Original Article

Inhalable Wood Dust: Risk Assessment of Occupational Exposure

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Abstract

Background and Purpose: Wood dust have been approved as a harmful and carcinogenic agent for humans. This study aimed to evaluate risk assessment of Workers' exposure to inhalable wood dust among 100 workers in 25 furniture manufacturing workshops in one of the northern cities in Iran.

***Materials and Methods*:** NIOSH0501 method was used to assess the occupational exposure to Inhalable wood dust and Semi-quantitative risk assessment method recommended by Singapore Department of Occupational Health was used to assess risk level of occupational exposure. Airborne particles were collected from the workers' breathing zone using calibrated personal sampler pump and a PVC filter with a 25 mm diameter, 5 µm pore size embedded inside an IOM Sampler.

***Results*:** The mean occupational exposure to inhalable wood dust among all exposed workers was found to be 22.3 ± 6.9 (Mean ± SD) $mg.m^{-3}$. The risk level of workers' exposure to inhalable wood dust was also documented to be in medium level in all workshops. In addition, the researchers found that among environmental variables, the door area of workshops was the most effective predictor variable to predict variations of workers' exposure to inhalable wood dust ($ADJ.R^2=0.113$, $R^2=0.122$, $p<0.001$).

***Conclusion*:** Exposure to inhalable wood dust was several times higher than the OEL of Iran and TLV recommended by ACGIH. Since the risk level of workers' exposure to inhalable wood dust was in medium level, their health could be threatened by prolonged exposure. Therefore, technical-engineering and managerial controls seemed to be necessary.

***Key words*:** Wood dust; Occupational Exposure; Risk Assessment; Furniture

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1. Introduction

Exposure to inhalable chemicals and particulate air pollution in the workplace is one of the dangerous situations that threatens human life and health. Nowadays, around the world, millions of people are working in air polluted workplaces every day, and the most common way to get dust into the body is inhalation (1,2). Environmental factors, working and workplace conditions can influence the exposure level to these airborne particles (3,4). Wood have been recognized as an important and renewable source in the world, and wood dust contains a wide range of organic and inorganic particles including self-wood fragments, toxic and chemicals, minerals, and metals and microorganisms, such as bacterial and fungal spores (5,6). In 1995, the International Agency for Research on Cancer (IARC) classified hardwood dust as Group 1 human carcinogen. Also, 7 years later, the dust of some softwood species was also classified as group 1 human carcinogen (4). In addition to being recognized as a potential risk factor for lung cancer, wood dust can cause headaches, coughs, weakness, chest pain, acute or chronic respiratory diseases, occupational asthma, lung functional disorders, nose cavity cancer risk., dryness and skin irritation, decrease in FVC and FEV1 levels, nasal congestion, redness of the eyes, itching of the eye, rhinorrhea (fluid filling the nasal cavities), genetic poisoning, DNA damage, and liver toxicity. Pulmonary dysfunction is one of the most common respiratory problems in wood related industries, especially in furniture manufacturing industries (7–10). Kauppinen et al. (2006) estimated the number of workers exposed to wood dust to be 3.6 million between 2003 and 2000. Of these, 713,000 were active in the furniture manufacturing industries and 86500 were exposed to wood dust higher than 5 $mg.m^{-3}$(11). In Iran, more than half of the wood industries are owned by the furniture manufacturing industries, and many people are working in these industries (12). In recent years, the city of Bahnamir has become one of the hub of furniture manufacturing in the north of Iran, which had attracted many people to work in this industry. In the city, at least 1,000 people work directly and indirectly in more than 70 furniture manufacturing workshops, and more than 1,500 people are working in more than 150 furniture fairs and shops (13). This study aimed to evaluate risk assessment of workers' exposure to inhalable wood dust in furniture manufacturing workshops in Bahnamir city, Mazandaran Province in Iran.

2. Materials and Methods

2.1. Sample Size and Sampling Location

This cross-sectional study was conducted on 100 workers who were working in 25 furniture manufacturing workshops in Bahnamir ity, Mazandaran Province in Iran (Figure 1).

