Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Indoor environmental quality in the university laboratories

Üniversite laboratuvarlarında iç ortam çevre kalitesi

Burcu ONAT[1*], *Gonca YAŞAR*[1], *Burcu UZUN*[1], *Coşkun AYVAZ*[1], *Ülkü ALVER ŞAHİN*[1]

[1]Department of Environmental Engineering, Faculty of Engineering, Istanbul University-Cerrahpaşa, İstanbul, Turkey.
bonat@iuc.edu.tr, goncayasar@gmail.com, burcu.uzun@ogr.iuc.edu.tr , coskunayvaz@iuc.edu.tr, ulkualver@iuc.edu.tr

Received/Geliş Tarihi: 11.04.2022 Revision/Düzeltme Tarihi: 20.10.2022 doi: 10.5505/pajes.2022.37941
Accepted/Kabul Tarihi: 18.11.2022 Research Article/Araştırma Makalesi

Abstract

This study presents the indoor environmental quality in the university laboratories which are used for different purposes. Within this aim, thermal comfort parameters (temperature, relative humidity, air speed, lighting), carbon dioxide (CO_2) were monitored and respirable particles (PM_4, smaller than 4 µm) were collected on the quartz filter in five laboratories for 8 hours. The mass concentration of the dust collected on filter were determined, after that the filters were decomposed, and elemental analysis were performed for Cd, Cr, Co, Cu, Ni, Mn and Pb elements using by Graphite Atomic Absorption Spectrophotometer. It was determined that the 8-hour average PM_4 concentrations varied between 57.0-186.3 µg/m^3, the highest average PM_4 concentration was observed in Lab C where pyrolyze and solid waste combustion activities were performed. It was observed that the average 8-hour CO_2 concentrations varied between 484-666 ppm and during the laboratory lesson, CO_2 concentration raised to 2000 ppm in Lab B and exceeded the limit value of 1000 ppm. The 8-hour average temperature, relative humidity, lighting, and air velocity in all laboratories changed between 22.0-24.0 ^{0}C, 21.8-41.2%, 156-415 Lux and 0.05-0.10 m/s, respectively. We observed that lighting level in the laboratories did not comply with the standard (500-750 Lux). Opening of windows or door might be prevent increasing of CO_2 during laboratory lesson with high occupancy. The lighting system in all laboratories should be improved. We also recommend that using of hood exhaust fan system to increase ventilation rates and filtration of particles.

Keywords: Indoor air, University laboratory, Respirable particles, Comfort parameters.

Öz

Bu çalışmada, farklı amaçlar için kullanılan üniversite laboratuvarlarında iç ortam çevre kalitesi belirlenmiştir. Bu kapsamda, 5 farklı laboratuvarda 8 saat süreyle termal konfor (sıcaklık, rölatif nem, hava hızı, aydınlatma) ve karbon dioksit (CO_2) parametreleri ölçülmüş, quartz filtrelere solunabilir partikül (PM_4, 4 mikrondan küçük partiküller) örneklemesi yapılmıştır. Filtrede örneklenen tozun kütlesel konsantrasyonları belirlenmiş, daha sonra filtrelere ayrıştırma işlemi uygulanmış ve Grafit Atomik Absorpsiyon Spektrometresi ile Cd, Cr, Co, Cu, Ni, Mn ve Pb elementlerinin konsantrasyonları tespit edilmiştir. 8-saatlik ortalama PM_4 konsantrasyonlarının 57.0-186.3 µg/m^3 aralığında değiştiği belirlenmiş ve en yüksek ortalama konsantrasyon piroliz ve katı atık yakma faaliyetlerinin yapıldığı Lab C'de gözlenmiştir. 8-saatlik ortalama CO_2 konsantrasyonlarının 484-666 ppm arasında değiştiği, laboratuvar dersi sırasında CO_2 konsantrasyonunun Lab B'de 2000 ppm'e ulaştığı ve limit değeri (1000 ppm) aştığı gözlenmiştir. Laboratuvarlarda 8-saatlik ortalama sıcaklık, rölatif nem, aydınlatma ve hava hızı'nın sırasıyla 22.0-24.0 °C, 21.8-41.2 %, 156-415 Lux ve 0.05-0.10 m/s arasında değiştiği görülmüştür. Tüm laboratuvarlarda aydınlatma seviyelerinin standart ile uyumlu olmadığı görülmüştür (500-750 Lux). Katılımın yüksek olduğu laboratuvar derslerinde pencere veya kapıların açılması CO_2 artışını engelleyebilir. Tüm laboratuvarlardaki aydınlatma sistemi iyileştirilmelidir. Havalandırma oranlarını ve partiküllerin filtrasyonunu artırmak için davlumbaz egzoz fan sisteminin kullanılması da tavsiye edilebilir.

Anahtar kelimeler: İç ortam havası, Üniversite laboratuvarı, Solunabilir partiküller, Konfor parametreleri.

1 Introduction

People spend most of their times (more than 80% on weekend days and more than 85% on workdays) indoors [1]. Indoor Air Quality (IAQ) refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants [2]. IAQ is affected by several actions such as ventilation, human activity, use of indoor materials and chemicals [3]-[8]. Common indoor pollutants are volatile organic carbons (VOCs), formaldehyde (HCOH), nitrogen dioxide (NO_2), polycyclic aromatic hydrocarbons (PAH), radon, bacteria, fungi and mould [9], [10]. Carbon monoxide (CO), carbon dioxide (CO_2), pesticides, VOCs, dust, fine particulate matter ($PM_{2.5}$), lead (Pb) are important air pollutants in especially commercial and institutional buildings [11],[12]. Comfort parameters such as temperature, relative humidity and air velocity are also investigated in various indoor environments [13],[14].

