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Original article

Indoor air quality assessment in painting and printmaking department of a fine arts faculty building



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ARTICLE INFO

Article history:

Received 25 February 2015

Received in revised form

22 May 2015

Accepted 25 May 2015

Available online 14 October 2015

Keywords:

Indoor air quality

Fine arts

Painting and printmaking department

Diffusive sampling

ABSTRACT

Measurements for indoor air quality assessment were carried out in Painting and Printmaking Department of Anadolu University Faculty of Fine Arts in Turkey. Concentrations of nitrogen dioxide (NO₂), ozone (O₃) and 29 Volatile Organic Compounds (VOCs) were measured simultaneously by using diffusive samplers. Simultaneous outdoor measurements were also performed at some sampling points. Analyses of NO₂ and ozone samples were performed by using ion chromatography and VOCs were analyzed by using gas chromatography-mass spectrometry. Indoor NO₂ and ozone concentrations varied between 13.47–89.77 µg m⁻³ and 3.89–51.82 µg m⁻³, respectively. Average indoor NO₂ concentration was obtained as 35.37 ± 10.9 µg m⁻³. Indoor/outdoor NO₂ ratio (I/O) was found as 1.44 ± 0.4 which indicated the presence of some indoor sources. Average indoor ozone concentration was 9.97 ± 4.4 µg m⁻³ and I/O ratio was obtained lower than 1 (0.46 ± 0.4). The highest VOC concentrations were observed at workshops where oil painting and stained glass studies were performed. Especially, the concentrations obtained from the stained glass workshop (benzene: 3.98 ± 1.3 µg m⁻³, toluene: 999.33 ± 104.2 µg m⁻³, ethyl benzene: 66.06 ± 16.1 µg m⁻³, m,p xylene: 129.44 ± 33.1 µg m⁻³, o-xylene: 76.14 ± 23.1 µg m⁻³) were much higher than the other sampling points. Toluene concentrations exceeded the WHO (World Health Organization) limit value (260 µg m⁻³ weekly average) at 40% of the sampling points. Cancer risks were estimated by using the personal exposure concentrations. Lifetime cancer risks for the people working in the department such as faculty members and technicians were obtained higher than USEPA acceptable risk value (1 × 10⁻⁶) while the risks for the students were below this value.

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1. Introduction

The number of studies carried out about indoor air pollution have increased in recent years since people spend more than 80% of their time indoors either in the home or in the work place in modern urban areas (Baya et al., 2004; Ohura et al., 2009). The poor air quality of indoor environments causes acute and chronic health problems. Since people spend most of their time indoors, determination of indoor air quality is crucial to protect public health. Volatile Organic Compounds (VOCs), nitrogen dioxide (NO₂) and

ozone (O₃) are known to be important pollutants which may have variety of indoor sources.

Volatile Organic Compounds (VOCs) are a group of major indoor air pollutants that has been associated with many health problems (Jones, 1999; Hellén et al., 2002; Parra et al., 2008). Benzene has been identified as a Group-I human carcinogen by the International Agency for Research on Cancer (IARC) (IARC, 1982). Aromatic hydrocarbons such as benzene, toluene, ethyl benzene, and isomeric xylenes (BTEXs) are an important group of air pollutants among VOCs. In particular, the exposure risks of benzene and toluene should be investigated in detail because of their high toxicity/carcinogenicity and/or high concentrations measured in the air. Environmental tobacco smoke (ETS), personal care products, cleaning products, perfumes, glues, paints, solvent based products, and some building and construction materials are major indoor sources of VOCs (Adgate et al., 2004; Dodson et al., 2007; D'Souza et al., 2009; Pandey and Kim, 2010).

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Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

Nitrogen dioxide (NO_2) can cause many health problems including eye mucosa, irritation of nose, throat and respiratory system (Berglund, 1993; Kattan et al., 2007; Kornartit et al., 2010; WHO, 2010). The most important indoor sources of NO_2 are gas appliances such as stoves, ovens, space and water heaters, unflued kerosene heaters (Levy, 1998; Willers et al., 2006) and also tobacco smoke (Cyrus et al., 2000). Additionally, outdoor air is known as an important source for indoor NO_2 pollution.

Ozone (O_3) is one of the important indoor air pollutants because of its health effects like reduced lung function, development of asthma and atherosclerosis (Gong et al., 1998; Helaleh et al., 2002; WHO, 2005). Beside its health effects, it is a strong oxidant and plays an important role in some chemical reactions such as formation of aldehydes by reaction with VOCs (Zhang et al., 1994; Rancière et al., 2011). Additionally, ozone in the indoor atmosphere causes chemical deterioration of the subjects and it is an important problem especially in the historical places such as museums, palaces and temples (Salmon et al., 2000; Loupa et al., 2006). Outdoor air as well as equipments including air cleaners, fax machines, laser printers, scanners, and photocopying machines is also among important sources of indoor ozone (Poupard et al., 2005).

There are number of studies on indoor air quality (IAQ) in certain microenvironments such as restaurants (Baek et al., 1997; Lee et al., 2001), mosques (Ocak et al., 2012), schools (Lee and Chang, 2000; Rivas et al., 2014), kinder gardens (Zuraimi and Tham, 2008; St-Jean et al., 2012) and laboratories (Ugranli et al., 2015). Fine arts faculties are special indoor environments considering materials used and processes carried out during education of the students. Different types of paints and solvents are used in certain applications. The objective of this study is to investigate indoor air quality in the Painting and Printmaking Department of Fine Arts Faculty of Anadolu University in Turkey. Concentrations of nitrogen dioxide (NO_2), ozone (O_3) and 29 target Volatile Organic Compounds (VOCs) were measured simultaneously in different indoor environments such as offices, workshops, corridors and classrooms by using diffusive samplers. Outdoor concentrations of the same pollutants were measured simultaneously at some sampling points. Cancer risks due to exposure of VOCs were also estimated.

2. Materials and methods

2.1. Study area and sampling points

This study was carried out in Painting and Printmaking Department of Faculty of Fine Arts at Anadolu University in Turkey. The faculty building has three floors and Department of Painting and Printmaking is on the third floor. There is a road which is not busy and a parking lot near the faculty building and there is no industrial complex around the building. As shown in Fig. 1, there are five workshops (four of them are painting workshops and one of them is stained glass workshop), seven offices, four main corridors, demonstration room, conference hall and secretariat in the department. Measurements were conducted out in three of the offices, all workshops, corridors, demonstration and conference room. Diffusive sampling was also performed at the edge of the window of the demonstration room which receives air flow through ventilation shaft from glass workshop in the first floor of the building. This place was chosen intentionally because occupants of the building were suffering from bad smell coming from ventilation shaft during opening of the windows. In two sampling points, outdoor measurements were also carried out simultaneously with the indoor measurements. Outdoor samplers were placed at the edge of the windows of office 1 and office 2 to

represent different faces of the building and sampling points were at 10 m above the street level. Also, measurements were performed on the stairs at the entrance of the department and on the second floor (floor below of Painting and Printmaking Department). Sampling was carried out during one week period between 20 and 27 December 2012 by using diffusive samplers. Some information about sampling program such as measured pollutants, number of the samplers, number of the blanks and sampling locations were summarized in Table 1. As a total of 114 samples together with blanks (15 blanks) were analyzed. In some locations such as workshops samples were collected from different corners of the room to represent the whole area.