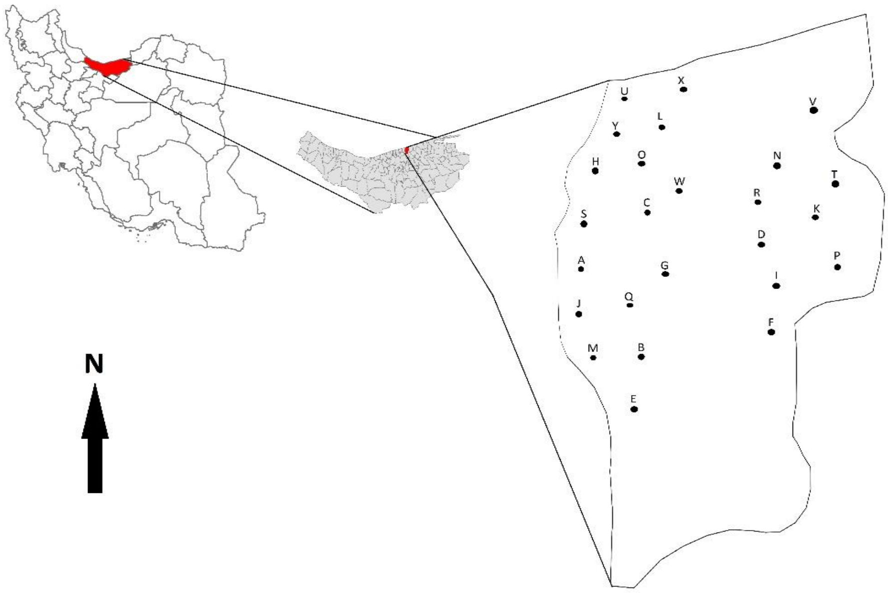

Figure1. Distribution of furniture manufacturing workshops in Bahnamir city

The sample size was calculated using the following formula according to previous studies (14).

$$n = \frac{N z^{2}_{1-\frac{\alpha}{2}}\, p(1-p)}{(N-1)d^{2} + z^{2}_{1-\frac{\alpha}{2}}\, p(1-p)} = 90.05,\ p = 0.3,\ N = 100,$$

$$\alpha = 0.05,\ d = 0.1p = 0.03,\ z = 1.96$$

Workshops were randomly selected through snowball sampling from the Bahnamir furniture manufacturing workshops. Finally, personal exposures of 100 workers who exposed directly to particulate air pollutants were evaluated. This study also considered time constraints, as well as financial and human resources to calculate the sample size.

2.2. Measurement Method

NIOSH0501 Method was used to assess the occupational exposure to inhalable wood dust (15). IOM Sampler and 25mm PVC filter with a 5 µm pore size (SKC, UK) were used to collect airborne particles from the workers' breathing zone during an 8-hour shift-work. Air sampling was also performed using calibrated Airchek3000 personal sampler pump (SKC, UK) with a constant flow rate of 2 L / min. A critical orifice was designed and used to keep the constant flow rate during sampling. A desiccator containing silica gel was also used for 24 hours for desiccating after and before sampling. A microbalance (Sartorius ME5, Germany) with an accuracy of 1 µg was used for weighing before and after sampling. For each 10 samples (filters), one filter was considered as blank filter. Then, the Equation 1 was used to calculate the concentration of inhalable wood dust:

$$C\left(\frac{mg}{m3}\right) = \frac{[(W2-W1)-(B2-B1)](mg)}{Vs(L)} \times 10^{3}$$

(Equation 1)

C: Concentration of inhalable wood dust ($mg.m^{-3}$)

W_1: Initial weight of filters with no wood dust (mg)

W_2: Secondary weight of filters with wood dust (mg)

B_1: Initial weight of blank filters before sampling (mg)

B_2: Secondary weight of blank filters after sampling (mg)

Vs: Standardized sampled air volume (L)

2.3. Risk Assessment of Occupational Exposure

Semi-quantitative method of Singapore Department of Occupational Health was used to assess risk level of occupational exposure to inhalable wood dust (16). Risk assessment was carried out in four stages: determination of HR (Hazard Rate), ER (Exposure Rate), RS (Risk Score) and RL (Risk Level). The Hazard Rate (HR) for inhalable wood dust was calculated according to the type of wood consumed in the workshops (mainly softwoods; Russian woods; fir, pine, spruce) and the occupational exposure limit guidelines (17) using Table 1.