Sick building syndrome (SBS) is defined as complaining of the symptoms (headache, dizziness, eye, nose, or throat irritation; dry cough; dry or itchy skin etc.) associated with acute discomfort [15]-[18]. The reason of SBS can be a poor IAQ. The indoor of the university laboratories which are used by students and researchers during lessons and experimental studies are areas that should be taken into consideration. The species and concentrations of indoor air pollutants vary according to the characteristics of the laboratories [19]-[22]. In some studies, the indoor air pollutants such as total VOC, HCHO, particulate matters ($PM_{2.5}$, PM_{10}, PM_1) and thermal comfort parameters (air and radiant temperatures, relative humidity, lighting, air velocity) in the laboratories were investigated [14],[22],[23]-[27] and SBS symptoms such as watery/dry eyes, fatigue, dry throat, drowsiness, nasal congestion, headache and itching were detected [20],[28]. The effect of ventilation rate, air cleaners and number of occupancies to IAQ were investigated in other studies [6],[29].

Recently, the importance of CO_2 in the indoor environment has been emphasized in some studies. During respiration, CO_2 and

*Corresponding author/Yazışılan Yazar

bioaerosols which contain viruses are emitted into air and accumulated [30],[31]. Occupants are the main source of CO_2 in the indoor [32],[33] and CO_2 is correlated with the occupancy in the indoor spaces [27]. The ventilation and activity [34],[35] and the size of the indoor spaces [27] effects the CO_2 concentration.

Recently, some studies conducted on the determination of the trace metals of airborne particles in the laboratories [6],[36]. The high concentrations of Ba, Cd, Cu, Ni and Zn were observed indoor air of the university laboratories [36]. Ardashiri and Hashemi [37] evidenced that the heavy metal concentrations in the laboratory was higher than the concentrations at home, classroom, and office. There have been many studies on respirable particulate matter in different indoor environments conducted in Turkey [38]-[43] nevertheless, a few studies [23] were performed at the university laboratories. [23] investigated air quality parameters ($PM_{2.5}$, PM_{10}, TVOC, CO_2 and CO) and relative humidity and temperature as thermal comfort parameters in Chemistry and Chemical Engineering laboratories at the university in Izmir and they found that the ventilation system was able to curb CO_2 boost. However, it was not sufficient to prevent VOC increments.

The limit values for respirable particles are available in the national and international occupational regulations for the workplace environments [12],[44]. The size of respirable particle (PM_4, particles smaller than 4 micrometer) is defined as the mass fraction of inhaled particles penetrating to the unciliated airways, that's why respirable particles is more related to the health compared to inhalable particles [45]. Both researchers and students spend most of their time at the laboratories. It is crucial to investigate the sources of indoor air pollutants at the university laboratories, to determine the health risks, to provide data for improving the indoor environments and to develop effective control strategies to effectively decrease these emissions.

The main purpose of this study was to determine the indoor air quality and thermal comfort parameters in the laboratories, to investigate the elemental content of respirable particulate matter at the university laboratories. Within this scope, the monitoring and sampling campaign were conducted at the university in the Environmental Engineering laboratories used for different purposes. The measurement campaign comprised PM_4 sampling, CO_2 and thermal comfort parameters (relative humidity, temperature, air velocity, lighting) monitoring and investigating of potentially toxic elements (Mn, Cr, Pb, Ni, Cu, Co, and Cd) in PM_4.

2 Methodology

2.1 Study location

This study was performed in the Avcılar Campus of Istanbul University-Cerrahpaşa. Avcılar Campus is in the district of Avcılar which has dense residential and traffic emissions. The campus is near the D-100 highway. The monitoring study was conducted in five laboratories of Environmental Engineering Department which is in the building of the Engineering Faculty. The distance of the faculty building to the highway is approximately 200 m. The Environmental Engineering laboratories were used for multipurpose; Lab A was used more actively by researchers for various research studies while Lab B was mostly used for laboratory class. Lab C, Lab D and Lab E were used for more specific analysis as solid waste, water analysis and elemental analysis, respectively. Figure 1 shows the sampling points in the laboratories.

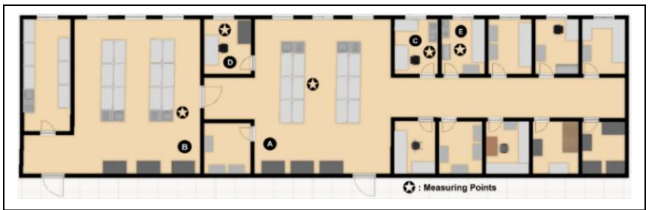

Figure 1. Location of laboratories and sampling points: (a): Lab A. (b): Lab B. (c): Lab C. (d): Lab D. (e): Lab E.

The measurements were conducted during cold season, we had no control over windows and ventilation. It was observed that the ventilation was done with opening windows for a period of 30-60 minutes during day in Lab A and Lab B. The doors were kept closed except for people coming in and out. The cleaning of the laboratories was done once a week by wiping with water only. The details of the laboratories were given in Table 1.

2.2 Monitoring and sampling

The first and second semester of an academic year in Turkey generally begins in October and February, while the summer vacation is between July and September. In this study, sampling was performed between February 2016 to March 2016.

Table 1. Characteristics of laboratories.