The heating of the building is maintained by central heating system and natural gas is used for the heating purpose. It is a naturally ventilated building where air exchange occurs through opening doors and windows; no mechanical ventilation system exists in the building. The materials used in the workshops like paints, varnishes, adhesives can be considered as important sources of indoor pollutants since they include many VOC species (Srivastava et al., 2000; Ilgen et al., 2001; Yuan et al., 2010). In the first painting workshop where first-year students study, students usually draw pencil sketch. In the second, third and fourth painting workshops, students use water-based and oil-based paints. In the stained glass workshop, various varnishes and adhesives are used extensively.

2.2. Preparation of the diffusive samplers

Nitrogen dioxide (NO_2), ozone (O_3) and Volatile Organic Compounds (VOCs) were measured by using tailor-made diffusive samplers developed at Anadolu University, Turkey. Extensive field validation studies were carried out for all the compounds before starting the sampling studies. In general, two different types of diffusive samplers were used for the measurements. The dimensions (2.5 cm length and 2 cm inner diameter) and main parts (plastic body, plastic ring, and stainless steel mesh barrier and close cap) of all the diffusive samplers were same, but materials of the samplers and collecting mediums were different for each pollutant. Ozone and VOC diffusive samplers were made from delrin while NO_2 diffusive sampler was made from teflon.

Whatman GF/A fiber glass filter paper impregnated with 20% TEA aqueous solution for NO_2 and 1% NaNO_2 + 2% Na_2CO_3 + 2% glycerol aqueous solution for ozone was used. The impregnated filter papers were dried and placed at the bottom of the samplers and fixed with the 5 mm fixer ring. The inlet ends were then closed with a plastic cap. Technical and analytical details of these diffusive samplers can be found elsewhere (Özden, 2005; Gül et al., 2011; Gaga et al., 2012; Özden and Döğeroğlu, 2012; Demirel et al., 2014).

For the measurement of VOCs, 200 ± 1 mg 18–35 mesh granular activated carbon was used as adsorbent. Activated carbon was weighed in a clean environment and placed at the bottom of the sampler. Then, the pressed glass wool was fixed on the activated carbon with the plastic ring to avoid the spilling over of the activated carbon during transportation and sampling. The inlet end was closed with a plastic cap. The results of an extensive field validation study was presented in a recent publication (Özden Üzmez et al., 2015) and validation parameters such as detection limit, precision, bias, recovery, self-consistency, shelf life, storage stability and reusability were investigated in accordance with the European Standards (EN 13528-1 and 13528-2). Also, comparison studies with some commercial diffusive samplers such as 3M OVM 3500 and Radiello were performed to test the performance of the new diffusive sampler. Uptake rates for the measured VOCs were determined and they were evaluated together with the meteorological parameters (temperature, humidity, wind speed). After

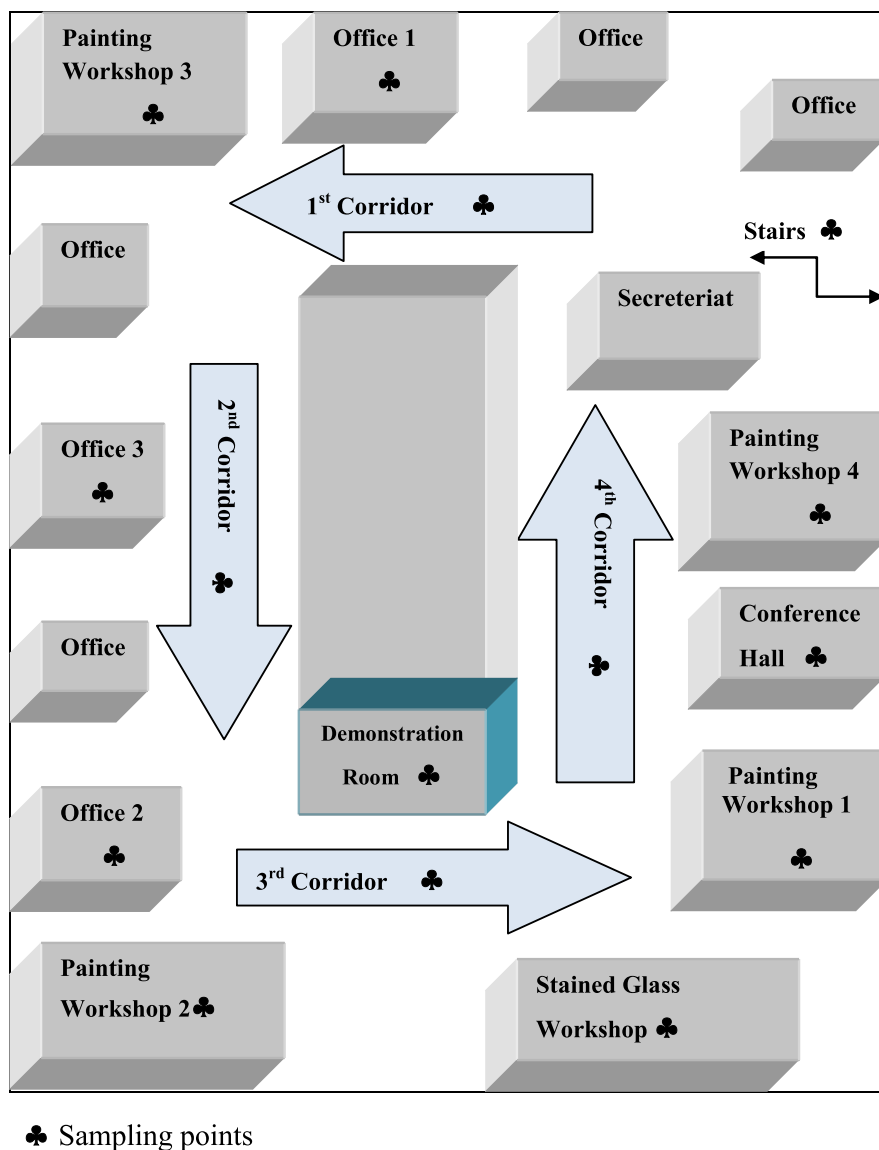


Fig. 1. The schematic diagram of the Painting and Printmaking Department.

completion of the validation study, the sampler was registered as Utility Model by Turkish Patent Institute (Document No: TR 2012 06997 Y).

As mentioned in Section 2.1, simultaneous outdoor measurements were also performed at some sampling points. During the

sampling period, to minimize turbulence effect of wind inside the sampler (especially for outdoor samplers), a stainless steel mesh barrier was placed at the open end, and the barrier was replaced with a close cap during the transportation of the sampler. The outdoor samplers were mounted vertically with open end

Table 1
Diffusive sampling information.

