Design, Construction and Evaluation of Local Exhaust Ventilation System for the Control of Total Dust and Crystalline Silica in a Tile Manufacturing Factory

Abdorreza Zarei[1], MSc; Mehdi Jahangiri[2], PhD; Alireza Koohpaei[3], PhD; Ahmad Zolfaghari[4], MSc; Abolfazl Barkhordari[5], PhD; Morteza Mortezavi Mehrizi[6], PhD student

[1]MSc in Occupational Health, Occupational Health Department, Health Faculty, Qom University of Medical Sciences, Yazd, Iran
[2]Assistant Professor of Occupational Health, Department of Occupational Health, School of Health and Nutrition, Shiraz University of Medical Sciences, Shiraz, Iran
[3]Associate Professor in Occupational Health, Department of Occupational Health, Health Faculty, Qom University of Medical Sciences, Qom, Iran
[4]MSc in Occupational Health, Health & Medicine Department, PIHO (petroleum industry health organization), Isfahan, Iran
[5]Professor in Occupational Health, Occupational Health Department, Health Faculty, Yazd University of Medical Sciences, Yazd, Iran
[6]PhD candidate, Occupational Health Department, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran

Correspondence:
Morteza Mortezavi Mehrizi, PhD student; Department of Occupational Health, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran
Tel: +98 9132565064
Email: matinmehrsa1360@gmail.com
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Abstract

Background: Crystalline silica is one of the compounds used in different industries. One of the industries in which this compound is used is the tile industry that can cause disabling lung disease. The purpose of this study was to reduce and eliminate workplace air pollutants by Local Exhaust Ventilation system (LEVs).

Methods: In this interventional-practical study, designing LEVs is accomplished according to the velocity pressure method balanced system design of the American Conference of Governmental Industrial Hygienists (ACGIH) and is performed in spray dryer hall in a tile factory. The studied population consisted of 22 workers selected randomly. After implementation, the LEVs efficiency was evaluated, both in terms of occupational health and fluid mechanics. In order to evaluate the system from the point of view of occupational health, the measurement of Crystalline silica, inhalable and total dust was done before and after installation of LEVs by the National Institute of Occupational Safety and Health (NIOSH) 7601, 0600 and open face methods, respectively; also, to evaluate the system as to fluid mechanics, we measured the velocity and flow rate in some hoods and ducts.

Results: Results showed that the obtained mean values of total, inhalable and silica dust after installation of LEVs had a statistically significant difference before the use of LEVs ($P<0.05$); also, the efficiency of removing the mentioned pollutants was 66, 94 and 96%, respectively.

Conclusion: The performance of the ventilation system was in accordance with the values obtained in the design.

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Introduction

There is a risk of exposure to silica dust in various occupational activities such as mining, glass manufacturing, pottery, casting, and tile production.[1] The estimated number of workers exposed to crystalline silica in the European Union and the United States is 3200000 and 1700000, respectively.[2] The occupational disease caused by inhalation of silica dust is called silicosis.[1] The risk of silicosis after a lifetime of exposure is within the permissible limit of 0.05 mg/m^3 and is likely to be 20-40.[2]

Tile industry is one of the important industries in terms of economic and the number of human resources which is very significant due to occupational health. In the process of tile manufacturing, many raw materials such as quartz, feldspar, talc, and kaolin are used. The pollutants released in these processes are quartz and forms of crystalline silica.[3] These pollutants can be located in the respiratory environment of the workers. Silica can lead to lung diseases such as silicosis,[4] lung cancer[5, 6] and airway diseases.[7, 8] According to previous studies, exposure to even very low levels of silica decreases the lung function [9] and subsequently individual inability.[10] Unfortunately, silicosis is not curable, but it can be prevented.[11-13] Therefore, the level of workers' exposure to chemical hazards should be reduced to the lowest acceptable level or the level lower than the acceptable one;[14, 15] several studies have been done in order to reduce and control pollutants. Pollutant control includes ways to solve the problem of air pollution.[16] One of these ways is engineering controls applied to reduce the amount of dust in a workplace.[17] Proper ventilation systems should be designed based on the type and toxicity of the pollutants. LEVs are very effective and helpful for reducing and removing pollutants at the source of their emissions.[16] The proper functioning of LEVs in decreasing pollutants depends on its compliance with standards in design, installation and regular maintenance.[18, 19] Wet scrubber is one of the components of the ventilation system which plays a key role in controlling the emitted pollutants in the work environment.[20, 21] Steps such as physical examination (visual examination), investigation of its performance variables, and efficiency and adequacy assessment of the system to reduce the concentration of pollutants in the environment can be cited.[19] The aim of the present study is to design, implement and assess the local exhaust ventilation system for decreasing crystalline silica dust, inhalable particles and total dust in one of the plants manufacturing tiles in Yazd province during 2016.