Laboratory	Activity	Number of windows	Number of people	Number of doors	Volume (m^3)	Ventilation	Front
A	Environmental chemistry laboratory-1	5	3-5	2 (opening to building corridor and Lab B)	100	Natural	North
B	Environmental chemistry laboratory-2	5	1-2 (up to 60 during lab class)	2 (opening to building corridor and Lab A)	120	Natural	North
C	Pyrolyze/solid waste	1	1-3	1 (opening to Lab A)	15	Natural ventilation aided with propeller fan	North
D	Water analysis	3	1-5	1 (opening to Lab A)	18	Natural	North
E	Elemental analysis	3	1-2	1 (opening to Lab A)	15	Natural ventilation aided with propeller fan	North

At each laboratory, one location was chosen for sampling and measurement. The equipment was placed at breathing height. Thermal comfort parameters (relative humidity (RH), temperature (T), lighting and air velocity) and indoor air quality (IAQ) parameter (CO_2) were monitored (Testo 480) at five laboratories and measured by time interval was 10 second. The respirable particles, PM_4 was sampled on quartz filter with plastic cyclone sampler at each laboratory. The flow rate was 1.7 L/min of the pump (Thermo pDR 1200 pump). PM4 sampling was done on the same filter for 3 consecutive days for collecting enough dust. All measurement campaign was done between 9:00-17:00 hours. In this study, the indoor-outdoor measurements could not be performed simultaneously because of the lack of sampler. However, on the days of indoor measurements, outdoor CO_2, T and RH measurements were conducted three times a day (morning, noon, evening) for 15 minutes with the same monitor.

2.3 Elemental analysis

The dust filters were decomposed with a microwave oven with using a solution of mixing of HNO_3 (5mL, 65%), HCl (1 mL, 30%), and hydrogen fluoride (0.5 mL). After decomposing process, sample was diluted with distilled to 15 ml with water and stored in the cooler at -4 °C until elemental analysis. To clarify the digestion process and analytical set up, SRM 1648 (urban particulate matter) and standard solution (Merck) were utilized and applied recovery procedure. The recovery of metals was between 90 and 105%. Cd, Cu, Co, Cr, Ni, Mn and Pb were analysed in samples using by graphite atomic absorption spectrophotometer (Perkin Elmer, USA). Three readings were done on each sample (measurement repeatability <2%). Calibration curve was obtained using five standard solutions (R^2>0.99) [43],[46].

2.4 Statistical analysis

The 8-h mean concentrations were calculated from 10-second readings recorded by measurement device. The variability of CO_2, temperature, humidity, lighting, and air velocity parameters among laboratories were analysed using the Anova, Tukey multiple comparison test. SPSS 20 program was used to compute the statistical parameters.

3 Results and discussion

3.1 Indoor air quality and environmental comfort

The 8-hour average, standard deviation, median, minimum, and maximum concentration results of the parameters recorded in five laboratories were displayed in Table 2.

Table 2. Concentration of indoor air quality and environmental comfort parameters and standards.

	Lab	N	8-hour average (± Std. dev)	Median	Min.	Max.	Median	Indoor air limit / source	Occupational air limit / source
			Indoor				Outdoor		
PM_4 (µg/m^3)	A	9	129.1 (35.1)	129	94	164.2		100 / (PM_{10}, 8 hour), Hong Kong[a] 45/(PM_{10}, 24 hour), WHO[h], 50 / (PM_{10}, 24 hour), Turkey[i]	5000 / (PM_5, 8 h) Turkey[b]; (PM_4, 8 h) OSHA[e]
	B	9	90.3 (13.3)	87	79	105			
	C	9	186.3 (13.5)	190	49	320			
	D	9	123.7 (56.0)	125	67	179			
	E	6	57.0 (12.5)	56	45	70			
CO_2 (ppm)	A	11	484 (59)	467	401	722	415	1000 / Hong Kong[a]	5000 (8 h) / OSHA[e], NIOSH[f], ACGIH[g]
	B	11	635 (361)	470	366	2168	425		
	C	9	577 (111)	577	376	1094	436		
	D	9	666 (139)	664	411	1123	454		
	E	3	540 (64)	549	381	755			
T (^{0}C)	A	11	22.0 (1.8)	21.7	13.9	25.5	12.5	20-25.5 / Hong Kong[a] 20-24/ ASHRAE[c]	
	B	11	22.3 (2.4)	22.8	9.5	26.1	10.5		
	C	9	23.3 (1.8)	23.4	14.4	26.0	13.5		
	D	9	23.3 (1.0)	23.3	17.5	25.1	17.3		
	E	3	24.0 (2.0)	23.9	12.8	26.4			
RH (%)	A	11	34.4 (4.7)	35.0	24.0	57.7	57.3	30-60 ASHRAE[c]	
	B	11	31.6 (8.1)	31.0	19.2	51.3	52.4		
	C	9	36.9 (3.9)	36.5	29.1	61.0	64.0		
	D	9	41.2 (4.1)	41.2	32.5	67.7	55.7		
	E	3	21.8 (2.7)	21.5	18.7	43.6			
Lighting (Lux)	A	11	415 (35)	417	287	498		500-750 lux / IESNA[d] (for laboratory classroom)	
	B	11	295 (146)	346	12	526			
	C	9	215 (89)	218	15	1571			
	D	9	261 (106)	249	68	758			
	E	3	156 (85)	180	12	873			
Air velocity (m/s)	A	11	0.06 (0.03)	0.05	0.01	0.62		< 0.3 /Hong Kong[a] < 0.2/ ISO 17772, EN 15251 <0.1 /ASHRAE 55, EN 16798	< 0.8 / ASHRAE[c]
	B	11	0.05 (0.03)	0.05	0.01	0.46			
	C	9	0.10 (0.06)	0.09	0.01	0.44			
	D	9	0.05 (0.03)	0.04	0.01	0.36			
	E	3	0.07 (0.04)	0.05	0.01	0.41			

N: Number of measurement day/sampling day; [a]: Hong Kong, 2019 [56]; [b]:Turkey, ÇSGB, 2013 [44]; [c]: ASHRAE, 2013 [54]; [d]: IESNA, 2000 [57]; [e]: OSHA, 2015 [12]; [f]: NIOSH, 1998 [58]; [g]: ACGIH, 2001 [59]; [h]: WHO, 2021 [10]; [i]: Turkey, Outdoor air quality standard [60].

