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Indoor environmental quality in chemistry and chemical engineering laboratories at Izmir Institute of Technology

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ABSTRACT

Indoor air pollution in university research laboratories may be important to building occupants, especially for those who work in the laboratories. In this study, indoor air quality (IAQ) and indoor environmental comfort were investigated in research laboratories of two departments at a university. $PM_{2.5}$, PM_{10}, TVOC (total volatile organic compounds), and CO concentrations, and three comfort variables which are temperature, relative humidity, and CO_2 were measured. $PM_{2.5}$ concentration was determined gravimetrically by collecting particles on glass fiber filters, whereas the remaining pollutants and comfort variables were measured using a monitoring device. IAQ measurements showed that levels of all pollutants were under the limits in both of the departments except for TVOC in one laboratory which had a mean concentration of 182 ppb. The comfort variables were in the comfort ranges for laboratories in both of the departments except for temperature in one laboratory with a mean value of 30 °C. In conclusion, measures are needed for extensive uses of organic solvents because ventilation may not be sufficient to keep VOC concentrations within the limits, and to provide thermal comfort.

Keywords: *University, laboratory, indoor air quality, comfort*

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1. Introduction

Air quality of indoor environments such as homes, schools, offices, and hospitals draw attention because relatively higher pollutant concentrations in combination with longer time spent indoors can result in higher exposures and associated adverse health effects. In developed parts of the world people spend more than 80% of time indoors, so poor indoor air quality is an important source of exposure that may result in health effects spanning from building related symptoms to chronic–toxic and carcinogenic effects (Jones, 1999). Some of the important indoor air exposure concerns can be listed as particulate matter (PM), volatile organic compounds (VOCs), and carbon monoxide (CO), in addition to comfort variables, such as carbon dioxide (CO_2), temperature, and relative humidity (RH). PM is a significant threat to respiratory system and also causes toxicity depending on the substances present in its structure and the pollutants adsorbed on its surface. A few of the VOCs were reported to be carcinogenic, whereas some of them were reported as mutagenic substances (Maroni et al., 1995). Nonetheless, many VOCs have chronic–toxic effects. VOCs are also a group of substances frequently associated with building related symptoms such as tiredness, irritation (inflammation) of the upper respiratory tract, eyes, and skin, headache, blurred vision, loss of memory, and shortness of breath (Godish, 2000a).

Educational institutions are one of the most studied indoor environments with a focus on kindergartens and primary and high schools, because they house high density populations who are still growing, making them susceptible to the effects of pollution (Norback et al., 1990; Faustman et al., 2000; Adgate et al., 2004; Godwin and Batterman, 2007; Sofuoglu et al., 2011). Universities, however, have not drawn much attention. University buildings such as library and office buildings were studied. Righi et al. (2002) investigated indoor air quality by measuring total volatile organic compounds (TVOC) and dust in four libraries of the University of Modena and Reggio Emilia Northern Italy. Mean total dust concentration was 187 µg/m³ while TVOC concentrations ranged between 203 and 709 µg/m³ which were in the irritation class (Molhave, 1991). Gaidajis and Angelakoglou (2009) conducted a study about indoor $PM_{2.5}$ and PM_{10} concentrations in university classrooms in the Democritus University, School of Engineering, Xanthi, Greece. The average $PM_{2.5}$ and PM_{10} concentrations in the classrooms were between 32–188 µg/m³ and 25–151 µg/m³, respectively.