Materials and Methods

Location Investigation and Environmental Variables

The factory investigated was located in Yazd province. The study was conducted on a part of tile manufacturing process in spray dryer hall with a lot of dust. In order to reduce the total dust at the source, this hall was separated from the other ones. Then, the LEVs were designed and installed according to ACGIH principles and standards, based on velocity pressure method. Appropriate location was selected to install the ventilation system equipment in the source emitting pollutants. Different parts of the generated dust include handling conveyors, hoists, materials mixers, storage of raw materials, and vibratory sieves. Hall Map and locations of generation of pollutants were prepared. Then, appropriate hood locations were identified. In the next step, psychrometric variables and the actual values were measured and determined, using the psychrometric chart. Psychrometric variables include Wet-bulb Temperature, Dry-bulb Temperature, Specific volume, Specific humidity, and altitude. These are variables affecting the design factors in the ventilation systems, which include flow rate and pressures.[22]

LEVs Design Process and its Components

Regarding the equipment type, appropriate hoods were designed according to the ACGIH. Instruction of the ventilation system was based on VS.[23] Then, for the equipment without VS, the hood was designed according to the form of contamination source, available spaces, physicochemical properties of the pollutant and the method of pollutant emission. In Figure 1, components of ventilation system in an isometric form (1a) and horizontal plan (1b) of the ventilation system are shown.

LEVs were designed by considering variables like temperature and altitude (to determine the air pressure) in the calculations.[24] Then, the correction index of the flow rate (K_Q) and pressure correction index (K_P) were calculated by taking pressure corrected and volumetric flow rate into account.

The static pressure in parallel ducts was balanced. Ventilation standard used in this design was VS-50-21 and all calculations were performed in the calculation table using formulas. The hoods and transitions were shown by numbers and letters, respectively. In all the design process, the two connecting ducts were done by an entrance. Therefore, a hood-to-entrance or entrance-to-entrance duct was represented by a combination of characters (e.g., 1-A, A-B). A connection between two main ducts and sub-ducts or connection of duct-hood was represented by a two-letter sign (e.g. 1-A). In the design process, 9 hoods were considered in certain places at the top of the conveyors and other equipment at the place of pollutant emission. Wet scrubber was used in designing because of two important reasons: 1) Purification of the polluted air in the ventilation system to prevent environmental contamination; and 2) Reuse of raw materials captured was carried out due to the nature of pollutants in the form of slurry in the cycle of generation.

All of the parts including the ducts, elbows, entrances and hoods were made of black iron with appropriate thickness. Important factors for determining appropriate thickness include materials, static pressure in each part of the duct and diameter of theduct in each part of the ventilation system. Thickness of duct walls was calculated by considering static pressure inside the duct, and duct diameter (Equation 1):