In the university laboratories, there are occupants such as researcher, technicians, and students. Therefore, occupational safety guidelines and indoor air quality standards can be used to appraise the laboratory indoor air quality and exposure of people [23]. The limit values and recommended values of the occupational and indoor air standards for the measured parameters were also given in Table 2. The highest average PM_4 concentration was observed in Lab C (186.3 µg/m^3). The activities such as pyrolyze and solid waste combustion in Lab C could be the probable reason of the high particulate matter concentration. The lowest average PM_4 concentration (57 µg/m^3) was found in Lab E where only metal analysis was performed. The second highest average PM_4 concentration (129.1 µg/m^3) was observed in Lab A which was used actively by research assistants and graduate students. Previous studies showed that PM indoor concentration are contributed by resuspension of deposited PM because of occupant's movements [47],[48]. PM_4 concentration in Lab B was lower (90.3 µg/m^3) than the concentration in Lab A. Lab A and Lab B have similar features like the size and the number of windows, however, there was no routine work carried out in the Lab B, except on the days of the laboratory lesson. All PM_4 concentration results were below the occupational limit (5000 µg/m^3) listed in Table 2. Indoor air limit is available for PM_{10} given as 100 µg/m^3 by Hong Kong indoor air standards, although not the same particle size, we found that PM_4 concentration in Lab C was above this limit. It should be noted that all PM_4 results in this study were above the limit value recommended by WHO (45 µg/m^3) for PM_{10}. Most of previous studies investigated $PM_{2.5}$ and PM_{10} parameters in laboratories [23],[27],[48]-[50]. In Turkey, [23] reported that $PM_{2.5}$ and PM_{10} concentrations in naturally ventilated laboratories changed between 9.3-26.2 µg/m^3 and 26.1-60.0 µg/m^3, respectively. In Delhi, [48] found that the highest PM_{10} and $PM_{2.5}$ were in chemical laboratory and reported that the coarse particles were highly affected by indoor activity and other cleaning activities. Although the size of PM is not the similar, we observed that the results in this study were higher than PM_{10} results reported in the previous studies. The variable factors such as the number of occupants [27], type of activities [48], location of the building, outdoor air quality [14] and the frequency of cleaning facility [48] can affect PM in the laboratories.

The 8-hour average CO_2 concentrations in five laboratories changed between 484 ppm and 666 ppm. The highest 8-hour average CO_2 concentration was observed in Lab D. Ugranlı et al. [23] reported that 8-hour average CO_2 concentration in naturally ventilated chemistry laboratories was between 412 ppm and 514 ppm.

Some studies evidenced that CO_2 in different indoor environments were variable; in pharmacy laboratory in Malesia [32] was between 400-700 ppm, and in the university classrooms in Brazil [51] was between 520-1433 ppm. In the university laboratory in India was between 684-701 ppm. The major factor of CO_2 variation was the number of occupants present [26].

Lab D was used actively by researchers for instrumental analysis and has limited naturally ventilated with one window. CO_2 concentrations in Lab C and Lab E which combustion processes is done were lower than the concentration in Lab D. The contributors of CO_2 in the indoor environments are the respiration of occupants and fuel combustion [52]. On the other hand, inadequate ventilation is an important factor affect the indoor CO_2 level [22],[26],[49],[53]. CO_2 concentration is lower and significantly different in mechanically ventilated indoors than in naturally ventilated indoors [51]. Therefore, the probable reason of the variable CO_2 concentration might be the difference on ventilation rate, number of occupants [32], frequency of combustion facilities [52], and the size of the laboratory [27]. Additionally, low air velocity levels were observed in all laboratories. The highest values (0.07 and 0.10 m/s) were monitored in Lab C and Lab E which have propeller fan. Low indoor air velocity reported in buildings could have no fans or additional ventilation mechanisms [14]. Air velocity lower than 0.15 m/s is defined as still air for mechanically ventilated areas in ASHRAE 55 Standard [54] and the limits for air velocity is given in Table 2. In the naturally ventilated areas, an adequate indoor air quality is specified by CO_2 concentration [55].

The limit for CO_2 concentration was given between 600-800 ppm in many standards and adjusted based on the outdoor ambient level. Some standards discuss the use of CO_2 level to show the ventilation rate.

ISO 17772, EN 16798, EN 15251 and ISHRAE 10001 define the limiting concentrations for indoor CO_2 depend on the outdoor level for different indoor air categories. ASHRAE 10001 and EN 15251 accept 350 ppm above outdoor CO_2 level for Category I, while ISO 17772 and EN 16798 accept 550 ppm for Category I [55]. In the present study, CO_2 concentration in the laboratories did not exceed the limit value (i.e, 1000 ppm recommended by ASHRAE and Hong Kong).

The mean temperature in the laboratories changed between 22.0 - 24.0 ^{0}C, this range complied with the Hong Kong and ASHRAE standard (Table 2). The average lowest and highest RH were 21.8% in Lab E and 41.2% in Lab D, respectively, and these values were also complied with the standard except Lab E. Elemental analysis was carried out in Lab E, and high temperature can be occurred. When temperature increases, RH drops if no moisture is added. The variation in RH and CO_2 are affected by environment, while variation in air velocity and temperature influenced by outdoor [14]. Lighting was observed below the acceptable limit (500-750 Lux, IESNA) in all laboratories, while the lowest value was 156 Lux in Lab E.