Table 1. Determination of the Hazard Rate (HR)

Hazard Rating	Description of Effects/Hazard Category
1	– No known adverse health effects – ACGIH A5 carcinogens – Not classified as toxic or harmful
2	– Reversible effects to the skin, eyes or mucous membranes, not severe enough to cause serious health impairment – ACGIH A4 carcinogens – Skin sensitisers and skin irritants
3	– Possible human or animal carcinogens or mutagens, but for which data is inadequate – ACGIH A3 carcinogens – IARC Group 2B – Corrosive (pH 3 to 5 or 9 to 11) , respiratory sensitizers, harmful chemicals
4	– Probable human carcinogens, mutagens or teratogens based on animal studies – ACGIH A2 carcinogens – NTP Group B – IARC Group 2A – Very corrosive (pH 0 to 2 or 11.5 to 14) – Toxic chemicals,
5	– Known human carcinogens, mutagens or teratogens – ACGIH A1 carcinogens – NTP Group A – IARC Group 1 – Very toxic chemicals

The Exposure Rate (ER) was also calculated according to the average inhalable wood dust concentration in the workshops (M), the number of exposure days (F) per week, the average daily exposure time (D), the average working hours per week (W), and OEL (1mg.m^{-3}) using the Equation 2 and Table 2:

$$E = \frac{F.D.M}{W} \qquad \text{(Equation 2)}$$

F=6, D=8h, W=40h

Risk Score (RS) was determined using the Equation 3:

$$\text{Risk Score} = \sqrt{HR \times ER} \qquad \text{(Equation 3)}$$

Table 2. Determination of the Exposure Rate (ER)

E / OEL	Exposure Rating (ER)
< 0.1	1
0.1 to < 0.5	2
0.5 to < 1.0	3
1.0 to < 2.0	4
≥ 2.0	5

Risk level (RL) was also determined according to Risk Score (RS) using Table 3.

Table 3. Determination of Risk Level (RL)

Risk Score (RS)	Risk Level (RL)
0-1.7	Negligible
1.7-2.8	Low
2.8-3.5	Medium
3.5-4.5	High
4.5-5	Very High

2.4. Temperature and Relative Humidity

To obtain environmental information, such as temperature and relative humidity during sampling days, the Babolsar Meteorological Station Registry data were used.

2.5. Data Storage and Statistical Analysis

Data and information about workers and their workplace were also collected using a questionnaire and designed checklist. Checklists and questionnaires were adapted from Health and Safety for Small- and Medium-Sized Woodworking Shops and wood dust controlling the risk (18,19). SPSS 25 and Excel 2013 were used to analyze the data. The statistical tests which were used in this study included: Kolmogorov-Smirnov test, One Way-ANOVA analysis and LSD test, Two-sample independent T-test, Pearson's correlation, and multiple linear regression tests (Stepwise method). (Ethics and Approval Code: IR.MAZUMS. REC. 1397. 3059).

3. *Results*

Table 4 provides information on dust concentration, temperature, humidity, as well as age and work experience of workers.

Table 4. Results of Descriptive Statistics for Personal Variables of Workers and Environmental Variables of Workshops

Variables	Month	N	Mean	SD	Minimum	Maximum
Concentration of inhalable wood dust	January and February	100	22.3	6.9	6	34.4
	January	50	21.4	7.5	6	32.2
	February	50	23.3	6.2	10	34.4
Temperature (°C)	January	50	10.6	1.9	7.8	13.9
	February	50	10	1.7	7.3	13.3
Relative humidity (%)	January	50	79.3	7.4	68	91
	February	50	81	6.8	65	91
Age	-	100	31.5	9.5	17	58
Work Experience	-	100	8.5	7.7	1	35

Figure 2., illustrates the average concentration and error bars (based on Standard Error) of inhalable wood dust by type of workshop.