$$t = 0.00035 \times d\sqrt[3]{(|SP|) \times (52 + d)} \quad \text{(Eq 1).}$$

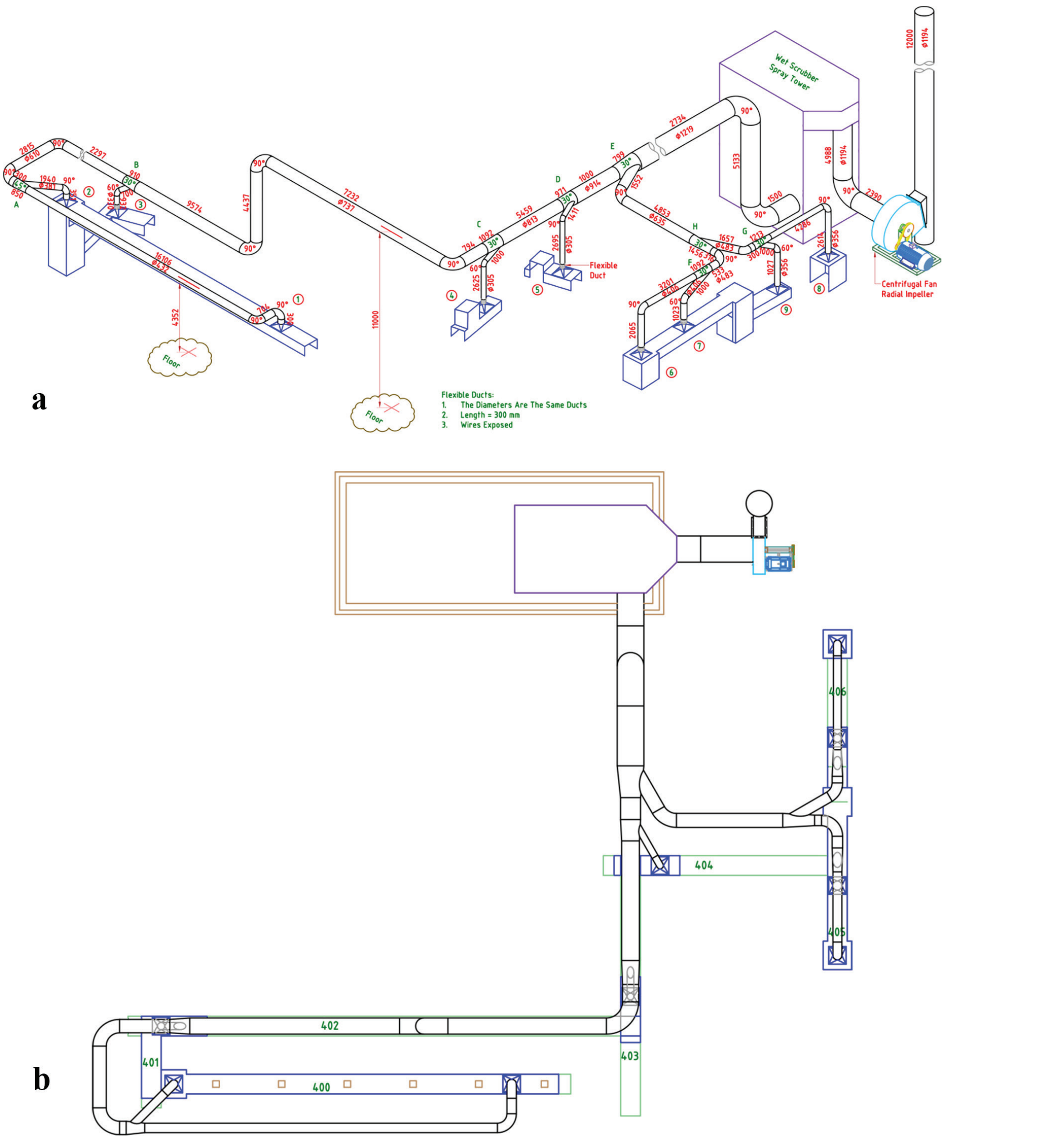

Figure 1: a) Location and arrangement of local exhaust ventilation system, b) Horizontal plan of the designed local exhaust ventilation system

SP=static pressure inside the duct (Inches of Water Gauge (W.G.))
D=duct diameter (inch)
T=thickness of duct walls of iron (inch)

Air Sampling Methods and System Evaluation

In the present study, total dust, inhalable dust and silica were sampled and evaluated before and after the design and installation of the ventilation system. The study subjects comprised 22 persons working in the spray dryer hall exposed to dust and crystal silica. Before the study, an informed consent was obtained from the participants. Details and aims of the study were explained to all participants. The publication of this case was conducted with the approval of Shahid Sadoughi University of Medical Sciences Yazd ethics Committee in Iran. The code of ethics was 203995. The sampling method was simple method. Method No. 7601 of NIOSH was selected for gathering and analyzing crystalline silica and also method No. 0600 of the NIOSH for total dust.[25, 26] Samples were collected on Polyvinyl chloride filters with 37 mm in diameter and 0.5 µm pore size using nylon silicon and individual sampling pump (model SKC). The output flow rate was 2 $Lmin^{-1}$ and the total air volume was 400 lit. In the sampling process, in order to keep the filter weights below 2 mg, we considered the necessary accuracy.[25]