The differences in CO_2, temperature, humidity, lighting, and air velocity parameters for each laboratory (A, B, C, D and E), were analysed using the Anova, Tukey multiple comparison test. According to the test results, the differences between the group averages of CO_2, temperature, humidity, lighting and air velocity parameters were significant ($p< 0.05$). The results of the multiple comparison test showed that the difference between the average temperature measured only in the C and D laboratories was not significant.

3.2 Temporal trend of CO_2 during lesson

It was not observed that a significant temporal variation of CO_2 concentration in laboratories except Lab B, that's why the daily trend of CO_2 concentration was given only for Lab B on the day of lesson. Figure 2 shows the CO_2 variation on days with and without laboratory lesson in Lab B. The 8-hour average and standard deviation of CO_2 concentration was 665±361 ppm in Lab B. Although the average CO_2 was not exceeding the standards (<1000 ppm), we observed that the concentration of CO_2 raised rapidly to 2000 ppm due to the increase in the number of occupants during the lesson in the afternoon.

Because of respiration, CO_2 level increase [32], and high occupancy and inadequate ventilation are the main reasons for an increase in CO_2. Telejko [29] showed that the CO_2 level increased rapidly with the beginning of the lesson and increased to 3200 ppm and decreased to 400-500 ppm after the lesson. We observed that after the lesson. The measurement campaign was done in cold season (February-March), and we have no information about the windows were open or not during the lesson. As can be seen in Figure 2, during the lesson 3 times small drops in CO_2 were occurred. The probable reason of that could be opening the laboratory door or window. After the lesson, CO_2 concentration decreased to 1000 ppm within 30 minutes. The possible reason of that could be the dilution of CO_2 depending on the size of the laboratory and air velocity level. While there was no lesson in Lab B, the concentration of CO_2 was quite stable around 400-500 ppm.

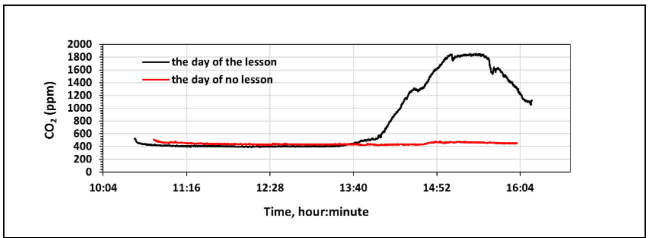

Figure 2. CO_2 concentration variation in Lab B (red line shows the day of no lesson; dashed black line shows the day of the lesson).

3.3 Elemental composition of respirable particle

The average concentrations of elements in PM_4 collected in five laboratories are displayed in Figure 3. The mean concentrations of elements in the laboratories varied between 79-1336 ng/m^3, these results were quite higher than the outdoor concentrations. In the previous study [46], conducted in the outdoor of Istanbul University- Cerrahpasa (Avcılar Campus), the elemental content of particulate matter was determined. We observed that our study results were 8-743 fold that of elements found in the outdoor TSP in traffic site [46] $PM_{2.5}$ in traffic site [61] and $PM_{2.5}$ in suburban site [62] samples (Figure 3). The high concentrations of Cr were found as 717, 902 and 1351ng/m^3 in Lab A, Lab C and Lab D, respectively. In these laboratories, both researcher and students are performed various environmental parameter analysis and in this analysis the usage of oxidizing agents such as potassium dichromate ($K_2Cr_2O_7$) is very common. So, it can be said that the material used in laboratories can be suspended in air and settled on respirable particles. Additionally, Mn was observed in all samples and the concentration of Mn varied between 610-2.450 ng/m^3. The highest Mn concentration was found in Lab E where elemental analysis application with instrumental devices, and the highest concentrations of Cd and Pb were observed in Lab E as well. The probable reason of that might be that analyzing of these metals during sampling days.

Previously reported studies showed that the elemental concentrations were variable in the laboratory environment. In the hospital laboratory in Greece [63], the mean concentrations Cr, Cu, Mn, Ni and Pb in $PM_{2.5}$ were found between 1.6 and 3.3 ng/m^3, respectively, and lower than founded in our study. However, in Malaysia [6], Cd, Cu and Ni in university building which has laboratories were very similar to results in this study.

4 Conclusions

In this study, indoor environmental quality assessment was conducted in the five laboratories of an engineering faculty in Istanbul. PM_4 showed high concentration in all laboratories. The average CO_2 concentration, relative humidity and temperature in all laboratories were found within the standards while lighting was not conformity to the standard. It was noted that the high occupancy during the lesson in the laboratory, CO_2 concentration exceeded the limit value. The elemental composition of respirable particles varied in the laboratories, and the concentration of Cd, Cu, Co, Cr, Ni, Mn and Pb were quite higher than outdoor concentrations. The present findings showed that the existing ventilation was not sufficient for filtration of respirable particles, also it could not to prevent rising of CO_2 concentration during laboratory lesson.

To prevent CO_2 increase with high occupancy, opening of windows or door should be recommended. The current lighting system should be replaced with new lamps have more light power or new additional lighting system should be set up. The mechanical ventilation such as hood exhaust fan should be used to increase the ventilation rate and the filtration of respirable particles in the laboratories. The limitation of this study is that concurrent measurements were not performed. The further study should be considered I/O ratios for all parameters and included the long term, detailed investigation for composition of respirable particles.