Sampling point	Number of diffusive sample/Blank (O ₃ , NO ₂ and VOCs)		Sampling point	Number of diffusive sample/Blank (O ₃ , NO ₂ and VOCs)	
	Sample	Blank		Sample	Blank
Painting Workshop 1	3	1	Demonstration Room	1	—
Painting Workshop 2	3	—	1. Corridor	4	—
Painting Workshop 3	3	—	2. Corridor	1	—
Painting Workshop 4	2	—	3. Corridor	2	—
Stained Glass Workshop	3	—	4. Corridor	1	—
Office 1	1	1	Stairs	1	—
Office 2	1	—	Second Floor	1	—
Office 3	2	—	Outdoor Air	2	2
Conference Room	1	—	Total number of samples	33 × 3 ^a = 99	5 × 3 ^a = 15
Ventilation Shaft	1	1			

^a The number of measured pollutant species: (1) NO₂, (2) O₃ and (3) VOCs.

downward in a shelter to protect the samplers from the negative effects of the meteorological parameters (rain, high wind speed, etc.) during sampling period. Diffusive samplers were delivered to the sampling points and collected back after one week.

2.3. Extractions and analyses of the samples

Filter papers were removed from NO₂ and ozone diffusive samplers and extracted with 10 mL ultra pure water for 15 min. All the analyses were performed by using Dionex 2500 ion chromatograph equipped with GP 50 gradient pump, LC 25 column oven and a conductivity detector. An eight-point calibration curve was used for the quantification of the pollutants.

The extractions of VOC samples were carried out with carbon disulfide (CS₂) (ReagentPlus, redistilled, ≥99.9%, low benzene) in 2 mL Eppendorf centrifuge tubes. Activated carbons in the VOC samplers were transferred to the centrifuge tubes and mechanically agitated by a shaker for 5 min at room temperature and then, they were extracted in an ultrasonic bath for 30 min. Ice blocks were added into the bath to avoid temperature change due to ultrasonic power. After extraction, the samples were centrifuged at 10 000 rpm and –5 °C for 20 min to obtain a clear phase (supernatant) at the top. The extracts of all the samples were transferred into GC auto sampler vials and analyzed immediately. The samples were analyzed with an Agilent 6890N gas chromatograph (GC) equipped with an Agilent 5973 inert mass selective detector (MSD). DB 624 capillary column was used for the analyses. The GC oven temperature was set initially to 35 °C for 5 min, increasing at a rate of 10 °C min⁻¹ to 245 °C and then holds for 1 min. ChemService ozone precursor VOC standard was used for the calibration of the instrument. A six-point calibration curve was prepared for quantifying the VOCs in the samples.

The concentrations of all the pollutants were determined by using Fick's first law (Gorecki and Namiesnik, 2002).

2.4. Quality assurance (QA)/quality control (QC) for the diffusive samplers

Different parameters such as accuracy, precision, detection limit, blank values, recovery (for VOC samplers) were evaluated within the quality assurance and quality control (QA/QC) studies for the diffusive samplers.

QA/QC parameters for NO₂ and ozone diffusive samplers were evaluated in some previous studies (Özden, 2005; Gül et al., 2011; Gaga et al., 2012; Özden and Döğeroğlu, 2012; Demirel et al., 2014). The detection limit for a 1-week sampling period, determined as three times the standard deviation of the field blanks, was obtained approximately as 1.00 µg m⁻³ for NO₂ and 2.42 µg m⁻³ for ozone. Accuracy of the NO₂ diffusive sampler was determined by comparison with a Thermo 42i chemiluminescence NO–NO₂–NO_x Continuous Automatic Gas Analyzer and it was found lower than 15% as percent relative error. 42 M UV Photometric Environment S.A. automatic ozone analyzer was used for the determination of accuracy of the ozone diffusive sampler. Percent relative error was found to be lower than 15% similar to NO₂ sampler. Precision values for the samplers were determined as coefficient of variance (CV, %). Coefficient of variance was found lower than 11% for NO₂ and approximately 12% for ozone for triplicate measurements. Mean blanks (indoor and outdoor blanks were evaluated together) for NO₂ and ozone were determined as 2.58 ± 0.6 µg m⁻³ and 1.68 ± 0.2 µg m⁻³, respectively.

QA/QC parameters for VOC diffusive sampler were evaluated within an extensive field validation study for the measured 29 VOCs (Özden Üzmez et al., 2015). The detection limit values calculated as three times the standard deviations of the field blanks

for 24-h sampling period were between 0.01 and 0.11 µg m⁻³. For all the VOCs, relative percent error was below 16% (for BTEX < 15%). Precision values as CV for one-week sampling and six replicates of the sampler were between 5 and 10%. Recoveries of VOCs from the adsorbent were found to be in the range of 80% and 110%. Average sample/blank ratios were obtained between 6.5 and 175.

3. Results and discussions

3.1. Inorganic pollutants (NO₂ and ozone)

Nitrogen dioxide (NO₂) concentrations measured at each sampling point were shown in Fig. 2. Average NO₂ concentrations for indoor and outdoor environments were 37.71 ± 10.8 µg m⁻³ and 26.24 ± 2.6 µg m⁻³, respectively. Average indoor/outdoor ratio was calculated as 1.44 ± 0.4 (>1) which indicated the presence of some indoor sources. Fire process at high temperatures is performed in the glass workshop located at the ground floor and it is thought that the emissions from this workshop may contribute to NO₂ levels in the building because higher NO₂ levels were measured in the second floor (56 µg m⁻³), on the stairs (57 µg m⁻³) and in the ventilation shaft (89 µg m⁻³). Other possible important indoor source of NO₂ might be smoking. It was proven that tobacco smoke is one of the main sources of indoor NO₂ (Baek et al., 1997; Lee et al., 1999). Face-to-face interviews showed that students sometimes smoke during their activities in the painting workshops and at the corridors which may also explain relatively high NO₂ concentrations measured at those places.

Ozone concentrations measured at each sampling point were shown in Fig. 3. The results of indoor measurements varied between 3.89 and 51.82 µg m⁻³. The highest concentration (51.82 µg m⁻³) was obtained in the fourth corridor. Photocopy machine in the secretariat might be an important source in this corridor. The average indoor and outdoor ozone concentrations were 11.37 ± 8.7 µg m⁻³ and 24.74 ± 9.5 µg m⁻³, respectively. As shown in Fig. 3, outdoor concentrations were obtained higher than indoor concentrations and for this reason, indoor/outdoor ratio (I/O) was obtained <1 (0.46 ± 0.4). Absences of indoor ozone sources such as photocopy machines (except for secretariat) or ozone generators in many of the places may be the reason of low indoor levels (Blondeau et al., 2005). Additionally, low I/O ratios might be due to deposition of ozone on various surfaces such as floor, furniture, wall and some chemical reactions with VOCs (Reiss et al., 1994; Moriske et al., 1998; Blondeau et al., 2005).