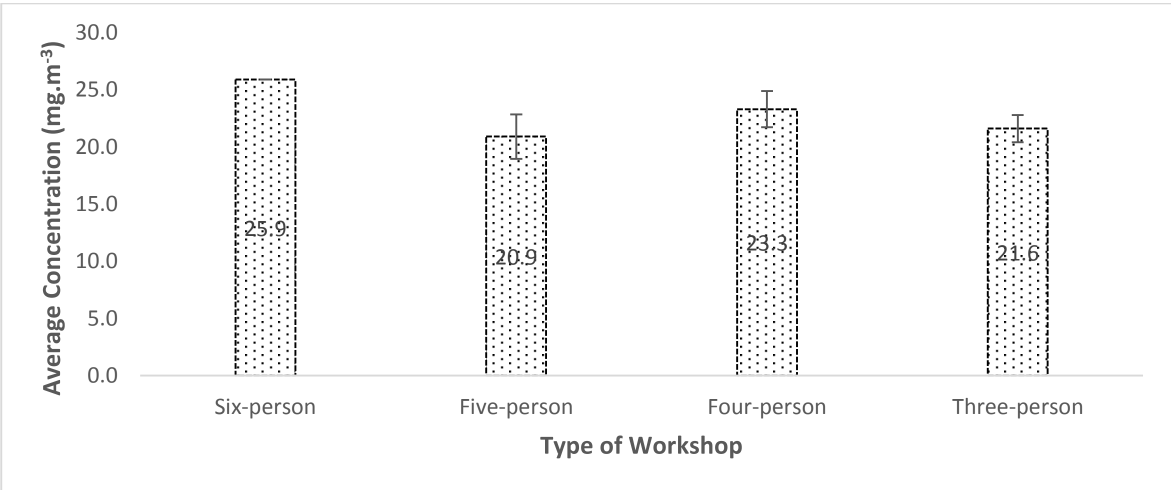

Figure 2. Average concentration of inhalable wood dust by type of workshop in terms of number of workers in workshops

In Table 5, information on the risk assessment of workers' exposure to inhalable wood dust based on type of workshop is given.

Table 5. Results of risk assessment of occupational exposure to inhalable wood dust according to the type of workshop

Workshop	HR	ER	E	E/OEL*	RS	RL
Six-person	2	5	31.1	31.1	3.2	Medium
Five-person	2	5	25.1	25.1	3.2	Medium
Four-person	2	5	27.9	27.9	3.2	Medium
Three-person	2	5	26.0	26.0	3.2	Medium

***OEL=1mg.m^{-3}**

The results of One Way-ANOVA analysis (Table 6) showed that the difference between the mean concentration of inhalable wood dust in the 25 workshops was significant (p=0.000).

Table 6. Results of One Way-ANOVA analysis

Source of Variance	Sum of Squares	df	Mean Square	F	Sig
Between Groups	1990.975	24	82.957	1.599E+32	0.000
Within Groups	0.000	75	0.000		
Total	1990.975	99			

LSD (multiple Comparison) test results also showed that there was a significant difference between the mean concentration of inhalable wood dust in pairwise comparisons between 25 different workshops (The workshops were compared in pairs, and the P-value was determined to be equal to 0.000).

The results of comparing the inhalable wood dust average concentrations of workshops A, B and C (among 25 workshop from A to Y) with 3 workshops are listed in Table 7, and due to the large volume of these results, other comparisons are avoided.

Table 7. Results of LSD test for comparing the inhalable wood dust average concentrations of workshops A, B, and C with 3 workshops

LSD	Mean Difference	Std. Error	Sig
A - B	-1.95	0.00	0.000
A - C	-8.73	0.00	0.000
A - D	-15.95	0.00	0.000
A -...	…	0.00	0.000
A -Y	…	0.00	0.000
B - A	1.95	0.00	0.000
B - C	-6.78	0.00	0.000
B - D	-14.00	0.00	0.000
B -…	…	0.00	0.000
B -Y	…	0.00	0.000
C - A	8.73	0.00	0.000
C - B	6.78	0.00	0.000
C - D	-7.22	0.00	0.000
C -…	…	0.00	0.000
C -Y	…	0.00	0.000

The most important activities and environmental conditions in the workshops that could have caused high dust production in workshops were extracted from the designed checklists and questionnaires, and their percentages, which were calculated by Excel, were as follows: Sanding by hand-held tools (75%), using compressed airlines to blow dust (80%), not using local exhaust ventilation (85%), inappropriate installation location for general ventilation (60%), using Russian woods (80%), and sweeping up and not using vacuum cleaner (90%). The results of Kolmogorov-Smirnov test showed that the inhalable wood dust concentration among 100 workers followed the normal distribution (KS = 0.087, p=0.062). T-test with two independent samples was performed to compare the mean concentration of inhalable wood dust in January and February. The results showed that, the differences were not significant (p=0.175). Results of Pearson's correlation test also showed that, the variables of Temperature (r=-0.235, p=0.018), Workshop area (r=0.318, p=0.001), window area (r=0.295, p=0.003) and door area (r=0.349, p=0.000) had a significant effect on mean concentration of inhalable wood dust in workshops, and there was no significant relationship between relative humidity (r=-0.020, p=0.845), and number of workers (r=0.045, p=0.654) with mean concentration of inhalable wood dust, respectively. In addition, the results showed that, the correlation between humidity and temperature was not significant (r=-0.048, p=0.637). According to the results of multiple linear regression test (Stepwise Method), among variables of temperature, workshop area, window area and door area, the door area was selected as the most effective predictor that alone predicted 11.3% of the variations of mean concentration of inhalable wood dust in the workshops (ADJ.R^2=0.113, R^2=0.122, p=0.000). And the variables of temperature, workshop area and workshop window area were excluded from the regression model. Figure 3 illustrates the results of this analysis.