5 Acknowledgement

This study was funded by Scientific Research Projects Coordination Unit of Istanbul University-Cerrahpasa. Project number FYL-2019-33302.

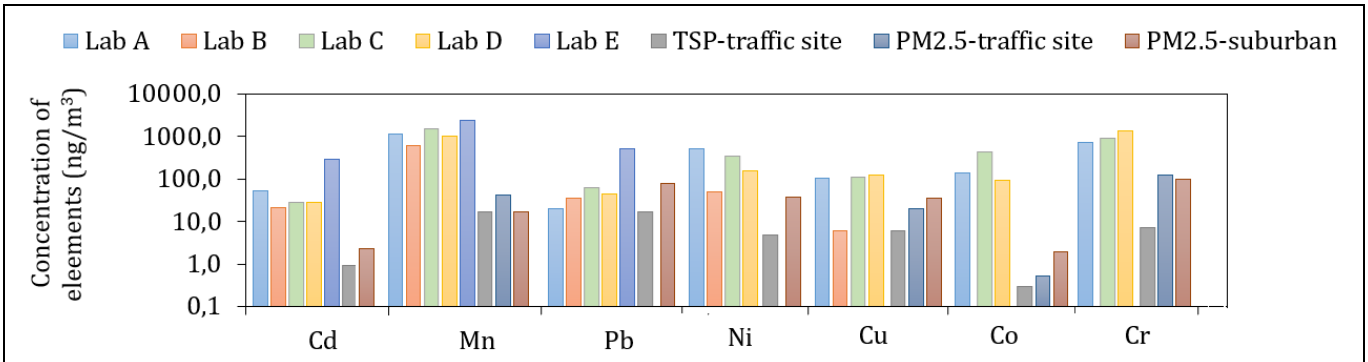

Figure 3. Elemental composition of PM_4 and comparison with outdoor (TSP-traffic site; $PM_{2.5}$-traffic; $PM_{2.5}$-suburban.

6 Author contribution statements

Burcu ONAT, Conceptualization, Writing-Reviewing and Editing. Gonca YAŞAR, Experimental study and Writing-Original draft preparation. Burcu UZUN, Data curation and Editing. Coşkun AYVAZ, Visualization. Ülkü ALVER ŞAHİN, Visualization and Editing.

7 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared.

There is no conflict of interest with any person or institution in the article prepared.

8 References

[1] Odeh I, Hussein T. "Activity pattern of urban adult students in an Eastern Mediterranean Society". *International Journal of Environmental Research and Public Health*, 13(10), 1-6, 2016.

[2] Environmental Protection Agency (EPA). "Introduction to Indoor Air Quality". https://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality#health (03.05.2020).

[3] Howard-Reed C, Wallace LA, Emmerich SJ. "Effect of ventilation systems and air filters on decay rates of particles by indoor sources in an occupied townhouse". *Atmospheric Environment*, 37(38), 5295-5306, 2003.

[4] Meadow JF, Altrichter AE, Kembel SW, Kline, J, Mhuireach G, Moriyama, M, Green JL. "Indoor airborne bacterial communities are influenced by ventilation, occupancy, and outdoor air source". *Indoor Air*, 24(1), 41-48, 2014.

[5] Andersen HV, Klinke HB, Funch LW, Gunnarsen LB. *Emission of Formaldehyde From Furniture.* 1st ed. Copenhagen, Denmark, The Danish Environmental Protection Agency, 2016.

[6] Ali MY, Hanafia MM, Khan MF, Latif MT. "Quantitative source apportionment and human toxicity of indoor trace metals at university buildings". *Building and Environment*, 121, 238-246, 2017.

[7] Huang K, Song J, Feng G, Chang Q, Jiang B, Wang J, Fang X. "Indoor air quality analysis of residential buildings in northeast China based on field measurements and longtime monitoring". *Building and Environment*, 144, 171-183, 2018.

[8] Rupakheti D, Oanh NTK, Rupakheti M, Sharma RK, Panday AK, Puppala SP, Lawrence MG. "Indoor levels of black carbon and particulate matters in relation to cooking activities using different cook stove-fuels in rural Nepal". *Energy for Sustainable Development*, 48, 25-33, 2019.

[9] Heseltine E, Rosen J. *WHO Guidelines For Indoor Air Quality: Dampness and Mould.* 1st ed. Copenhagen, Denmark, World Health Organization, 2019.

[10] Harrison R., Saborit JMD, Dor F, Henderson R. *WHO Guidelines for Indoor Air Quality: Selected Pollutants.* 1st ed. Geneva, Switzerland, World Health Organization, 2010.

[11] U.S. Environmental Protection Agency (USEPA). "Risk Assessment Guidance for Superfund: Volume I-Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment)". Washington DC, EPA, 540, -R-070, 002, 2009.

[12] Occupational Safety and Health Administration (OSHA). "Indoor air Quality in Commercial and Institutional Buildings". Washington, USA, 17, 2015.

[13] Alves CA, Calvo AI, Castro A, Fraile R, Evtyugina M, Bate-Epey EF. "Indoor air quality in two university sports facilities". *Aerosol and Air Quality Research*, 13(6), 1723-1730, 2013.

[14] Mundackal A, Ngole-Jeme VM. "Evaluation of indoor and outdoor air quality in university academic buildings and associated health risk". *International Journal of Environmental Health Research*, 32(5), 1076-1094, 2022.

[15] Lu C, Deng Q, Li Y, Sundell J, Norbäck D. "Outdoor air pollution, meteorological conditions and indoor factors in dwellings in relation to sick building syndrome (SBS) among adults in China". *Science of the Total Environment*, 560, 186-196, 2016.