3.2. Organic pollutants (VOCs)

In the Painting and Printmaking Department, concentrations of 29 target VOCs were measured. Ambient concentrations of VOCs were very low as expected because there was no important ambient source of VOCs like industrial complexes, petrol station, solvent storage or busy traffic around the faculty building. Considering indoor sources, paints, varnish, thinner, and adhesives which are widely used in the department were found as major contributors to indoor VOC concentrations. Measured concentrations of VOCs were shown in Table 2.

Concentrations of seven aromatics namely toluene, m/p-xylenes, o-xylene, ethyl benzene, p-ethyl toluene, 1,2,4 trimethyl benzene, and 1,3,5 trimethyl benzene were high in the stained glass and painting workshops. The concentrations of these pollutants accounted for about 79.8% of total VOC concentration measured in the workshops. High concentrations of such VOCs are thought to be related to oil-based paint, thinner, varnish and adhesives which are densely used in these workshops. Based on source profiles of VOCs in the literature, aromatic hydrocarbons are the dominant species

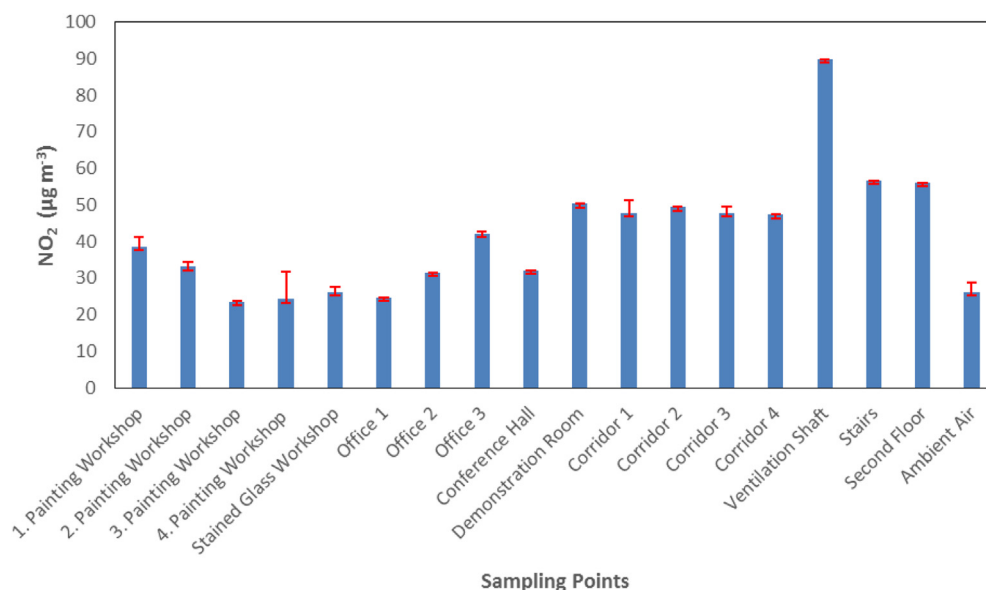


Fig. 2. NO₂ concentrations measured in different microenvironments in the department and outside the building (µg m⁻³).

associated with the painting applications (Vega et al., 2000; Na et al., 2004; Liu et al., 2008; Yuan et al., 2010; Colman Lerner et al., 2012). In the study of Yuan et al. (2010) which was carried out in Beijing, China, BTEX concentrations were determined as the dominant species in architectural paint emissions with accounting for 49.7% and accounted for more than 98% in the emissions of the furniture painting processes. In our study, concentrations of n-nonane and n-octane (especially n-nonane) were also found high in the workshops of Painting and Printmaking Department. These two compounds are widely used as solvent in the paints (Borbon et al., 2002; Guo et al., 2004a).

In this study, among all VOCs, toluene concentrations were obtained as the highest at all sampling points, ranged from 56.37 µg m⁻³ (conference hall) to 999.33 µg m⁻³ (stained glass workshop). Toluene levels obtained from stained glass workshop, second, third and fourth painting workshops, and office 3 were higher than the weekly limit value (260 µg m⁻³) established by World Health Organization (WHO) for indoor air (lower threshold) (WHO, 2000). It was found that toluene was the most abundant species among the solvent-based VOCs in previous studies (Vega et al., 2000; Ilgen et al., 2001; Na et al., 2004; Liu et al., 2008; Yuan et al., 2010; Guo, 2011). Since toluene is a major component

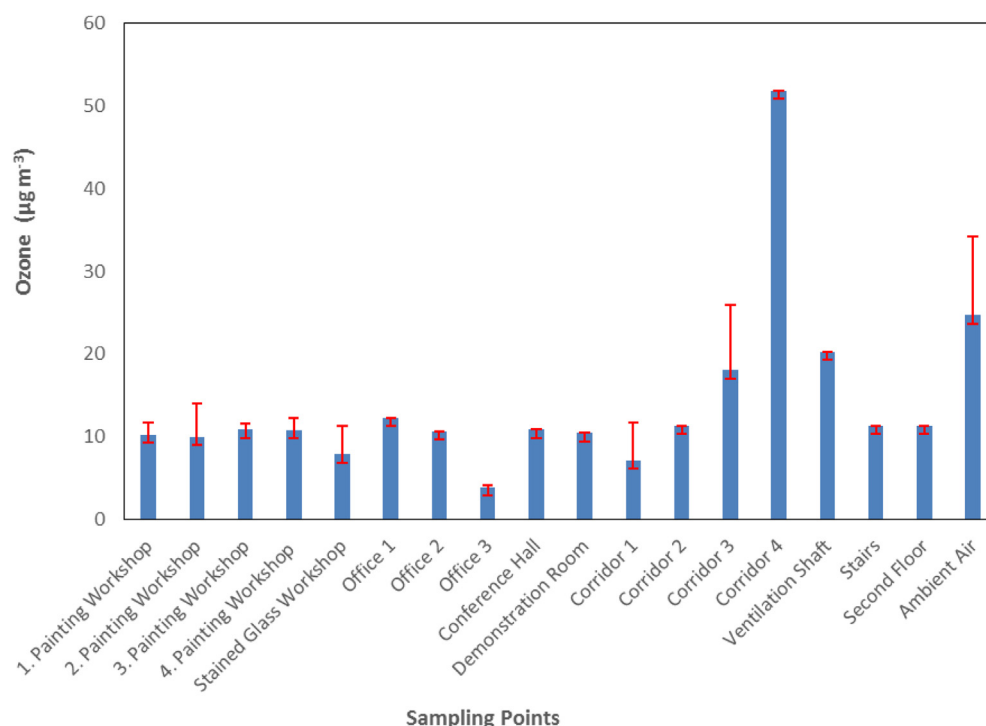


Fig. 3. Ozone concentrations measured in different microenvironments in the department and outside the building (µg m⁻³).

Table 2Measured VOC concentrations in the sampling points ($\mu\text{g m}^{-3}$).