Laboratories are special micro–environments in school buildings, in which specific pollutant concentrations may be high depending on the nature of the experiments conducted and number of people working (Park et al., 2014). Laboratory workers (technicians, specialists, and teaching/research assistants) during their working life, and students during their university life are exposed to pollutants which may result in acute and chronic–toxic health effects. Although potentially important in terms of number and strength of indoor sources, there are very limited investtigations regarding university laboratories. Park et al. (2014) measured VOC concentrations at the stacks of laboratory fume hoods in a university campus in South Korea. Sum of 11 VOC concentrations was ranged between 85 and 393 μg/m^3, and 9 and 19 μg/m^3 for laboratory and non–laboratory buildings, respectively. The difference may be due to the poorer indoor air quality in the laboratories and/or experiments conducted in the hoods. Valavanidis and Vatista (2006) studied indoor air quality in Department of Chemistry at the University of Athens, Greece, measuring CO, CO_2, TVOC, and total respirable suspended particulate matter (RSP). High median levels were observed in the undergraduate laboratories compared to the research laboratories which reached up to 980 ppm and 3.2 ppm for CO_2 and CO, respectively, in autumn+winter period, whereas up to 8 500 μg/m^3 and 700 μg/m^3 for TVOC and RSP, respectively, in spring+summer period. Rumchev et al. (2003) investigated indoor air quality in 15 university laboratories in Curtin University of Technology, Perth, Western Australia. The pollutants; TVOC, PM_{10}, $PM_{2.5}$, ultrafine particles (UFP, particulate matter <100 nm in diameter) and comfort variables; temperature and RH; were measured during semester and midterm break for four hours in several departments. The highest median concentrations of TVOC (29.9 μg/m^3), UFP (21 694 particles/cm^3), temperature (23.5 °C), and RH (52.5%) were detected in the chemistry laboratory. Although the highest PM_{10} and $PM_{2.5}$ concentrations were measured in the engineering laboratory (27.0 μg/m^3) and biology laboratory (10 μg/m^3), levels in the Chemistry laboratory were comparable. Furthermore, it was concluded that PM_{10}, TVOC, and temperature were higher in laboratories without air conditioning than the ones with air conditioning. It was also stated that all measured parameters during the break were lower than the semester.

The published studies show that university laboratories are important micro–environments. In this study, indoor air quality in three research laboratories each in Departments of Chemistry (Chem) and Chemical Engineering (ChE) at Izmir Institute of Technology, Izmir, Turkey was investigated. Concentrations of CO, CO_2, TVOC, $PM_{2.5}$, and PM_{10} were measured, along with two thermal comfort variables, temperature and relative humidity.

2. Materials and Methods

2.1. Site description

Izmir Institute of Technology is located in Urla near Gulbahce village, 60 km away from Izmir city center, the third largest metropolis in the country. Three laboratories each in Chem and ChE were selected. These were biochemistry, analytical chemistry, and organic chemistry laboratories which were denoted as Lab–1, Lab–2, and Lab–3 in Chem, respectively. Environmental engineering laboratory, a multipurpose laboratory where various types of research studies were conducted, and polymer engineering laboratory were selected and denoted as Lab–1, Lab–2, and Lab–3 in ChE, respectively. ChE laboratories were mechanically ventilated, whereas Chem laboratories were naturally ventilated. Research activities were carried out in all laboratories but with varying intensity. Number of people working in the laboratories ranged from one to six.

Volume of Lab–1 and Lab–3 were comparable (175 m^3 vs 185 m^3), whereas volume of Lab–2 was about two times higher in Chem. Each laboratory has an entrance door and three windows in analytical chemistry and two windows in biochemistry and organic chemistry laboratories that were kept closed during the sampling campaign. Equipment present in the laboratories varied by number and type because different types of research were conducted. Although Lab–3 has a relatively smaller volume, it had the highest number of equipment, while the lowest were in Lab–2. One research assistant was working in each laboratory.

Laboratories of ChE were similar in terms of volume (~275 m^3). Each laboratory has three windows that were kept closed during the sampling campaign. There are two doors to the laboratories; one from the hallway (main entrance) and the other from the staff station. Both of the doors are kept closed except for people coming in and out. Each laboratory is equipped with one ducted fume hood. Hoods were run only if required by the experiment conducted. Type and number of other equipment were different due to differences in areas of research. Lab–3 had the highest number of researchers (six), while Lab–1 was the least frequently used laboratory by one researcher. Additionally, cleaning products used in Lab–2 and Lab–3 were the same as the other parts of the department, Lab–1 was only cleaned with water in order not to influence the performed experiments.