[16] Sun Y, Hou J, Cheng R, Sheng Y, Zhang X, Sundell J. "Indoor air quality, ventilation and their associations with sick building syndrome in Chinese homes". *Energy and Buildings*, 197, 112-119, 2019.

[17] Zainal ZA, Hashim Z, Jalaludin J, Lee LF, Hashim JH. "Sick Building Syndrome among Office Workers in relation to Office Environment and Indoor Air Pollutant at an Academic Institution, Malaysia". *Malaysian Journal of Medicine and Health Sciences*, 15(3), 126-134, 2009.

[18] Babaoglu UT, Milletli Sezgin F, Yag F. "Sick building symptoms among hospital workers associated with indoor air quality and personal factors". *Indoor and Built Environment*, 29(5), 645-655, 2020.

[19] Latif MT, Baharudini NH, Velayutham P, Awang N, Hamdan H, Mohamad R, Mokhtar MB. "Composition of heavy metals and airborne fibers in the indoor environment of a building during renovation". *Environmental Monitoring and Assessment*, 181(1-4), 479-489, 2011.

[20] Kwong QJ, Abdullah J, Tan SC, Thio THG, Yeaw WS. "A field study of indoor air quality and occupant perception in experimental laboratories and workshops". *Management of Environmental Quality: An International Journal*, 30(2), 467-482, 2019.

[21] Kallawicha K, Chao HJ, Kotchasatan N. "Bioaerosol levels and the indoor air quality of laboratories in Bangkok metropolis". *Aerobiologia*, 35(1), 1-14, 2019.

[22] Amira'Ainaa'Idris S, Hanafiah MM, Ismail M, Abdullah S, Khan MF. "Laboratory air quality and microbiological contamination in an university building". *Arabian Journal of Geosciences*, 13(13), 1-9, 2020.

[23] Ugranli T, Toprak M, Gursoy G, Cimrin AH, Sofuoglu SC. "Indoor environmental quality in chemistry and chemical engineering laboratories at Izmir Institute of Technology". *Atmospheric Pollution Research*, 6(1), 147-153, 2015.

[24] Sahu V, Elumalai SP, Gautam S, Singh NK, Singh P. "Characterization of indoor settled dust and investigation of indoor air quality in different micro-environments". *International journal of Environmental Health Research*, 28(4), 419-431, 2018.

[25] Ali SM, Martinson B, Al-Maiyah S. "Evaluating indoor environmental performance of laboratories in a Northern Nigerian university". *In 33rd PLEA International Conference: Design to Thrive, Network for Comfort and Energy Use in Buildings*, Edinburgh 2-5 July, 2017.

[26] Sahu V, Gurjar BH. “Spatial and seasonal variation of air quality in different microenvironments of a technical university in India”. *Building and Environment*, 185, 1-10, 2020.

[27] Seseña S, Rodríguez AM, Palop ML. “Indoor air quality analysis in naturally ventilated university training laboratories: a health risk assessment”. *Air Quality, Atmosphere & Health*, 15, 1817-1837, 2022.

[28] Md Saad Z, Rasdi I, Zainal Abidin E. “Indoor air quality and prevalence of sick building syndrome among university laboratory workers”. *Sciences: Basic and Applied Research*, 29(2), 130-140, 2016.

[29] Telejko, M. “Attempt to improve indoor air quality in computer laboratories”. *Procedia Engineering*, 172, 1154-1160, 2017.

[30] Qian H, Miao T, Liu L, Zheng X, Luo D, Li Y. “Indoor transmission of SARS-CoV-2”. *Indoor Air*, 31(3), 639-645, 2021.

[31] Hadei M, Hopke PK, Jonidi A, Shahsavani A. “A letter about the airborne transmission of SARS-CoV-2 based on the current evidence”. *Aerosol Air Quality Research*. 20, 911-914, 2020.

[32] Yau YH, Chew BT, Saifullah AZA. “Studies on the indoor air quality of Pharmaceutical Laboratories in Malaysia”. *International Journal of Sustainable Built Environment*, 1(1), 110-124, 2012.

[33] Morawska L, Tang J, W, Bahnfleth W, Bluyssen PM, Boerstra A, Buonanno G, Yao M. “How can airborne transmission of COVID-19 indoors be minimised?”. *Environment International*, 142, 1-7, 2020.

[34] Peng Z, Jimenez JL. “Exhaled CO_2 as a COVID-19 infection risk proxy for different indoor environments and activities”. *Environmental Science & Technology Letters*, 8(5), 392-397, 2021.

[35] Persily A, Bahnfleth W, Kipen H, Lau J, Mandin C, Sekhar C, Weekes LCN. “ASHRAE's new position document on indoor carbon dioxide”. *ASHRAE Journal*, 64(5), 50-52, 2022.

[36] Hashemi SE, Fazlzadeh M, Ahmadi E, Parand M, Ramavandi B, Taghizadeh F, Arfaeinia H. “Occurrence, potential sources, in vitro bioaccessibility and health risk assessment of heavy metal in indoor dust from different microenvironment of Bushehr, Iran”. *Environmental Geochemistry and Health*, 42(11), 3641-3658, 2020.

[37] Ardashiri S, Hashemi SE. “Health risk assessment of heavy metals in indoor dust from Bushehr, Iran”. *Iranian Journal of Health, Safety and Environment*, 5(2), 966-971, 2018.

[38] Şahin ÜA, Onat B, Stakeeva B, Ceran T, Karim P. “PM10 concentrations and the size distribution of Cu and Fe-containing particles in Istanbul’s subway system”. *Transportation Research Part D: Transport and Environment*, 17(1), 48-53, 2012.