During the sampling process, the sampling pumps were calibrated by a Rota meter. The volume of the sampled air was rectified due to alterations of the height from the sea level, air pressure and temperature. Before sampling, the filters were dried in a desiccator for 24 hours. Then, the filters were weighed. In order to determine the place of sampling and weight changes greater than 2 mg in the filters, an identification code was considered for each filter and petri dish. After the sampling process, the filters were put in a Petri dish with the related code and weighted by special scale. To determine the concentration of silica, we analyzed the air samples by calorimetric method using spectrophotometry device of visible light. After construction and installation of the ventilation system, the efficiency and adequacy of the components were evaluated by measuring. The variables studied include velocity at the face of hood, volumetric flow rate in the face of the hood, minimum design duct velocity, velocity pressure, and air velocity in the duct. Then, the measured values were compared with designed values. The U-shape manometer in the ducts was used to measure the minimum design duct velocity and velocity pressure. Also, for measuring the velocity at the Face of hood, Anemometer VAN device of calibrated model DVA30 was used. Then, static pressure in the hood was measured for determining the flow rate in each hood and the amount of flow rate was calculated using the formula, $Q=4005\ C_eA\sqrt{SP_h}$

For determining the air velocity in the duct, velocity pressure was measured in several points of the duct based on the method of ACGIH. Then, the mean velocity pressure values were calculated using the formula, $V=4005\sqrt{vp}$. The velocity values of air in the ducts and velocity were calculated and compared with the designed velocity. Statistical analysis for the samples was done by SPSS21; Kolmogorov-Smirnov test was used in order to determine the normal distribution of the obtained data. Paired sample and one-sample T-tests were used for comparing the variables measured before and after applying the ventilation system.

Results

Results of the present study revealed a considerable decrease in the mean of measured values of total dust, inhalable dust and silica (66%, 94% and 96%, respectively), after the installation and implementation of the ventilation system (Table 1). Statistically, a significant difference was observed between the mean concentrations of the mentioned contaminants (P<0.05) (Table 1).

Table 2 revealed that there was no statistically significant difference between the mean of measured velocities for G-H and 5-D with the value of obtained in the design (P>0.05), respectively) (Table 2).

The findings showed that there was a significant difference between the mean of the flow rate measured in the duct and designed value for G-H (P>0.031), while there was no significant difference in 5-D duct (P>0.05) (Table 2).

The results showed that the mean velocity measured in the face of hood was less than the designed velocity for hoods C-4 and G-8. Statistically, this difference was not significant (P<0.05) (Table 3). Therefore, the findings revealed that the mean flow rate measured at the face of hood was less than the designed flow rate for hoods C-4, and G-8. This difference was statistically significant (P<0.05) (Table 3).

Discussion

In the present study, LEVs were used for controlling pollutants including crystal–silica. The produced crystalline silica increases the respiratory problems, lung cancer and disability. Several studies showed the effects of the ventilation system for elimination of pollutants from workplace to lower than permissible limits.[10, 16, 27-29] Based on the obtained results in this study, the mean values of total dust measured, inhalable dust and silica before the control was higher than permissible limits determined by NIOSH (Table 1). Findings of Nor's (2014) study showed that the efficiency of local ventilation system in the reduction of air pollutants

Table 1: Mean concentration of the measured values (Total dust, Inhalable Dust, Silica, permissible standard limit by the NIOSH and efficiency) before and after implementation of LEVs

Type of pollutant	Average of density of measured pollutants mg/m3		p value* and t in comparison before and after of control		Permissible contact standard density mg/m3	p value and t in comparison Before of control and permissible standard limit		p value** and t in comparison after of control and permissible standard limit		Values of efficiency after of control (%)
	Before control	After control	t	P		t	P	t	P	
Total dust	28.58±8.15	9.29±1.79	9.75	0.001	10	10.69	0.001	-0.18	0.85	66
Inhalable Dust	16.73±5.16	2.84±1.11	12.38	0.001	3	12.46	0.001	-0.67	0.5	94
Silica	0.15±0.08	0.044±0.014	6.75	0.001	0.05	5.86	0.001	-1.83	0.081	96

*Paired sample t-test, **One sample t-test

Table 2: Comparison of the mean of measured velocities and flow rates with designed values in the two ducts

duct profile	mean of measured velocities (fpm)	mean of designed velocities (fpm)	P value*	mean of measured flow rate (cfm)	mean of designed flow rate (cfm)	P value*
G-H	4693±1.14	4722	0.13	9296±2.42	9298	0.031
5-D	6367±23	6371	0.4	4998±18.29	5004	0.17