VOCs	Painting workshop 1 (n ^a = 3)	Painting workshop 2 (n = 3)	Painting workshop 3 (n = 3)	Painting workshop 4 (n = 2)	Stained glass workshop (n = 3)	Rooms (offices, demonstration room, conference hall) (n = 6)	Corridors (n = 8)	Second floor (n = 1)	Stairs (n = 1)	Ventilation shaft (n = 1)	Outdoor air (n = 2)
Toluene	90.22 ± 6.4	382.13 ± 30.7	285.11 ± 16.9	297.40 ± 73.9	999.33 ± 127.5	149.93 ± 84.2	93.40 ± 30.3	62.69	69.80	86.96	3.58 ± 0.8
Benzene	1.29 ± 0.2	5.34 ± 0.2	1.75 ± 1.1	1.47 ± 0.3	3.98 ± 1.6	2.50 ± 1.6	1.44 ± 0.4	0.94	1.35	4.67	1.54 ± 0.1
m + p Xylenes	7.08 ± 0.6	32.29 ± 3.7	30.16 ± 1.6	26.24 ± 12.5	129.49 ± 40.2	10.13 ± 7.3	4.94 ± 1.7	2.15	2.85	2.90	0.35 ± 0.01
o-Xylene	4.71 ± 0.5	15.98 ± 1.7	17.5 ± 0.9	12.84 ± 4.6	76.14 ± 28.2	4.49 ± 2.6	2.90 ± 0.9	1.19	1.74	1.69	0.24 ± 0.01
Ethylbenzene	3.99 ± 0.4	18.89 ± 1.9	18.11 ± 0.9	14.47 ± 6.4	66.06 ± 19.7	5.90 ± 4.1	2.80 ± 0.9	1.13	1.59	1.88	0.19 ± 0.01
2 methylhexane	0.40 ± 0.1	1.09 ± 0.1	0.41 ± 0.3	0.29 ± 0.1	0.51 ± 0.3	0.50 ± 0.3	0.34 ± 0.1	0.16	0.38	0.72	0.32 ± 0.06
Cyclohexane	5.76 ± 0.8	16.51 ± 0.6	4.39 ± 3.8	4.04 ± 0.3	7.34 ± 4.1	7.40 ± 4.6	4.37 ± 1.9	1.97	5.30	10.73	3.64 ± 1.8
2,4dimethylpentane	1.07 ± 0.1	1.22 ± 0.2	0.82 ± 0.3	0.96 ± 0.1	1.10 ± 0.2	0.98 ± 0.3	0.85 ± 0.2	0.56	0.93	0.63	0.49 ± 0.2
Methylcyclopentane	0.59 ± 0.1	1.05 ± 0.1	0.72 ± 0.2	0.63 ± 0.1	0.72 ± 0.1	1.04 ± 0.7	0.59 ± 0.1	0.49	0.69	0.69	0.50 ± 0.3
3 methyl hexane	0.46 ± 0.4	0.97 ± 0.1	1.02 ± 0.2	0.85 ± 0.2	0.92 ± 0.1	0.83 ± 0.4	0.63 ± 0.1	0.47	0.69	0.54	0.22 ± 0.1
3 methyl pentane	2.47 ± 0.1	3.58 ± 0.6	1.24 ± 1.1	1.63 ± 0.2	1.71 ± 0.4	1.79 ± 0.7	1.56 ± 0.7	0.72	1.76	1.02	1.49 ± 0.7
n-heptane	2.78 ± 0.3	4.16 ± 0.4	4.86 ± 0.5	2.68 ± 0.6	2.58 ± 0.3	2.17 ± 1.0	1.55 ± 0.4	0.75	1.41	0.93	0.61 ± 0.2
Methyl cyclohexane	2.78 ± 0.3	4.30 ± 0.5	6.26 ± 0.5	2.62 ± 0.7	2.34 ± 0.4	1.92 ± 1.5	1.02 ± 0.2	0.26	0.57	0.53	0.08 ± 0.01
2,3,4trimethylpentane	2.07 ± 0.5	2.94 ± 0.3	4.35 ± 0.2	2.16 ± 0.6	2.08 ± 0.4	1.15 ± 0.4	1.04 ± 0.3	0.85	0.60	0.75	0.64 ± 0.17
2 methyl heptane	2.22 ± 0.2	3.86 ± 0.3	5.43 ± 0.3	2.40 ± 0.8	2.17 ± 0.64	1.72 ± 1.0	1.02 ± 0.3	0.32	0.48	0.32	0.33 ± 0.01
3 methyl heptane	1.57 ± 0.2	2.92 ± 0.4	3.64 ± 0.3	1.82 ± 0.8	1.97 ± 0.6	1.28 ± 0.8	0.63 ± 0.2	0.18	0.32	0.22	0.10 ± 0.08
n-octane	10.56 ± 0.9	21.19 ± 1.9	28.73 ± 1.5	7.51 ± 0.1	15.59 ± 5.5	5.69 ± 4.1	3.86 ± 1.2	0.92	1.83	1.02	0.14 ± 0.01
n-nonane	26.94 ± 4.7	51.34 ± 4.6	82.98 ± 3.0	31.61 ± 9.6	20.10 ± 3.4	13.80 ± 9.1	10.33 ± 3.4	1.72	4.62	2.79	0.25 ± 0.06
Styrene	0.71 ± 0.1	0.53 ± 0.1	0.74 ± 0.1	1.27 ± 0.4	2.25 ± 0.3	0.64 ± 0.2	0.70 ± 0.1	0.72	0.79	0.70	0.53 ± 0.11
Isopropyl benzene	3.04 ± 0.2	2.76 ± 0.2	9.14 ± 0.5	7.84 ± 3.2	17.40 ± 3.1	2.02 ± 0.7	2.46 ± 0.9	0.88	1.45	0.72	0.05 ± 0.03
n-propyl benzene	3.33 ± 0.5	5.71 ± 0.5	9.74 ± 0.5	4.99 ± 2.2	2.50 ± 0.4	1.59 ± 1.0	1.26 ± 0.4	0.39	0.7	0.42	0.25 ± 0.01
1,3,5trimethylbenzene	8.14 ± 1.2	14.42 ± 1.3	25.52 ± 0.9	12.87 ± 5.7	5.43 ± 1.1	4.18 ± 2.6	3.29 ± 0.9	1.14	1.64	0.92	0.11 ± 0.01
o-ethyl toluene	3.68 ± 0.3	6.04 ± 0.3	10.46 ± 0.2	5.74 ± 2.3	2.54 ± 0.4	1.79 ± 1.1	1.56 ± 0.5	0.42	0.90	0.49	0.29 ± 0.04
1,2,3trimethylbenzene	6.55 ± 0.7	11.01 ± 0.8	15.34 ± 0.8	8.68 ± 3.9	3.26 ± 0.6	3.02 ± 2.2	2.04 ± 0.7	0.41	1.02	0.44	0.23 ± 0.03
m-ethyl toluene	5.91 ± 0.5	10.58 ± 0.9	18.27 ± 0.8	9.46 ± 4.2	3.62 ± 0.7	2.94 ± 1.9	2.33 ± 0.7	0.6	1.20	0.67	0.24 ± 0.01
p-ethyl toluene	24.57 ± 2.1	39.90 ± 3.4	58.38 ± 3.4	33.88 ± 14.6	12.32 ± 2.3	11.47 ± 8.3	7.99 ± 2.6	1.9	3.89	1.76	0.21 ± 0.04
1,2,4trimethylbenzene	11.93 ± 0.9	18.52 ± 1.7	23.91 ± 1.6	14.10 ± 5.9	4.82 ± 0.1	5.36 ± 4.3	3.40 ± 1.2	0.54	1.5	0.60	0.07 ± 0.01
m-diethyl benzene	1.77 ± 0.2	3.10 ± 0.7	4.54 ± 0.3	3.12 ± 1.4	0.90 ± 0.2	0.98 ± 0.8	0.63 ± 0.2	0.13	0.27	0.16	0.05 ± 0.01
p-diethyl benzene	7.74 ± 0.7	12.14 ± 1.1	16.38 ± 0.1	9.99 ± 4.3	3.28 ± 0.7	3.58 ± 2.7	2.42 ± 0.8	0.42	1.07	0.50	0.08 ± 0.01

^a n: number of the sampler placed to sampling points.

of solvents, higher concentrations were observed especially in the sampling points where painting activities were carried out.