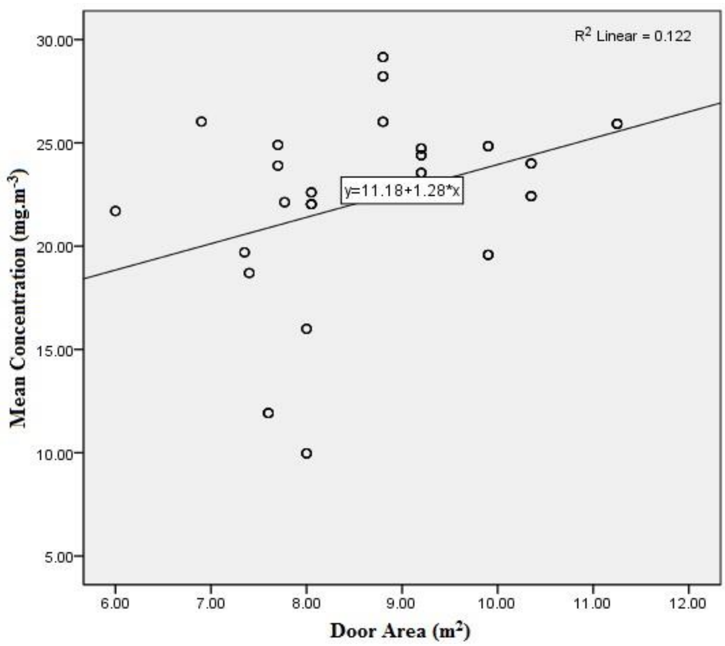

Figure 3. The linear relationship between door area and mean concentration of inhalable wood dust in workshops

4. Discussion

This study aimed to evaluate risk assessment of Workers' exposure to inhalable wood dust among 100 workers in 25 furniture manufacturing workshops in Bahnamir city, Mazandaran Province in Iran. The mean age of the workers and their work experiences were 31.5 ± 9.5 and 8.5 ± 7.7 (Mean ± SD) years, respectively (Table 4). The average occupational exposure of all workers who were directly exposed to inhalable wood dust in all workshops was higher than the recommended threshold by OEL of Iran and TLV recommended by American Conference of Governmental Industrial Hygienists (ACGIH), (Table 4, Figure 2). The OEL of Iran for occupational exposure to inhalable wood dust is 0.5 $mg.m^{-3}$ for western red cedar and 1 $mg.m^{-3}$ for other wood species (17). The risk level of exposure to inhalable wood dust was found to be in medium level in all workshops (Table 5). Many studies have reported that occupational exposure to inhalable wood dust in the furniture manufacturing industry at workplace was usually between 0.1 $mg.m^{-3}$ to 100 $mg.m^{-3}$ (10,20,21). In a study by Badirdast et al., (2016), it was reported that the average occupational exposure of wood chipboard workers was 32 $mg.m^{-3}$, and the average exposure to inhalable wood dust in the crushing section of the plant was more than 60 $mg.m^{-3}$ (14). In the current study, the mean occupational exposure of the workers who were directly exposed to inhalable wood dust was documented to be 22.3 ± 6.9 (Mean ± SD) $mg.m^{-3}$, while the maximum inhalable wood dust concentration was 34.4 $mg.m^{-3}$ (Table 4). Scheeper et al. (1995) studied the personal exposure rate of workers who were working in two woodworking plants and one furniture manufacturing factory. They evaluated the exposure to inhalable wood dust during 8-hour shift. The results of their study showed that, the average personal exposure to inhalable wood dust in two woodworking plants was much lower than in the furniture manufacturing factory. They found that the changes in personal exposure to inhalable wood dust at the furniture manufacturing factory was higher than carpentry, and this amount of dust was usually reported to be above 5 $mg.m^{-3}$. They also found that the large difference could be due to the more use of sanding and woodworking tools in the furniture manufacturing factory than the carpentry factories (22). These findings were in line with the results of the present study. Furthermore, the results of a study, that was carried out by Mohammadyan and Afzali (2013) in Nekachoob Factory in Sari city, showed that the workers who were working in furniture sector were exposed to more dust than those who were working in the chipboard sector (23). Wood sanding in the wood related industries is one of the most important sectors of these industries for manufacturing wood products (24). Ojima (2016) conducted a study to evaluate the amount of wood dust produced and the size distribution of particles while the person was sanding and manually processing wood. The results of his study showed that, softwoods during sanding and processing, due to differences in wear durability, produced more wood dust than hardwoods, which can be as much as 3 to 6 times higher. He also found that, sandpaper meshing can have a significant effect on wood dust production and particle size distribution, so that, coarser sandpaper could produce more dust than fine sandpaper. This can even be up to 8 times greater when applying sanding softwoods (4). Since, 80 percent of the workshops in the present study used Russian woods