2.2. Sampling and monitoring

Three weekday measurements were performed in each laboratory for 8 hours a day. A sampling system and a monitoring device were used for indoor air quality (IAQ) measurements. The sampling system consisted of a Harvard impactor connected to a sampling pump for collection of $PM_{2.5}$ on 37–mm glass fiber filters. The $PM_{2.5}$ concentration was determined gravimetrically. The filters were kept in 450 °C overnight and conditioned for at least 24 hours in a desiccator prior to weighing. Filters were weighed by a 0.00001 g balance (Sartorius CPA225D) before and after sampling. The monitoring device was Quest EVM–7 which is capable of simultaneously monitoring CO, CO_2, PM_{10}, TVOC, temperature, and RH. The calibration of the device for PM was based on Arizona Street Dust by the manufacturer, so a correction factor was required for reliable results in a specific indoor environment. This correction factor was determined by conducting a preliminary sampling campaign in the ChE laboratories that monitored the PM concentrations and subsequently collected the counted particles on a filter placed into the internal filter holder of the device. Comparison of the mass and counter based concentrations resulted in a factor value of two (Toprak et al., 2013).

Sampling flow rate of the Harvard impactor was calibrated to 20 L/min at the beginning of the each sampling day using Defender 510 calibration device. After sampling, air flow rate was measured again to make sure that the difference in the flow rates in the beginning and at the end was no more than 10%. All samples complied with this criterion.

EVM–7 measures PM_{10} concentrations by a 90° optical light emitting photometer. TVOC concentrations are measured with a photo ionization detector (PID) in ppb units. CO_2 and CO concentrations are measured in ppm units with a non–dispersive infrared sensor (NDIR). At measurement location, EVM–7 was placed above the ground at the breathing zone height in the middle of the laboratory. Concentrations and comfort variable levels were measured at 15 second intervals and reported as 5–min averages.

3. Results

Both indoor air quality and occupational safety guidelines/standards may be used to evaluate the laboratories because they can be considered both as an occupational micro–environment for those who work there and as a general micro–environment for the students. Indoor air quality standards and occupational safety standards from around the world (Table 1) were compiled by Toprak et al. (2013). Because IAQ standards are always less than or equal to occupational standards, comparing with only IAQ standards is sufficient as a first step.

Table 1. *Indoor environmental quality/occupational safety standards*

Indoor Air Quality Parameter	Indoor Air Limit / Guideline	Averaging Time	Source of Indoor Air Limit / Guideline	Occupational Limit	Averaging Time	Source of Occupational Air Limit / Guideline
$PM_{2.5}$ (μg/m^3)	65	24 h	USEPA[a]	5 000	8 h	OSHA[h]
	100	1 h	HC[b]	3 000	8 h	ACGIH[i]
PM_{10} (μg/m^3)	150	24 h	USEPA[a]	10 000	8 h	ACGIH[i]
	100	1 h	HC[b]			
	180	8 h	Hong Kong[c]			
TVOC	261 (ppb)	8 h	Hong Kong[c]			
	600 (μg/m^3)	8 h	Hong Kong[c]			
	300 (μg/m^3)	8 h	Seifert et al., 1999			
CO (ppm)	9	8 h	USEPA[a]	30	8 h	MAK[j]
	11	8 h	HC[b]	25	8 h	ACGIH[i]
	10	8 h	WHO[d]			
	8.7	8 h	Hong Kong[c]			
	15	8 h	Germany[e]			
CO_2 (ppm)	1 000	8 h	Hong Kong[c]	5 000	8 h	OSHA[h], NIOSH[k], ACGIH[i]
				10 000	1 h	MAK[j]
Temperature (°C)	24.5–28	Summer	ASHRAE[f]	23–26	Summer	CSA[l]
	23–25.5	Winter		20–23.5	Winter	
	20–25.5		Hong Kong[c]			
Relative Humidity (%)	30	Summer	ASHRAE[f]			
	60	Winter				
	30–60		Alberta[g]			
	40–70		Hong Kong[c]			

[a]*USEPA, 2000;* [b]*HC, 1995;* [c]*Hong Kong, 2003;* [d]*WHO, 2000;* [e]*Germany, 2006;* [f]*ASHRAE 2004;* [g]*Alberta Infrastructure, 2003;* [h]*OSHA, 2004;* [i]*ACGIH, 2001;* [j]*MAK, 2000;* [k]*NIOSH, 1992;* [l]*CSA, 2005*

3.1. Department of chemistry laboratories

Indoor air quality. Measured concentrations and comfort variable levels in Chem are summarized in Table 2 as 8–h average for each measurement day, 3–day average, median, minimum, maximum, and standard deviation. Additionally, level of risk and related health effects are given for some of the pollutants according to Danish Building Research Institute and Nordtest (Nordic Ventilation Group, 1993) classification (Godish, 2000b).

