful pollutants and noise, underlying the study recommendations for improved compliance and training in PPE usage.

On the other hand, like any other scientific study, this study also had some constraints and limitations associated with six main factors, namely, sample size and selection bias, measurement time and frequency, COVID-19 Pandemic impact, use of personal protective equipment (PPE), technological and process variability, and environmental regulations and standards. As for the sample size and selection bias, the study investigated nine furniture manufacturing organizations, which, while providing valuable insights, may not fully represent the broader industry. Such a limitation was mainly caused due to the reluctance of the firms to participate in the study and the funding limitations of the researchers. This sample size is a potential constraint that limits the generalizability of the findings. Future studies could aim to include a more extensive range of companies from different geographical regions and varying sizes to enhance the representativeness of the results. Next, in the context of measurement time and frequency, the data collection was conducted based on a pre-determined schedule involving different time intervals of regular business hours, which might not capture the full spectrum of indoor air quality and noise levels, especially during peak production periods or seasonal variations in production intensity. Continuous monitoring over extended periods or during varied production phases could provide a more comprehensive understanding of the environmental conditions within furniture manufacturing facilities. Additionally, the study measured the indoor ambiance noise and air quality levels rather than exposure levels due to the participating firms' unwillingness, which was underlined by the risk of hindering the work pace and facing a prolonged measurement and documentation process. So, the study could not use NIOSH REL for recommendations; instead, WHO guidelines were used for reference values.

Moreover, the study was conducted amidst the COVID-19 pandemic, which has led to changes in workplace practices, including potential modifications in production processes, workforce density, and use of personal protective equipment (PPE). These factors could influence the study's findings and may not reflect typical industry conditions. Acknowledging the pandemic's impact on the furniture manufacturing environment is crucial for interpreting the results within the appropriate context. From the point of view of the use of PPEs, the authors' observations included a lack of proper use of PPE across most organizations. This observation could indicate a confounding factor, where the actual exposure of workers to pollutants and noise may be higher than measured if PPE use were more consistent. Future research could explore the effectiveness of PPE in mitigating health risks in this industry, providing a more nuanced understanding of occupational safety. Next, the study acknowledges variability in production processes and equipment across different companies, which could significantly affect indoor air quality and noise levels. This variability presents a challenge for generalizing findings, as the particular technologies and practices of the studied organizations may heavily influence specific results. Analyzing the technological and process-related factors contributing to environmental conditions could enrich future research. Last but not least, the study compared measured levels against particular guidelines and standards, which may vary by region and over time. The evolution of regulatory frameworks and the introduction of new pollution control and noise reduction technologies could impact the relevance of the study's findings in the future. Acknowledging the dynamic nature of environmental standards is essential for applying this research to broader contexts.

While the study provides valuable insights into the indoor air quality and noise pollution levels within furniture manufacturing facilities, acknowledging the aforementioned constraints is critical for appropriately interpreting and applying the findings. Future research should aim to address these limitations through expanded sample sizes, longitudinal studies involving furniture clusters in different geographic regions, assessment of noise and air pollutant exposure levels within the furniture industry, comparative studies focusing on two or more manufacturing sectors, and consideration of the broader technological, regulatory, and pandemic-related factors that influence workplace environmental conditions.

This study aimed to advance the understanding of occupational health risks associated with indoor air quality and noise pollution in furniture manufacturing facilities. As identified in the literature review, this topic has received relatively limited attention. The key aspects where this study contributes uniquely to the field could be summarized as follows.

Unlike many previous studies that focused on specific aspects of indoor pollution or targeted a particular scale of manufacturing facilities (*e.g.*, small-scale enterprises), this research encompassed a broad spectrum of organization sizes, including small, medium, and large-scale enterprises. This comprehensive approach made it possible to identify and compare the differential impacts of organization size and department types on PM2.5, HCHO, and noise levels, providing a nuanced understanding of the varied occupational health risks across different workplace settings. Moreover, the findings of the study contributed novel insights into the distribution and severity of PM2.5 and HCHO concentrations within furniture manufacturing environments. While previous studies such as Teixeira *et al.* (2018) and Vaizoğlu *et al*. (2005) have documented the presence of these pollutants, this work delved deeper into their spatial patterns across different departments and organization sizes, highlighting areas of exceptionally high risk and suggesting targeted interventions. Additionally, this study aligns with current global health standards by utilizing the latest World Health Organization (WHO) guidelines as a benchmark for evaluating the health risks associated with noise and air quality levels. This study not only updated the findings of previous research but also provided a relevant and actionable framework for industry stakeholders aiming to mitigate occupational health risks.