*One sample t-test

Table 3: Comparison of the mean velocities measured and the designed flow rate in the face of hood

Hood profile	Average of measured velocities (fpm)	Average of designed velocities (fpm)	t	P value*	Average of measured flow rates (cfm)	Average of designed flow rates (cfm)	t	P value*
C-4	248.8±1.81	250	-2.09	0.066	3567	5050	-135.9	0.001
G-8	249.6±2.41	250	-0.52	0.61	4153	4324	-17.80	0.001

*One sample t-test

was very high.[30] According to another similar study by Shepher (2009) in construction industry, it was revealed that exposure to inhalable dust and crystal silica was reduced to 90% and 95% using LEVs, respectively.[27] The present study showed that the efficiency of LEVs had 94% decrease for inhalable dust and 96% for crystalline silica (Table 1), which is consistent with the mentioned studies, while Mortazavi et al.'s study (2013) in casting industry showed the efficiency of LEVs in reduction of silica concentration at 82%[22] that is lower than the present study (Table 1). This difference has two main causes: difference in the place of installation of the ventilation system and environmental factors outside the workplace such as blowing of wind which can have a considerable influence on the efficiency of eliminating the pollutants. Glinski's study (2002) on grinding of cast iron showed that the LEVs had a significant reduction of dust with more than 90% efficiency.[31] In the present study, reduction of total dust was approximately 66% (Table 1), which is different from Glinski's study. Reasons of this difference are in the type of pollutants and the distance of dispersion source to the face of the hood; also, the weight of the pollutant is influential. Another study by Ojima et al. (2007) on metal abrasion operation showed that the efficiency of LEVs for total dust removal was maximum 37%, while this value was 66% in the present study (Table 1). This difference can be due to the weight of the produced particles in the operation of the metals' abrasion and velocity of throwing the pollutants and effective capture of pollutants by hood. As shown in Table 1, the remaining concentration of the pollutants was lower than the permissible limit determined by NIOSH after the installation of the ventilation system.[32]

Due to high costs of designing and installing the local ventilation system in factories, similar studies in this respect are rare. One of the differences of this study with other similar studies is the use of scrubber as dust collectors (Figure 2). Due to the humidity of the scrubber environment and high dust of the work environment, dust is gathered in the dust collectors using wet method and the consumed primary material is reused in the form of slurry. The use of scrubbers has a great effect on the collection efficiency of the particles[33] and decreases of the ventilation system costs.[15] Bahrami et al.'s study (2009) showed that cyclone and wet scrubber in LEVs could effectively eliminate a high percentage of silica at the entry to the system;[15] the results obtained in the present study is consistent with those of Bahrami's study. The fan used was designed based on valid standards. Therefore, after installation and evaluation of the ventilation system, volumetrics of the flow rate in the duct, and velocity at the face of the hood had little difference (Tables 2, 3).

In this study, for reducing the costs, instead of making the scrubber in the form of a unit cylinder, one has used a container with multiple small scrubbers (multi-scrubber). In the scrubber, the contact surface between the pollutant and water has increased