The highest 3–day average concentration of $PM_{2.5}$ was 26.2 μg/m^3 measured in Lab–3 which was the most actively used one because the research assistant in this laboratory was working more intensively than the others. The lowest concentration was recorded in Lab–1 which was the least actively used one so the $PM_{2.5}$ concentrations were ranked from high to low according to the level of activity in the laboratory. Therefore, it can be speculated that the main source of $PM_{2.5}$ was resuspension of settled dust on the floor by the movement of people working in the laboratory and their activities. The limits by U.S. EPA and HC values listed in Table 1 have averaging times of 24 h and 1 h, respectively, but the measurements in this study were performed for 8–h durations. Since 8–h $PM_{2.5}$ concentrations for all laboratories do not exceed any of the limit values, the concentrations would also meet a limit value with 8–h averaging time.

As in the case of $PM_{2.5}$, the highest 3–day average PM_{10} concentration was measured in Lab–3 as 63.0 μg/m^3. However, the lowest concentration was measured in Lab–2 as 26.1 μg/m^3, so the sampling and monitoring results agree in identifying the highest concentration laboratory, in terms of both $PM_{2.5}$ and PM_{10}. It can be speculated that some other sources, such as outdoor air due to windows being opened or cleaning of the dusty surfaces, may have altered the PM_{10} concentrations in Lab–1 and Lab–2. All measured PM_{10} concentrations were below the listed limits in Table 1.

The highest 3–day average TVOC concentration was measured in Lab–3 as 43.1 ppb. TVOC concentrations of Lab–1 and Lab–2 were similar to each other which are 33.3 ppb and 34.5 ppb, respectively. As these levels were all below 300 μg/m^3, no related complaints or symptoms are expected according to the risk classification, and all measured values were below the listed values (Table 1). Carbon monoxide concentrations were below the detection limit at majority of the time; therefore, it was not included here (Table 2).

Indoor environmental comfort. In all the laboratories, one research assistant was working. During the measurements windows and doors were kept closed except for people coming in and out, and there was not any CO_2 source such as combustion, e.g., a Bunsen burner. The highest 3–day average concentration of CO_2 was recorded in Lab–1 as 514 ppm probably because the laboratory door was closed for long periods of time. Since it is a biochemistry laboratory, organisms used in experiments may also have contributed. The lowest value was 414 ppm measured in Lab–3. The measured concentrations show that natural ventilation is sufficient to prevent CO_2 build–up with one person working. Probably, the fume hoods contribute to exhaust indoor air when they are in operation.

Temperature was also monitored in the laboratories as an indicator of thermal comfort. During measurements in 1st day of Lab–1 and 2nd day of Lab–2 the temperature data were lost and could not be reported here. The highest 8–h average temperature was measured in Lab–3 as 25.8 °C and the lowest one was in Lab–2 as 22.5 °C. Average temperature for all three laboratories were between the given comfort ranges (Table 1) so thermal comfort in terms of temperature for these laboratories was satisfactory. However, there were time periods that corresponds to 41% and 40% of the total monitoring time when 5–min average values were below the lower limit of the comfort range for Lab–1 and Lab–2, respectively.