Concentrations of BTEX except for benzene were found significantly higher in the stained glass workshop than painting workshops since varnish, thinner, and adhesive are densely used in addition to oil-based paints during stained glass process. On the other hand, concentrations of n-nonane, trimethyl benzenes, methyl toluene and p-diethyl benzene were higher in the painting workshops whereas lower concentrations were measured in the stained glass workshop. This result may be due to the contents of the materials used in the workshops since paints are intensely used in the painting workshops while adhesives, varnishes and thinners are mostly used in the stained glass process. Concentrations of VOCs were found to be varying in the painting workshops. For instance, lowest concentrations of VOCs were measured in the first painting workshop while the highest levels were observed in the third painting workshop. First year students use this workshop and they practice charcoal drawing techniques and do not use any solvent based paint.

Another interesting point was that VOC concentrations measured in the office 2 were higher than the other offices. Many oil paintings were kept in this place for storage and students use this room for their studies (mostly oil painting) during long hours. The odor was even sensible during delivery of the samplers to the office.

Table 3 shows BTEX concentrations measured in different indoor environments where painting applications were carried out. Concentrations measured in Mumbai (Srivastava et al., 2000) are much higher than the other studies. In all studies, toluene has higher concentrations compared to other VOCs and benzene concentrations were found as the lowest.

Mean indoor/outdoor ratios (I/O) were also determined for each VOC and the results were shown in Fig. 4. As it is seen from Fig. 4, the mean I/O ratio was >1 for all the compounds which indicates presence of some important indoor sources. Except for few compounds (benzene, 2 methyl hexane, cyclohexane, 2,4 dimethyl pentane, methyl cyclopentane, 3-methyl hexane and heptane), standard deviations of the mean I/O ratios of all compounds show great variability which reflects the concentration variation of those VOCs at different sampling points. According to the mean I/O ratios, VOCs might be classified into three groups as $I/O < 10$, $10 < I/O < 100$ and $I/O > 100$ (Fig. 4). The detailed bar graphs for each VOC separately for each sampling point can be found in Supporting Material (Fig. S1). For some compounds such as n-nonane, isopropyl benzene and 1,2,4 three methyl benzene, I/O ratios are higher than 100 which indicates very strong sources in some places such as stained glass workshop.

In Fig. 5, I/O ratios were shown separately for each VOC in each sampling point. Although there are some exceptions, I/O ratios of all VOCs follow a similar trend considering sampling points (Fig. 5). Especially in the workshops, I/O ratios are higher compared to the other sampling points. Concentrations of some VOCs such as xylenes, isopropyl benzene, toluene, were measured at higher levels at stained glass workshop. Similarly, benzene derivatives (1,2,4 three methyl benzene, 1,3,5 three methyl benzene, isopropyl benzene), n-nonane and p-ethyl toluene were measured at relatively higher concentrations at painting workshops. The major sources of those VOCs were identified as varnish (toluene, xylenes), paint thinners (isopropyl benzene, xylenes), certain paints and cleaners (1,2,4 three methyl benzene, toluene) and printing pastes, paints, varnishes, solvents (n-nonane) (Borbon et al., 2002; Guo et al., 2004b; Ling et al., 2011; Zhang et al., 2014).

3.3. Health risk assessment

The risk assessment study is important for the determination of chronic exposure to chemicals that may cause cancer or other toxic effects. The lifetime cancer risk (LCR) associated to the benzene exposure was calculated by multiplying the chronic daily intake (CDI) by the IRIS potency factor (IRIS-Integrated Risk Information System) (Colman Lerner et al., 2012). The inhalation exposure estimate was generally derived in terms of chronic daily intake ($\text{mg kg}^{-1} \text{day}^{-1}$) using Eq. (1) within the Superfund program of USEPA (U.S. EPA, 2009). This approach has been used by many researchers for the calculation of health risk (Guo et al., 2004c; Payne-Sturges et al., 2004; Massolo et al., 2010; Colman Lerner et al., 2012; Demirel et al., 2014).

$$\text{CDI}(\text{mg kg}^{-1} \text{day}^{-1}) = (\text{CA} \times \text{IR} \times \text{ET} \times \text{EF} \times \text{ED}) / (\text{BW} \times \text{AT}) \quad (1)$$

In Eq. (1), CA is contaminant concentration in air (mg m^{-3}), IR is inhalation rate ($\text{m}^3 \text{h}^{-1}$), BW is body weight (kg), ET is exposure time (hours day^{-1}), EF is exposure frequency (days year^{-1}), ED is exposure duration (years) and AT is the averaging time (period over which exposure is averaged) (days). LCR was calculated for different indoor environments (offices (office 1 and 2), painting workshops (workshop 1, 2, 3 and 4) and stained glass workshop). Those places were selected for risk calculation because they were occupied by faculty or technical stuff.

Benzene concentrations determined in office 1 ($0.00207 \text{ mg m}^{-3}$) and office 2 ($0.00389 \text{ mg m}^{-3}$) where academicians spend their time were used for LCR calculations. For this target group; ET is 8 h day^{-1} , EF is 220 days year^{-1} , ED is 30 years, AT is 25 550 days for a lifetime risk estimation. In the painting and stained glass

Table 3
Comparison of BTEX measurements carried out in different indoor environments with some literature.

Study	Location	Type of indoor environment	Sampling method	Remarks	Concentrations ($\mu\text{g m}^{-3}$)				
					Toluene	Benzene	Ethylbenzene	m/p-Xylene	o-Xylene
This study	Eskişehir, Turkey	Painting and stained glass workshops	Diffusive sampling for 1 week	14 samples	418.94 ^a /323.2 ^b	2.86 ^a /1.8 ^b	25.01 ^a /23.4 ^b	46.39 ^a /47.1 ^b	26.33 ^a /28.5 ^b
Colman Lerner et al., 2012	Buenos Aires, Argentina	Electromechanical repair and car painting center	Diffusive sampling for 30 days	5 samples	243.1 ^a	59.2 ^a	379.1 ^{a,c}	721.8 ^{a,d}	257.9 ^a
Srivastava et al., 2000	Mumbai, India	Wall being painted with oil-based paint	Active sampling, for 30 min.	1 sample	3480.9	68.7	2049.8	1230.6 ^d	2211.8
Du et al., 2014	Guangzhou, China	Homes with new renovations	Diffusive sampling for 24 h	43 homes	173.2 ^a /129.5 ^b	18.5 ^a /11.6 ^b	—	58.1 ^a /62.8 ^b	40.8 ^a /39.7 ^b

^a Arithmetic mean.