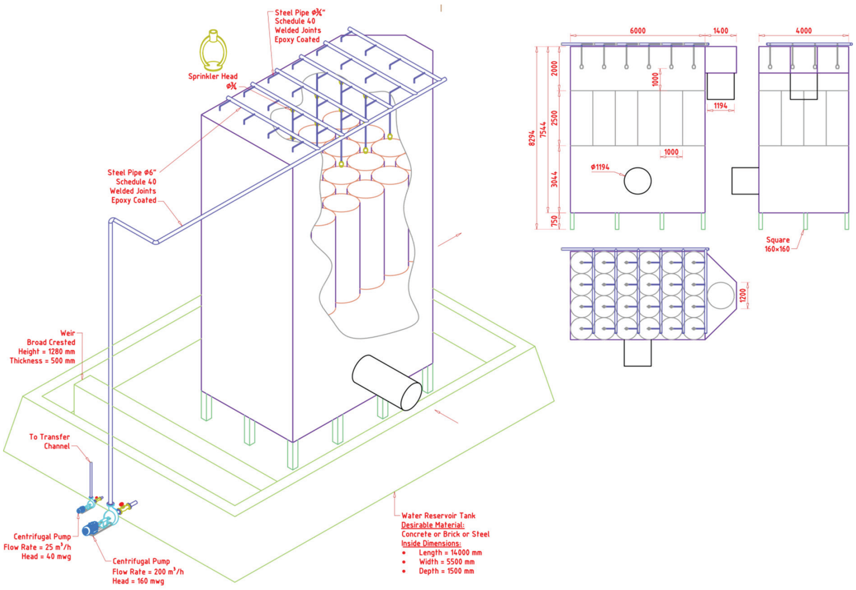

Figure 2: The designed multi-scrubber

considerably due to the increase in the area of droplets. The height-to-diameter ratio of the scrubber of 2.5 was considered. The diameter of the scrubber is determined by the air flow rate. If one scrubber is used in the mentioned system, due to velocity 256 fpm in the cross-section of the scrubber, diameter and height will become 16.1 and 53.28 ft, respectively. In order to prevent the flexural strains, the thickness of the plate should not be considered less than 8 mm. As welding, transportation and assembly of components of the scrubber is so difficult. Using the multi- scrubber, the weight of the consumed plate was reduced from 16012 to 4550 kg, while an iron plate saved up to11462 kg. The efficiency of the pollutant collection in wet scrubbers depends on the amount of the contact area of the pollutant with sprayed liquid in the scrubber. Therefore, if the diameter of liquid droplets is lower, the contact area is greater and consequently the efficiency of the collection of the pollutant will increase. If the scrubber is made in the unit form, due to high height of the scrubber, liquid droplets stick with each other due to molecular similarity and the diameter of droplets increases; consequently, the contact area decreases. Therefore, a separated water nozzle is considered for each of these scrubbers to increase the area of the liquids. The height of each scrubber is 2.5 m. The formation of bonding in the solvent droplets from the nozzles is never done during movement in the scrubber height. Hence increasing of the contact area between the particles and liquid droplets can cause an increase in the efficiency of the collection. Similarly, due to the short length of each scrubber, torsional and bending stress does not occur in the scrubber. Based on the above-mentioned explanations, thickness of the used plate in building this scrubber is 1.5 mm; hence, the designed scrubber has a high efficiency in collecting particles and is also economically efficient.

Furthermore, as the height of the dust collector decreases, that of the ducts placed before and after the purifier will be shorter. Also, the length of the pipe that transports water as a solvent in wet scrubber will be shorter. Therefore, a pump with less pressure is selected, thus decreasing the cost.

One of the influential factors on the costs is the minimum velocity of the duct design. Minimum velocity of the duct design depends on the type of pollutant which is given by ACGIH. If it is not selected properly, this prevents the sedimentation of pollutants in the duct. A value determined for this factor by ACGIH is 2500-3500 feet per minute. However, the minimum velocity in the duct is considered to be 4000; given the principle of Volumetric Flow, there is no duct with standard diameters in Iran. Therefore, we had to make the duct according to standards. Because of the high costs in duct making, we decreased the weight of the sheet used. Therefore, we increased the velocity in the duct; consequently, we had a reduced cross-section and weight in the duct. The flow rate is described by $Q=A_xV$ equation. In case the flow rate (Q) is fixed and has a higher velocity, the cross-section of the duct will be smaller; consequently, the iron weight consumed in the ducts decreases. Therefore, this reduces the required supports. Also, increase in the velocity and pressure loss increases the price of the fan. However, this increase in cost is much less than the reduced costs in the conformation of the ducts. Another reason of this engineering initiative is that if the diameter of the ducts is greater, the design is less beautiful and there is not enough room for installation.

In the present study, the velocity of the capture at the face of hood C-4 and G-8 had no significant difference because the measured values were close to the designed values (Table 3). The reason for this slight difference was placing the hoods at the vicinity of the hall doors, which was probably affected by the intruder currents derived from openness of the hall door. However, in this study, velocities in the ducts are measured and compared with the designed velocities and no significant difference was found and the values were close to each other.

Conclusion

The ventilation system in this study is designed based on standards and is economically efficient. Using this kind of local ventilation system has a considerable effect on the reduction of pollutants in the studied environments although this effect has a slight distance with the intended standards, and the pollutant control is done in a border manner. Similarly, the performance of the ventilation system was in accordance with the designed value.

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