Table 2. *Indoor air pollutant concentrations and comfort variable levels in Department of Chemistry Laboratories*

Pollutant	Lab No	8–h Average			3–day Average	Median (Min–Max)	Std. Dev.	Health Risk [a]	Effects [a]
		Day 1	Day 2	Day 3					
	1	13.0	9.56	5.31	9.30	9.56 (5.31–13.0)	3.16		
$PM_{2.5}$ (μg/m^3)	2	18.3	17.6	20.2	18.7	18.3 (17.6–20.2)	8.58		
	3	16.8	23.8	38.1	26.2	23.8 (16.8–38.1)	10.4		
	1	43.5	31.9	16.4	30.6	31.2 (8.70–79.5)	15.2		
PM_{10} (μg/m^3)	2	11.0	36.9	30.5	26.1	30.4 (5.00–62.4)	13.0		
	3	36.9	41.7	110	63.0	41.8 (14.6–328)	31.5		
	1	53.2	25.3	21.4	33.3	22.6 (0.00–78.3)	14.1	No [b]	
TVOC (ppb)	2	19.8	52.5	31.3	34.5	29.8 (0.00–82.2)	13.5	No [b]	SBS
	3	26.5	47.5	55.2	43.1	24.5 (0.00–938)	12.1	No [b]	
	1	473	561	506	514	503 (401–725)	36.4	Low	
CO_2 (ppm)	2	459	467	461	463	462 (409–544)	3.60	Low	Stale air
	3	440	414	388	413	415 (364–471)	21.3	Low	
	1		23.1	23.0	23.0	22.9 (21.5–24.6)	0.05	Medium	
T (°C)	2	25.1		22.5	23.8	25.2 (22.8–26.3)	1.32	Medium	Draft, cold, hot, dryness, SBS[c]
	3	24.2	25.1	25.8	25.0	25.2 (22.7–27.1)	0.66	High	
	1		34.9	35.8	35.3	35.6 (34.1–46.1)	0.48		
RH (%)	2	37.5		40.6	39.1	40.4 (36.0–46.1)	1.56		
	3	40.7	45.7	47.9	44.8	45.6 (37.7–51.5)	2.98		

[a] Nordic Ventilation Group (1993), [b] Seifert et al. (1999), [c] Sick Building Syndrome

RH was measured as another parameter that indicates thermal comfort. RH reached the highest 8–h average value in Lab–3 (47.9%) and the lowest average value was in Lab–1 (34.9%). All of the measured values fall in the comfort ranges (Table 1).

3.2. Department of chemical engineering laboratories

Indoor air quality. Measured concentrations in ChE laboratories are summarized in Table 3 as 8–h average for each measurement day, 3–day averages, median, minimum, maximum, and standard deviation. The highest 3–day average concentration of $PM_{2.5}$ (19.4 μg/m^3) was measured in Lab–3 which was the most actively used one. The lowest concentration was recorded in Lab–1 (7.64 μg/m^3) which was the least actively used one, which indicates that occupants and their activities and motion in the laboratory impacts the $PM_{2.5}$ levels. The measured values in three laboratories did not exceed the standards (Table 1).

The highest 3–day average PM_{10} concentration was measured in Lab–3 as 48.3 μg/m^3 and the lowest PM_{10} concentration was measured in Lab–1 as 12.5 μg/m^3 so the results of measurements were consistent in identifying both the highest and the lowest concentration laboratory, in terms of $PM_{2.5}$ and PM_{10}. Concentrations of PM_{10} in all three laboratories were below the limits (Table 1).

The highest 3–day average TVOC concentration was measured in Lab–3 as 182 ppb due to the two high concentration days in which solvents were used. TVOC concentrations of Lab–1 and Lab–2 are 13.8 ppb and 20.3 ppb, respectively. Limit value of TVOC for indoor air quality is 261 ppb for Hong Kong good class. Another value recommended by Seifert et al. (1999) as 300 μg/m^3 (which can be approximated as 130.5 ppb when conversion factor of Hong Kong in Table 1 is used). TVOC concentration in Lab–3 was above both levels by Seifert et al. (1999) and the Hong Kong limit. All CO concentrations measured in the laboratories were very low so resulting in 3–day averages <1 ppm below all guideline values listed in Table 1.