Furthermore, the context of the COVID-19 pandemic added a timely and critical dimension to this study. The pandemic has underscored the importance of indoor air quality and has likely influenced workplace practices and employee exposure to pollutants. This research offered preliminary insights into these dynamics, contributing to a growing body of knowledge on the pandemic's implications for occupational health and safety. Lastly, beyond academic contributions, the outcomes of this study offered concrete recommendations for improving workplace conditions in the furniture manufacturing industry. The study provided a foundation for targeted policy interventions and best practices that can enhance occupational health outcomes by identifying specific risk factors and their associations with different organizational characteristics.

In summary, this study built upon and extended the existing literature by providing a comprehensive, comparative analysis of indoor noise pollution and air quality risks in furniture manufacturing. Through a unique combination of methodological rigor, relevance to current health standards, and practical implications, this work aimed to inform both academic discourse and industry practices.

CONCLUSIONS

1. Both organization size and department were significant factors in fine particulates (PM 2.5) and formaldehyde (HCHO) parameters, while only department type was significant for noise levels.
2. Small and medium-sized organizations had very high average PM 2.5 levels, almost two times higher than large-sized organizations and six times higher than the World Health Organization (WHO) safety threshold.
3. Small-sized furniture manufacturing facilities had very unhealthy levels of HCHO concentrations, which were more than four times higher than the safe level of 0.1 µg/m3 set by the WHO. Medium- and large-sized firms also had average HCHO concentrations above healthy levels.
4. At all departments across all organization sizes, LAeq noise levels were below the safety threshold of 85 dB(A) defined by the WHO.
5. Within the scope of fine particulate matter (PM 2.5), warehouses of furniture manufacturing facilities were the least polluted areas, while sanding/finishing departments were the most polluted. None of the departments across all organization sizes met the safe levels stated by the WHO guidelines.
6. Sanding/finishing departments of the organizations had extremely high HCHO concentrations and suffered from a lack of use of respiratory system protective equipment and poor air ventilation.
7. The average temperature for the working environment across all departments of all organization sizes was 26 °C ± 2.78, with minimum and maximum temperature values of 23 °C and 32°C, respectively.
8. All firms subject to observations and measurements severely lacked proper use of ear- and respiratory system-protecting equipment (PPEs). Given the study results, all firms, especially small- and medium-sized organizations, could significantly benefit from improved ventilation systems. Moreover, furniture manufacturers could utilize occupational risks-related visual posts and occupational health and safety-focused on-site training activities to increase OHS awareness among employees.

Based on the aforementioned conclusive remarks, furniture manufacturing firms in the Bursa-Inegol region of Türkiye could benefit from better facility design and infrastructure, providing inadequate and sufficient air circulation and ventilation to eliminate the accumulation of particles and HCHO. Employees of these organizations could be prone to health risks associated with the respiratory system due to prolonged exposure to high levels of HCHO and fine particulate matter. On the other hand, these firms may not possess any noise-related occupational health risks, although they contain machinery-intense workstations.

In conclusion, this study documented the current status of indoor air quality and noise pollution of furniture manufacturing organizations of all sizes from a holistic perspective. It was expected to serve as a valuable resource and guide for academics interested in these subjects and for professionals who want to explore the subject matter and enhance their working environment.

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REFERENCES CITED

Abouleish, M. Y. Z. (2021). "Indoor air quality and COVID-19," *Public Health* 191, 1. DOI: 10.1016/j.puhe.2020.04.047

Abu, F., Gholami, H., Saman, M. Z. M., Zakuan, N., and Streimikiene, D. (2019). "The implementation of lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications," *Journal of Cleaner Production* 234, 660-680. DOI: 10.1016/j.jclepro.2019.06.279

Alptekin, O., and Çelebi, G. (2015). "Toz Partiküllerinin İç Mekân Hava Kalitesi Üzerindeki Etkilerinin İncelenmesi (Investigation of the Effects of Dust Particles on Indoor Air Quality)," *Kafkas Üniversitesi Fen Bilimleri Enstitüsü Dergisi* 8(1), 30-49.