(Softwoods; fir, pine, spruce) and sandpaper with different meshing to produce furniture, these factors could be considered as one of the reasons for the high concentration of inhalable wood dust in the studied workshops in the current study. Some other studies that were carried out by Welling et al., (2008), Keller et al., (2018) and Miroslav et al., (2019), showed that, in small and medium-sized workshops, sanding and woodworking with fixed and hand-held tools was the most important factor for increasing occupational exposure to inhalable wood dust, even if, there was adequate local exhaust ventilation (24–26). In the present study, and in the studied workshops, 75 percent of sanding was done by hand-held tools, while 85 percent of workshops were not using local exhaust ventilation (LEV), and 60 percent of these workshops had their air conditioners installed at the wrong place and wrong height, which can be considered as factors for the high concentration of inhalable wood dust in workers' breathing zone. Similar studies have shown that, cleaning with compressed air and hand tools are other important factors that increase the level of personal exposure to wood dust (27), In the current study, 80 percent and 90 percent of workshops used compressed airlines and sweeping up to clean dust from furniture, clothes, work surfaces, and processing tools, respectively. The results of the risk assessment of occupational exposure about two furniture manufacturing factories in a study carried out by Yang et al. (2019) through semi-quantitative method of Singapore Department of Occupational Health Risk Assessment showed that, in factory A risk score was between 3-4, and in factory B risk score was between 2-3 (28). In the current study, the results showed that the risk level of exposure to inhalable wood dust was in medium level in all furniture manufacturing workshops (risk score was calculated to be 3.2, and risk level was found to be in medium level, Table 5). A study conducted by Scarselli et al. (2008) aimed to assess the level of occupational exposure to wood dust in Italy, 1996-2006 (29). The results of their study showed that job category, industrial sector, workshop size, environmental factors, and geographical location of the workshop can influence the exposure level (29). Similar to these results, in the present study, we found that, the differences between the mean concentration of inhalable wood dust in the studied workshops was significant (Table 6 and Table 7, $p<0.001$). In addition, we found that the variables of workshop area ($p<0.05$), window area ($p<0.05$), and especially the door area of workshops (Figure 3, $p<0.001$) had a significant effect on mean concentration of inhalable wood dust in workshops. There was also no significant relationship between number of workers ($p>0.05$) with mean concentration of inhalable wood dust. Furthermore, Sampling month had no significant effect on concentration of inhalable wood dust ($p>0.05$). Larama et al., (2004), reported that exposure to wood dust on hot days with lower humidity was higher than on cold days with higher humidity (30). Also, according to the results of a study conducted by Teschke et al., (1999), the exposure level to inhalable wood dust decreased by increasing relative humidity (31). Contrary to imagination, we found that relative humidity had no significant effect ($p>0.05$) whereas temperature had significant ($p<0.05$) effect on the inhalable wood dust concentration in the studied workshops. In relation to humidity, this may be due to the low variations of relative humidity on sampling days (Table 4), and with regard to temperature, this may be due to the effect of temperature on Vs in Equation 1.

5. Conclusion

Occupational exposure of workers to inhalable wood dust in the studied workshops was several times higher than the OEL of Iran and TLV recommended by ACGIH. Since the risk level of workers' exposure to inhalable wood dust was in medium level, workers' health was also threatened by prolonged exposure. Therefore, by considering the effects of workplace conditions, as well as environmental and personal factors, it is vital to pay attention to technical-engineering and managerial control.

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Conflicts of Interest

None declared.

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