Indoor environmental comfort. All measured 5–min average CO_2 concentrations were <650 ppm resulting in 8–h averages of <450 ppm, which shows that mechanical ventilation was working well in the laboratories. The measurements were performed on May 2013, and temperature was varied between 21.0 and 32.0 °C during the 8–h sampling periods since air is not conditioned by the ventilation system. The highest 3–day average temperature was measured in Lab–2 as 30.0 °C, while the lowest one was measured in Lab–3 as 26.0 °C. The comfort ranges given by ASHRAE and CSA for summer is 24.5–28.0 °C and 23.0–26.0 °C, respectively (Table 1). Three–day average value of Lab–2 was above the upper limit of both of the ranges but Lab–1 and Lab–3 were in the comfort range by ASHRAE. Additionally, 8–h average temperatures of Lab–2 for all three days were above the upper limits. Forty nine percent and 97% of the 5–min average values of the total monitoring time were above the upper limits of the comfort range for Lab–1 and Lab–2, respectively. RH reached the highest 3–day average value in Lab–3 (46.0%) and the lowest average value was measured in Lab–2 (39.0%). Average RH values for all three laboratories were in the comfort zone of 30–60%.

4. Discussion

In this section, pollutant concentrations and indoor environmental comfort variables measured in Chem and ChE laboratories are compared to each other and to the literature. In this case, 3–day average values with ±standard deviation for each pollutant were used to facilitate the comparisons (Figure 1). The most stringent standard level (SSL) is also shown for each pollutant.

Figure 1a compares the concentrations measured in laboratories of the two departments in terms of $PM_{2.5}$, in which all concentrations were below the standard. Although $PM_{2.5}$ concentrations in the Chem laboratories were higher, in general, they are not as large to stand out. The median $PM_{2.5}$ concentrations that ranged between 8 and 10 μg/m^3 among different laboratories at Curtin University of Technology are comparable to the concentrations measured at in the present study (median range: 4.17–23.8 μg/m^3).

Table 3. *Indoor air pollutant concentrations and comfort variable levels in Chemical Engineering Laboratories*

Pollutant	Lab No	8–h Average			3–day Average	Median (Min–Max)	Std. Dev.	Health Risk [a]	Effects [a]
		Day1	Day 2	Day 3					
$PM_{2.5}$ (µg/m^3)	1	4.17	1.04	17.7	7.64	4.17 (1.04–17.7)	8.86		
	2	9.38	15.6	6.30	10.4	9.38 (6.30–15.6)	4.77		
	3	17.7	25.0	15.6	19.4	17.7 (15.6–25.0)	4.92		
PM_{10} (µg/m^3)	1	15.2	6.25	15.9	12.5	9.43 (2.35–39.0)	8.24		
	2	18.0	20.5	4.63	14.4	14.6 (1.35–47.1)	9.06		
	3	17.8	86.8	40.2	48.3	32.2 (6.10–206)	39.2		
TVOC (ppb)	1	8.38	20.8	12.0	13.8	14.1 (2.80–63.5)	7.55	No [b]	SBS
	2	12.3	22.2	26.3	20.3	13.8 (6.40–76.6)	15.3	No [b]	
	3	42.5	206	297	182	103 (3.70–2 379)	105.3	No [b]	
CO (ppm)	1	1.00	1.00	0.98	0.99	1.00 (0.60–1.05)	0.03	No	General symptoms
	2	0.51	1.00	0.44	0.65	0.95 (0.00–1.95)	0.50	No	
	3	0.01	0.00	0.22	0.08	0.00 (0.00–1.00)	0.24	No	
CO_2 (ppm)	1	390	459	391	413	398 (356–608)	42.0	Low	Stale air
	2	425	381	401	402	406 (316–622)	41.7	Low	
	3	398	434	396	410	411 (343–536)	35.0	Low	
T (°C)	1	27.0	28.0	29.0	28.0	28.0 (24.0–30.0)	1.00	High	Draft, cold, hot, dryness, SBS[c]
	2	30.0	30.0	29.0	30.0	30.0 (27.0–32.0)	1.00	High	
	3	26.0	25.0	27.0	26.0	26.0 (21.0–28.0)	1.00	High	
RH %	1	41.0	41.0	38.0	40.0	40.0 (37.0–47.0)	2.00		
	2	42.0	40.0	34.0	39.0	39.0 (30.0–49.0)	4.00		
	3	41.0	50.0	47.0	46.0	48.0 (35.0–53.0)	5.00		