Araz, Ç., and Yaşar, O. (2020). "An evaluation of the structural characteristics, distribution and problems of the furniture industry in Inegol District," *Kesit Akademi* 24(24), 173-203. DOI: 10.29228/kesit.45888

Batterman, S., and Peng, C. (1995). "TVOC and CO_2 concentrations as indicators in indoor air quality studies," *American Industrial Hygiene Association Journal* 56(1), 55-65. DOI: 10.1080/15428119591017321

Bharwana, S. A., Ali, S., Farid, M., Zubair, M., Rizwan, M., and Ahmad, R. (2019). "Occupational health and safety conditions in small medium sized enterprises of iron furniture manufacturing units," *Environmental Engineering and Management Journal* 18(3), 545-553. DOI: 10.30638/eemj.2019.051

Bozkurt, Z. (2018). "Investigation of regional, seasonal changes of PM10 and PM2.5 particles and relationships between meteorologica," *Düzce University Journal of Science and Technology* 6(4), 1305-1320. DOI: 10.29130/dubited.428821

Çınar, H. (2005). "An overview of the furniture design education and the furniture industry in Turkey," *Education and Science* 30(137), 82.

Coşkun, S. (2019). "The improving of export potential in furniture sector: Instance of İnegöl," *Uludağ Üniversitesi, Sosyal Bilimler Enstitüsü, Bursa*.

Duignan, J. (2016). *A Dictionary of Business Research Methods*, Oxford University Press. DOI: 10.1093/acref/9780191792236.001.0001

Durcan, F. M., and Burdurlu, E. (2018). "Effects of some machining parameters on noise level in planing of some wood materials," *BioResources* 13(2), 2702-2714. DOI: 0.15376/biores.13.2.2702-2714

Fidan, S. M., Sadiye Yasar, S., Komut, O., and Yasar, M. (2020). "A study on noise levels of machinery used in lumber industry enterprises," *Wood Research* 65(5), 785-796. DOI: 10.37763/wr.1336-4561/65.5.785796

Filipe, A. P., Silva, J. R. M. da, Trugilho, P. F., Fiedler, N. C., Rabelo, G. F., and Botrel, D. A. (2014). "Avaliação de ruído em fábricas de móveis," *CERNE* 20(4), 551-556. DOI: 10.1590/0104776020142004959

Fink, D. J. (2017). "What is a safe noise level for the public?," *American Journal of Public Health* 107(1), 44-45. DOI: 10.2105/AJPH.2016.303527

Goyer, N., Bégin, D., Beaudry, C., Bouchard, M., Carrier, G., Lavoué, J., Noisel, N., and Gérin, M. (2006). *Prevention guide - Formaldehyde in the workplace*, *IRSST*.

Guarnaccia, C., Mastorakis, N. E., and Quartieri, J. (2013). "Noise sources analysis in a wood manufacturing company," *International Journal of Mechanics* 7(2), 37-44.

IMOS. (2019). "Rakamlarla Inegol (Inegol with Numbers)," <www.imos.org.tr> (Jan. 1, 2021).

IRSST. (2006). *Prevention Fact Sheet: Exposure to Formaldehyde in the Workplace (Wood Furniture Manufacturing), Prévention au travail*.

Jacobsen, G., Schlunssen, V., Schaumburg, I., Taudorf, E., and Sigsgaard, T. (2008). "Longitudinal lung function decline and wood dust exposure in the furniture industry," *Eur. Respir. J.* 31(2), 334-342. DOI: 10.1183/09031936.00146806

Lie, A., Skogstad, M., Johannessen, H. A., Tynes, T., Mehlum, I. S., Nordby, K.-C., Engdahl, B., and Tambs, K. (2016). "Occupational noise exposure and hearing: A systematic review," *International Archives of Occupational and Environmental Health* 89(3), 351-372. DOI: 10.1007/s00420-015-1083-5

Malkin, R., Hudock, S. D., Hayden, C., Lentz, T. J., Topmiller, J., and Niemeier, R. W. (2005). "An assessment of occupational safety and health hazards in selected small businesses manufacturing wood pallets - Part 1. Noise and physical hazards," *J. Occupational and Environmental Hygiene* 2(4). DOI: 10.1080/15459620590921499

Mannan, M., and Al-Ghamdi, S. G. (2021). "Indoor air quality in buildings: A comprehensive review on the factors influencing air pollution in residential and commercial structure," *International Journal of Environmental Research and Public Health* 18(6), 1-24. DOI: 10.3390/ijerph18063276

Mikkelsen, A. B., Schlünssen, V., Sigsgaard, T., and Schaumburg, I. (2002). "Determinants of wood dust exposure in the Danish furniture industry," *The Annals of Occupational Hygiene* 46(8), 673-685. DOI: 10.1093/annhyg/mef082

Nezis, I., Biskos, G., Eleftheriadis, K., and Kalantzi, O. I. (2019). "Particulate matter and health effects in offices - A review," *Building and Environment* 156(November 2018), 62-73. DOI: 10.1016/j.buildenv.2019.03.042

Ntalos, G., and Papadopoulos, A. (2005). "Noise emission levels in Greek wood and furniture processing industry," *Journal of the Institute of Wood Science* 17(2), 99-103. DOI: 10.1179/wsc.2005.17.2.99

OSHA. (2011). *Formaldehyde, OSHA Fact Sheet*.