[39] Şahin ÜA, Kurutaş B. “Assessment of fine particulate matter and gaseous pollutants in workplace atmosphere of metallic industry”. *Bulletin of Environmental Contamination and Toxicology*, 89(4), 898-904, 2012.

[40] Yurtseven E, Erdogan MS, Ulus T, Sahin UA, Onat B, Erginoez E, Vehid S, Köksal S. “Assessment of indoor $PM_{2.5}$ concentrations at a medical faculty in Istanbul, Turkey”. *Environment Protection Engineering*, 38(1), 115-127, 2012.

[41] Onat B, Alver Şahin Ü, Sivri N. “The relationship between particle and culturable airborne bacteria concentrations in public transportation”. *Indoor and Built Environment*, 26(10), 1420-1428, 2017.

[42] Onat B, Şahin ÜA, Uzun B, Akın Ö, Özkaya F, Ayvaz C. “Determinants of exposure to ultrafine particulate matter, black carbon, and $PM_{2.5}$ in common travel modes in Istanbul”. *Atmospheric Environment*, 206, 258-270, 2019.

[43] Onat B, Çalışkan NS, Şahin ÜA, Uzun B. “Assessment of the health risk related to exposure to ultrafine, fine, and total particulates and metals in a metal finishing plant”. *Environmental Science and Pollution Research*, 27(4), 4058-4066, 2020.

[44] The Ministry of Labor and Social Security. “Regulation on Dust Controlling Turkey”. 2013. http://www.csgb.gov.tr/csgbPortal/isggm.portal?page=mevzuat&id (03.05.2020).

[45] Brown JS, Gordon T, Price O, Asgharian B. “Throcic and respirable particle definitons for human health risk assessment”. *Particle and Fibre Technology*, 10, 1-12, 2013.

[46] Şahin ÜA, Polat G, Onat B. “Mass size distribution and source identification of particulate matter metal components at four urban sites and a background site of Istanbul”. *Environmental Science and Pollution Research*, 23(11), 11085-11099, 2016.

[47] Goyal R, Khare M. “Indoor-outdoor concentrations of RSPM in classroom of a naturally ventilated school building near an urban traffic roadway”. *Atmospheric Environment*, 43, 6026-6038, 2009.

[48] Mishra AK, Mishra P, Gulia S, Goyal SK. “Assessment of indoor fine and ultra-fine particulate matter in a research laboratory”. *CIEQ: Asian Conference on Indoor Environmental Quality*, New Delhi, India, 1-2 February 2019.

[49] Valavanidis V, Vatista M. “Indoor air quality measurements in the chemistry department building of the University of Athens”. *Indoor and Built Environment*, 15(6), 595-605, 2006.

[50] Rumchev K, Broeck V, Spickett J. “Indoor air quality in university laboratories”. *Environmental Health*, 3(3), 11-19, 2003.

[51] Jurado SR, Bankoff AD, Sanchez A. “Indoor air quality in Brazilian universities”. *International Journal of Environmental Research and Public Health*, 11(7), 7081-7093, 2014.

[52] Widder SH, Haselbach L. “Relationship among concentrations of indoor air contaminants, their sources, and different mitigation strategies on indoor air quality”. *Sustainability*, 9(7), 1-16, 2017.

[53] Çobanoğlu N, Karadeniz ZH. “İç çevre kalitesi ve uyku”. *Türk Tesisat Mühendisleri Derneği*, 41, 74-75, 2021.

[54] American Society of Heating, Refrigerating and Air-Conditioning Engineers. “Ventilation for Acceptable Indoor Air Quality”. Atlanta, GA, 40, 2013.

[55] Khovalyg D, Kazanci OB, Halvorsen H, Gundlach I, Bahnfleth WP, Toftum J, Olesen BW. “Critical review of standards for indoor thermal environment and air quality”. *Energy and Buildings*, 213, 1-19, 2020.

[56] The Government of the Hong Kong Special Administrative Region. “Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places”. Indoor Air Quality Management Group, Hong Kong, 84, 2019.

[57] Rea MS. *IESNA Lighting Handbook*, 9th ed., Illuminating Engineering Society of North America, New York, 2000.
[58] National Institute for Occupational Safety and Health (NIOSH), "Permissible Exposure Limits-Annotated Tables". https://www.osha.gov/annotated-pels/table-z-1 (01.03.2021).
[59] American Conference of Governmental Industrial Hygienists. *Threshold limit values for chemical substances and physical agents and biological exposure indices.* 7th ed. Cincinnati, OH, American Conference of Governmental Industrial Hygienists, 2001.
[60] Republic of Türkiye Ministry of Environment, Urbanization and Climate Change. "Turkey Outdoor air Quality Assessment and Management Regulation". https://www.mevzuat.gov.tr/File/GeneratePdf?mevzuatNo=12188&mevzuatTur=KurumVeKurulusYonetmeligi&mevzuatTertip=5 (03.11.2021).
[61] Onat B, Sahin UA, Akyuz T." Elemental characterization of $PM_{2.5}$ and PM_1 in dense traffic area in Istanbul, Turkey". *Atmospheric Pollution Research*, 4(1), 101-105, 2013.
[62] Karaca F, Alagha O, Ertürk F, Yılmaz, YZ, Özkara, T. "Seasonal variation of source contributions to atmospheric fine and coarse particles at suburban area in Istanbul, Turkey". *Environmental Engineering Science*, 25(5), 767-782, 2008.
[63] Loupa G, Zarogianni AM, Karali D, Kosmadakis I, Rapsomanikis S. "Indoor/outdoor PM2.5 elemental composition and organic fraction medications, in a Greek hospital". Science of the Total Environment, 550, 727-735, 2016.