[a] Nordic Ventilation Group (1993), [b] Seifert et al. (1999), [c] Sick Building Syndrome

Figure 1b shows that the highest concentrations of PM_{10} were measured in Lab–3 in both of the departments. There is no PM_{10} concentration above the U.S. EPA standard, and in general, PM_{10} concentrations in Chem were higher but not as much to stand out. Higher PM concentrations in Chem compared to ChE laboratories may be reasoned with the possible higher transport of particles from outdoors with natural ventilation. The difference between the two department laboratories for $PM_{2.5}$ is more pronounced than for PM_{10}, which may be due to the difference in ventilation as filters of the ventilation system protecting the indoors from the generally outdoor sourced $PM_{2.5}$, whereas PM_{10} is of more indoor originated as the resuspension of the floor dust (Almeida et al., 2011). The average $PM_{2.5}$ to PM_{10} ratio for the laboratories of ChE (0.58±0.16) and Chem (0.48±0.21) were not considerably different pointing that the source of the PM probably is the same. The overall average ratio (0.53±0.18) is in the range reported for the urban background sites in European cities (Querol et al., 2004) as the study site is considered as a background site located about 60 km out of the City of Izmir. Lower $PM_{2.5}/PM_{10}$ ratio values (0.40 and 0.42) in the relatively higher concentration laboratories of the two departments than those (0.72, 0.72, and 0.61) of the lower concentration laboratories, supports the finding that the source of the higher concentrations are probably related to the intensity of the use of the laboratory.

The measured concentrations in this study are comparable to those measured by Rumchev et al. (2003) at the Curtin University of Technology (median concentration ranging from 17 to 27 µg/m^3) but much lower than the total RSP measured in University of Athens (median concentration of 700 µg/m^3 in the undergraduate laboratories in spring+summer) by Valavanidis and Vatista (2006) probably because laboratories had natural ventilation during summer and university building is located to an area where there is a soil dust problem due to low vegetation.

TVOC concentration in Lab–3 of ChE does not only have a very high value than the concentrations of the other laboratories in both ChE and Chem, but also it is greater than the recommended limit by Seifert et al. (1999) (Figure 1c). The other laboratories have similar TVOC concentrations, and all are below the standard value. Sum of 11 VOC compounds in the stack gases of laboratory buildings (Park et al., 2014) was in the range of 85 to 393 µg/m^3 (37 ppb–171 ppb). Except for the mean TVOC concentration of ChE Lab–3 (182.0 ppb), all concentrations measured in this study were lower than the reported range. This is probably because the given range was determined from the stack gases of a building with four laboratories, which includes gases from experiments in the hoods. The median TVOC concentrations in the undergraduate and research laboratories were recorded as 8 500 µg/m^3 (3 697 ppb) and 6 800 µg/m^3 (2 958 ppb) in spring+summer at University of Athens. When these data are compared with the data obtained from the Chem and ChE laboratories in this study, it can be concluded that 3–day average and median concentrations of TVOC were less than concentrations measured in the undergraduate and research laboratories in Athens, while they are higher than those measured in Perth (Rumchev et al., 2003).

CO concentrations were generally not detectable in the laboratories of Chem, whereas they were all <1 ppm in ChE laboratories, which were all below the U.S. EPA standard of 9 ppm. In the study of Valavanidis and Vatista (2006), median CO concentration in the undergraduate laboratories was recorded as 2.8 ppm in spring+summer. Median CO concentrations in the research laboratories were recorded as 2.3 ppm for spring+summer.

Similar CO_2 concentrations were observed among the ChE laboratories (Figure 1d). However, higher concentrations were measured in Lab–1 and Lab–2 of Chem probably because mechanical ventilation was more effective than natural ventilation. Valavanidis and Vatista (2006) stated that median CO_2 concentrations in the undergraduate and graduate laboratories were recorded as 840 ppm and 570 ppm for spring+summer. These concentrations are higher than the 3–day average and median concentrations measured in this study.