^b Standard deviation.

^c Ethylbenzene + m-Xylene.

^d p-Xylene.

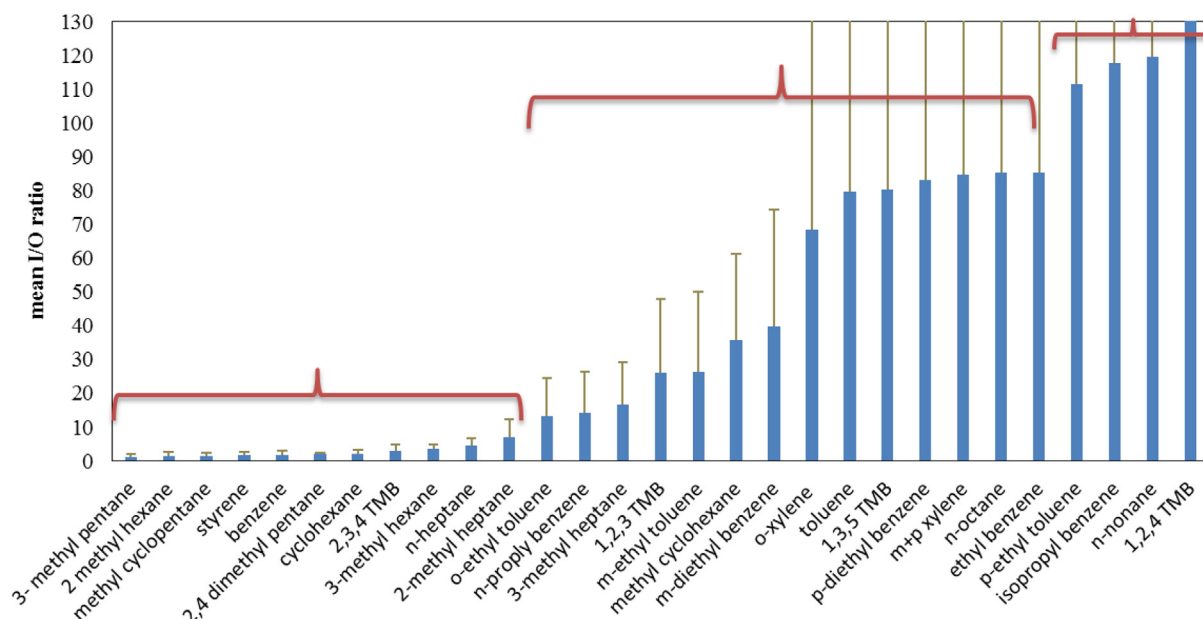


Fig. 4. Average of indoor/outdoor ratios (I/O) obtained for each VOC measured in the different microenvironments of the department.

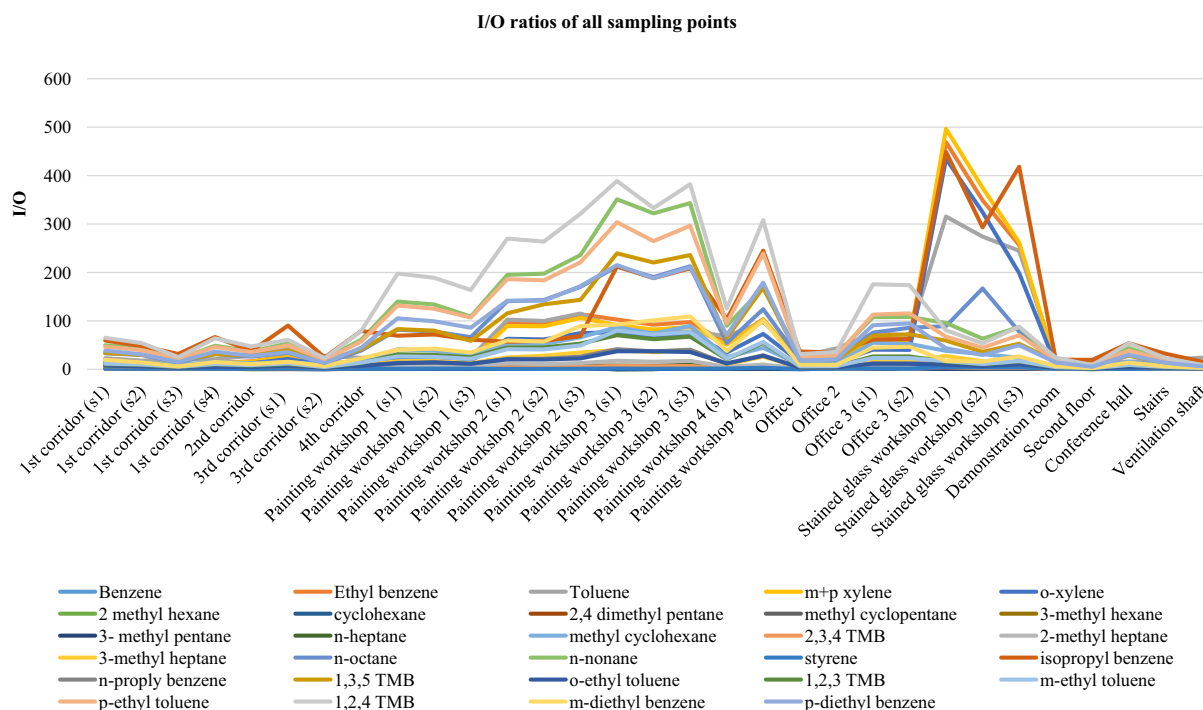


Fig. 5. I/O ratios for each VOC measured in each sampling point in the department.

workshops, LCR was assessed for the students. In Turkey, students get university training during 5 days in a week. It was assumed that they study in the workshops during 6 h in a day in general and have 120 school holidays; in other words, there are 32 weeks per year for courses at the university. Also, students must attend university during 4 years to graduate. So that for the students; ET is 8 h day⁻¹, EF is 160 days year⁻¹, ED is 4 year and averaging AT is 25 550 days. A technician works in the stained glass workshop continuously, so LCR was calculated for the technician for this microenvironment. For the technician, ET is 8 h day⁻¹, EF is 220 days year⁻¹, ED is 20 years and AT is 25 550 days for a lifetime risk estimation. A similar

calculation was also carried out for the risk assessment of academicians for workshops assuming 8 h exposure per day. The USEPA recommends some values for some parameters such as average body weight and amount of air breathed per day for adults and children (U.S. EPA, 2009) to be used in risk estimation calculations. Inhalation rate was taken as 20 m³ day⁻¹ and average body weight was 70 kg for the adults. Chronic daily intake was then multiplied by 0.029 (mg kg⁻¹ day⁻¹)⁻¹ which is the potency factor for benzene to calculate the risk (Demirel et al., 2014). Variables used for the calculation of LCR values for different indoor environments were shown in Table 4.