Persily, A. (2015). "Challenges in developing ventilation and indoor air quality standards: The story of ASHRAE Standard 62," *Building and Environment* 91, 61-69. DOI: 10.1016/j.buildenv.2015.02.026

Pirc, A., and Vlosky, R. (2010). "A brief overview of the US furniture industry," *Louisiana Forest Products Development Center Working Paper*.
Pirc Barčić, A., Kitek Kuzman, M., Vergot, T., and Grošelj, P. (2021). "Monitoring consumer purchasing behavior for wood furniture before and during the COVID-19 pandemic," *Forests* 12(7), article 873. DOI: 10.3390/f12070873
Ratnasingam, J., Khoo, A., Jegathesan, N., Wei, L. C., Abd Latib, H., Thanasegaran, G., Liat, L. C., Yi, L. Y., Othman, K., and Amir, M. A. (2020). "How are small and medium enterprises in Malaysia's furniture industry coping with COVID-19 pandemic? Early evidences from a survey and recommendations for policymakers," *BioResources* 15(3), 5951-5964. DOI: 10.15376/biores.15.3.5951-5964
Ratnasingam, J., Natthondan, V., Ioras, F., and McNulty, T. (2010). "Dust, noise and chemical solvents exposure of workers in the wooden furniture industry in South East Asia," *J. Applied Sciences* 10(14), 1413-1420. DOI: 10.3923/jas.2010.1413.1420
Saini, M., Joon, M., and Saini, S. K. (2022). "Human health effects of particulate matter," in: *Airborne Particulate Matter*, Springer Nature Singapore, Singapore, pp. 195-228. DOI: 10.1007/978-981-16-5387-2_9
Smardzewski, J. (2015). *Furniture Design*, Springer International Publishing Switzerland. DOI: 10.1007/978-3-319-19533-9
Soltanpour, Z., Mohammadian, Y., and Fakhri, Y. (2022). "The exposure to formaldehyde in industries and health care centers: A systematic review and probabilistic health risk assessment," *Environmental Research* 204(PB), article 112094. DOI: 10.1016/j.envres.2021.112094
Strelyaeva, A. B., Kalyuzhina, E. K., Lupinogin, V. V, and Alkneume, M. K. A. (2019). "Investigation of fine dust pollution during hard and soft works in warehouse complexes," *IOP Conference Series: Materials Science and Engineering* 698(2), article 022035. DOI: 10.1088/1757-899X/698/2/022035
Teixeira, R. L., Rezende, R. N., Silva, J. R. M. da, and Paula, L. E. de R. e. (2018). "Concentration and size of airborne particles in manufacturing environments," *Revista Árvore* 42(1). DOI: 10.1590/1806-90882018000100008
The Engineering ToolBox. (2004). "Sound - Leq - Equivalent Level," <https://www.engineeringtoolbox.com/equivalent-sound-level-d_721.html>.
Tian, X., An, C., Chen, Z., and Tian, Z. (2021). "Assessing the impact of COVID-19 pandemic on urban transportation and air quality in Canada," *Science of the Total Environment* 765, article 144270. DOI: 10.1016/j.scitotenv.2020.144270
US EPA. (2023). *Particle Pollution and Your Patients' Health*. Retreived From: https://www.epa.gov/pmcourse/particle-pollution-exposure.
Vaizoğlu, S. A., Aycan, S., Akin, L., Koçdor, P., Pamukçu, G., Muhsinoğlu, O., Özer, F., Evci, E. D., and Güler, Ç. (2005). "Determination of formaldehyde levels in 100 furniture workshops in Ankara," *Tohoku Journal of Experimental Medicine* 207(2), 157-163. DOI: 10.1620/tjem.207.157
Whitehead, L. W., Freund, T., and Hahn, L. L. (1981). "Suspended dust concentrations and size distributions, and qualitative analysis of inorganic particles, from woodworking operations," *American Industrial Hygiene Association Journal* 42(6), 461-467. DOI: 10.1080/15298668191420062
WHO. (2010). *WHO Guidelines for Indoor Air Quality: Selected Pollutants*.

WHO. (2002). *The World Health Organization Report 2002: Reducing Risks, Promoting Healthy Life*, WHO Library Cataloguing-in Publication Data, 232.

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