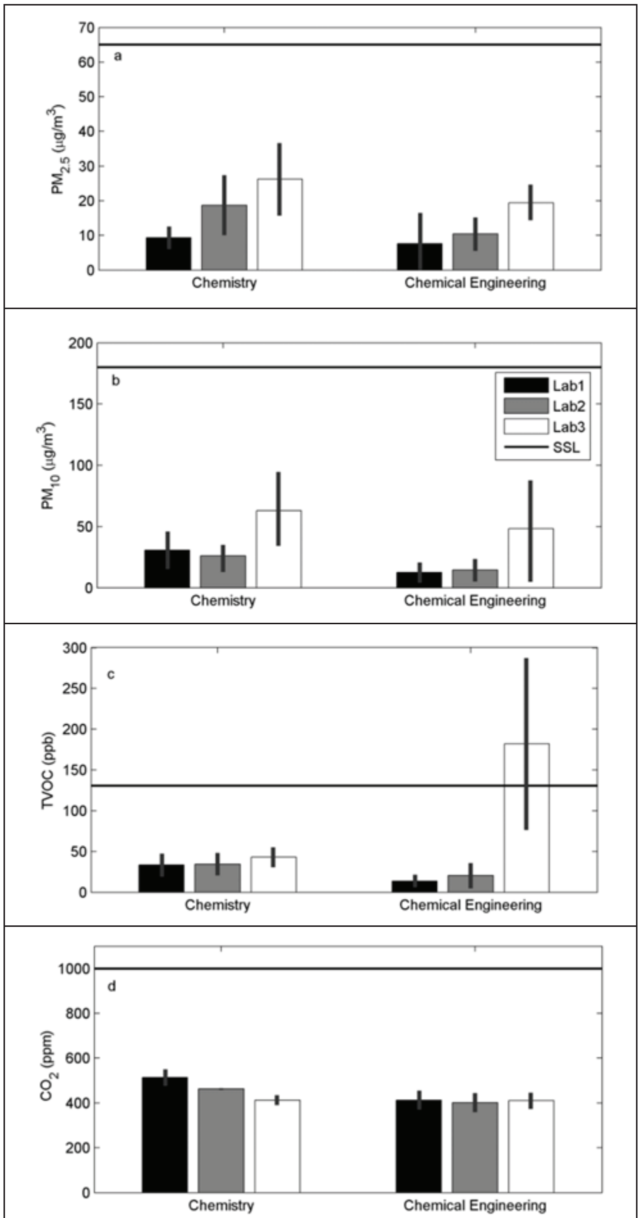

Figure 1. *Comparison of indoor air pollutant concentrations at Chem and ChE laboratories:* ***(a)*** *$PM_{2.5}$,* ***(b)*** *PM_{10},* ***(c)*** *TVOC,* ***(d)*** *CO (SSL: the most stringent standard level).*

5. Conclusions

Various indoor air pollutants with varying concentrations were detected in the laboratories of the two departments at Izmir Institute of Technology. Laboratory staff is exposed to these pollutants during their working life. University students are also exposed to the pollutants during their university education. Higher PM_{10} and $PM_{2.5}$ concentrations were observed in the more intensively used laboratories. However, both 8–h and 3–day averages of PM_{10} and $PM_{2.5}$ for both of the departments were lower than the respective limits. Eight–hour and 3–day average TVOC, CO_2, and CO concentrations also did not exceed the respective limits except for one laboratory for TVOC, hinting that ventilation in both of the buildings was generally satisfactory to avoid build–up. Thermal comfort variables (temperature and RH) were in the comfort zone for all laboratories in the Department of Chemistry. All three laboratories of Chemical Engineering were in the comfort zone in terms of RH (30–60%) but temperature in one laboratory exceeded the upper limit for summer (28 °C). The indoor air pollutant concentrations observed in the laboratories of the two departments were similar. The measured concentrations were comparable to those measured in university laboratories in Australia, Greece, and Korea. The results suggest that while the ventilation systems were able to prevent any CO_2 build–up, they may not be adequate to prevent VOC concentrations reaching considerably high levels depending on the experiments conducted/chemicals used. In addition, air conditioning is needed to provide thermal comfort.

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