Table 4

Variables used for the calculation of LCR values.

	CA	IR	ET	EF	ED	BW	AT
1. Painting Workshop (for students)	0.00129	20	6	160	4	70	25 550
2. Painting Workshop (for students)	0.00534	20	6	160	4	70	25 550
3. Painting Workshop (for students)	0.00175	20	6	160	4	70	25 550
4. Painting Workshop (for students)	0.00165	20	6	160	4	70	25 550
1. Painting Workshop (for academicians)	0.00129	20	8	220	30	70	25 550
2. Painting Workshop (for academicians)	0.00534	20	8	220	30	70	25 550
3. Painting Workshop (for academicians)	0.00175	20	8	220	30	70	25 550
4. Painting Workshop (for academicians)	0.00165	20	8	220	30	70	25 550
Office 1 (for academicians)	0.00207	20	8	220	30	70	25 550
Office 2 (for academicians)	0.00389	20	8	220	30	70	25 550
Stained Glass Workshop (for technician)	0.00398	20	8	220	20	70	25 550
Stained Glass Workshop (for students)	0.00398	20	6	160	4	70	25 550
Stained Glass Workshop (for academicians)	0.00398	20	8	220	30	70	25 550

Lifetime cancer risk results were given in Table 5 together with some relevant literature. The cancer risks for people working at offices and stained glass workshop (academicians and technician) were found higher than USEPA acceptable risk value (1×10^{-6}) while lifetime cancer risks for the students were lower than this value. Working people spend approximately 8 h each day in the department. This situation continues until their retirement (at least 20 years). But, the students spend much less time in a day and the number of the years they attend the university is only 4. In this study, the lifetime cancer risks were calculated for working environments using measured indoor concentrations. However, there are other microenvironments such as homes in which people spend their considerable amount of time. Therefore the risk levels calculated here probably underestimate the real health risk of those people.

As seen from Table 5, cancer risks were assessed in different occupational environments such as chemical analysis laboratories, sewing workrooms, electromechanical repair and car painting centers, take away food shops and a photocopy center. In the study of Colman Lerner et al. (2012), risk value calculated for

electromechanical repair and car painting center (1.44×10^{-4}) was found much higher than the other environments. In the study of Demirel et al. (2014), personal exposures of school children to BTEX were measured by using diffusive samplers and cancer and non-cancer risks were estimated by using personal exposure concentrations. The calculated cancer risk values were higher than 1×10^{-6} and also the mean cancer risks especially calculated for the students living in urban areas and with smoking parents were found significantly higher than the others. This results show that many parameters such as characteristics of the living site and smoking are also effective on the cancer risk. In the study of Guo et al. (2004c), the lifetime cancer risks for cooks and foodservice workers, office workers, housewives, and schoolchildren in Hong Kong were assessed. For all target groups of people, the lifetime risks were found higher than 1×10^{-6} .

4. Conclusion

In this study, indoor air quality assessment was carried out in Painting and Printmaking Department of Anadolu University

Table 5

Lifetime cancer risks (LCR) determined for various indoor environments in different studies.

Indoor environment	Lifetime cancer risk	Reference
1. Painting Workshop (for students)	6.69E-08	This study
2. Painting Workshop (for students)	2.77E-07	This study
3. Painting Workshop (for students)	9.08E-08	This study
4. Painting Workshop (for students)	8.56E-08	This study
1. Painting Workshop (for academicians)	9.21E-07	This study
2. Painting Workshop (for academicians)	3.81E-06	This study
3. Painting Workshop (for academicians)	1.25E-06	This study
4. Painting Workshop (for academicians)	1.18E-06	This study
Office 1	1.48E-06	This study
Office 2	2.78E-06	This study
Stained Glass Workshop (for technician)	1.89E-06	This study
Stained Glass Workshop (for students)	2.06E-07	This study
Stained Glass Workshop (for academicians)	2.84E-06	This study
Electromechanical repair and car painting center	1.44 E-04	Colman Lerner et al., 2012
Chemical analysis laboratories	8.17 E-05	Colman Lerner et al., 2012
Take away food shops	<2.37 E-06	Colman Lerner et al., 2012
Photocopy center	<1.29 E-06	Colman Lerner et al., 2012
Sewing work rooms	<2.43 E-06	Colman Lerner et al., 2012
Office	9.32 E-06	Guo et al., 2004b
Printing room	5.83 E-06	Guo et al., 2004b
Chinese Restaurant	4.93 E-05	Guo et al., 2004b
Canteen Restaurant	5.20 E-05	Guo et al., 2004b
Smoker's Home	8.35 E-05	Guo et al., 2004b
Nonsmoker's Home	1.81 E-05	Guo et al., 2004b
School (Sub-urban area)	1.8 E-05	Demirel et al., 2014
School (Urban area)	1.2 E-05	Demirel et al., 2014
Smoker's Home	2.34 E-05	Demirel et al., 2014
Nonsmoker's Home	1.31 E-05	Demirel et al., 2014

Faculty of Fine Arts in Turkey. Concentrations of nitrogen dioxide (NO_2), ozone (O_3) and 29 Volatile Organic Compounds (VOCs) were measured simultaneously by using diffusive samplers.

Different indoor sources were observed for different pollutants. Fire process and smoking were the main sources of NO_2 . Ozone concentrations were quite low since there is no any important indoor source for this compound. Higher VOC concentrations were found in the painting and stained glass workshops where oil-based paint, varnish and adhesives were used. Toluene was determined as the most abundant species among VOCs since very high levels of this compound were measured. Toluene concentrations measured in many sampling points (stained glass workshop, second, third, and fourth painting workshops, and office 3) were higher than the weekly limit value ($260 \mu\text{g m}^{-3}$) determined by WHO for indoor air. However, the highest toluene concentration measured at stained glass workshop (1.2 mg m^{-3}) was much lower than the 8-h occupational exposure limit of time-weighted average (192 mg m^{-3}) established by Ministry of Labour and Social Security (MLSS, 2013).

Results of the health risk assessment study showed that cancer risk levels calculated for the people working in the department (academicians and technicians) were found higher than USEPA acceptable risk value (1×10^{-6}). The cancer risks for the students were below this value since they spend much less time in the department.

This study is a snapshot of a special indoor environment about which little information has been found in the literature. It can be expanded to include personal measurements to investigate exposure of students and stuff more in detail. By this way, exposure concentrations can be correlated with activities carried out in the department to provide much more information about the sources of the pollutants. On the other hand, chemical composition of the materials used during art practices such as thinners, adhesives can be investigated or determined to apportion sources of each VOC.

Conflict of interest

We declare no conflict of interest.

Acknowledgment

The authors thank to Dr. Zeliha Akçaoğlu Tetik (chair of the department) very much for her good care and helps. This study represents the results of a bachelor's degree thesis prepared by Emre Can.

Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.apr.2015.05.008>.

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