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RESEARCH ARTICLE

Assessment of indoor air concentrations of VOCs and their associated health risks in the library of Jawaharlal Nehru University, New Delhi

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Abstract The present work investigated the levels of total volatile organic compounds (TVOC) and benzene, toluene, ethylbenzene, *m*/*p*-xylene, and *o*-xylene (BTEX) in different microenvironments in the library of Jawaharlal Nehru University in summer and winter during 2011–2012. Carcinogenic and non-carcinogenic health risks due to organic compounds were also evaluated using US Environmental Protection Agency (USEPA) conventional approaches. Real-time monitoring was done for TVOC using a data-logging photo-ionization detector. For BTEX measurements, the National Institute for Occupational Safety and Health (NIOSH) standard method which consists of active sampling of air through activated charcoal, followed by analysis with gas chromatography, was performed. Simultaneously, outdoor measurements for TVOC and BTEX were carried out. Indoor concentrations of TVOC and BTEX (except benzene) were higher as compared to the outdoor for both seasons. Toluene and *m*/*p*-xylene were the most abundant organic contaminant observed in this study. Indoor to outdoor (I/O) ratios of BTEX compounds were generally greater than unity and ranged from 0.2 to 8.7 and 0.2 to 4.3 in winter and summer, respectively. Statistical analysis and I/O ratios showed that the dominant pollution sources mainly came from indoors. The observed mean concentrations of TVOC lie within the second group of the Molhave criteria of indoor air quality, indicating a multi-factorial exposure range. The estimated lifetime cancer risk (LCR) due to benzene in this study exceeded the value of 1×10^{-6} recommended by USEPA, and the hazard quotient (HQ) of non-cancer risk came under an acceptable range.

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Introduction

Volatile organic compounds (VOCs) are considered as crucial parameters for examining the air quality in both indoor and outdoor because of their ubiquitous nature. VOCs include a large group of air pollutants which have significant impact on the atmosphere and human health (Lerner et al. 2012; Matsumoto et al. 2010). Exposure to VOCs has been a serious concern to the scientific community in the past decades (Andersson et al. 1997; Geiss et al. 2011; Rumchev et al. 2004). Vehicular and industrial exhausts, petroleum refineries, and solvent usages are major sources of VOCs in ambient air (de Blas et al. 2012; Esplugues et al. 2010). Furthermore, indoor sources include domestic products such as paints, varnishes, waxes, solvent, detergents, human activities, and building-related materials (de Blas et al. 2012; Ohura et al. 2009; Sofuoglu et al. 2010). VOC concentration and its occurrence in indoors are mainly governed by a number of factors such as outdoor infiltration, indoor sources, human activities, and seasonal variations (Missia et al. 2010; Schlink et al. 2004). The chemical diversity of the VOC group causes adverse impact on human health ranging from carcinogenic to non-carcinogenic effect (Lerner et al. 2012; Okada et al. 2012; Ramírez et al. 2012; Srivastava et al. 2005).

Ongoing research on indoor air is significant as people spend a large fraction of their time either at home or at the workplace (Liu et al. 2013). Further, when it comes to specific places like libraries, hospitals, and schools, it needs more attention. The library is one of the important places where the air quality is of great concern since people of different ages, i.e., young to old persons, use this place. Air quality in

the library has always been an issue for library patrons, staffs, and students (Righi et al. 2002). Apart from human activities and outdoor infiltration, the degradation of lignin and cellulose from older books, insulating materials, and furniture are the major sources of VOCs inside the library (Fenech et al. 2010). Nowadays, a new term, sick library syndrome, is used to describe health discomfort inside the library (Fantuzzi et al. 1996). In the past, few studies have been reported regarding indoor air quality measurements in the library (Fantuzzi et al. 1996; Fenech et al. 2010; Lee et al. 2011; Righi et al. 2002). Righi et al. (2002) investigated the air quality and assessed the sense of well-being perceived by library users in Modena, Italy. Another study carried out by Fenech et al. (2010) measured volatile aldehydes, acetic acid, and VOCs in libraries and archives.

The present study investigates indoor air quality (IAQ) in terms of total volatile organic compounds (TVOC) and benzene, toluene, ethylbenzene, *m*/*p*-xylene, and *o*-xylene (BTEX) in the different microenvironments in the library of Jawaharlal Nehru University, New Delhi. To compare it with outdoors, the corresponding outdoor environment was also monitored for the same pollutants. The measured data were statistically evaluated to examine the potential sources. Further, results were compared with the recommended US Environmental Protection Agency (USEPA) guideline given for cancer and non-cancer risks.

Materials and methods

Sampling sites

Indoor and outdoor sampling was scheduled at the library of Jawaharlal Nehru University (JNU), New Delhi during winter and summer seasons. The JNU campus is situated southwest of Delhi having a diverse group of natural vegetation covering 1,000 acres of area. It is surrounded by major roads and lacks any industrial activity near its vicinity. The library has nine floors altogether, and the area of the whole library building is 9,619.37 m^2. The library opens at 9:00 am and closes at 11:30 pm. The library has nearly 170 employees who have different types of occupation. During the experimental period, there were approximately 1,200–1,300 daily visitors. Eight different indoor environments were selected on the basis of different features such as room characteristics, size, kept materials, occupants, and activities. Possible sources of VOCs in these rooms can be considered as representative of the total exposure to the whole library. The reading hall I, reading hall II, Helen Keller hall, cyber room, photostat room, book section hall, reception hall, and basement were selected for sample collection. Information concerning the indoor microenvironments selected is described in Table 1.

Sample collection

Samples were collected for the period of three consecutive days for indoor and outdoor simultaneously, at each sampling microenvironments. Sample duration was for 8 h from 10:00 am to 6:00 pm during winter and summer seasons 2011–2012. Two different sampling instruments were used for TVOC and BTEX concentration measurements and placed above 1.5 m (breathing zone) from floor level at indoor and outdoor locations.

A portable, data-logging PhoCheck 5000 photo-ionization detector (PID) having 10.6-eV ultraviolet lamp technology (Ion Science Ltd, Cambridge, England) was used for real-time TVOC measurements. Here, TVOC comprise a large range of gases to characterize the pollutant load in terms of VOCs and a basis on which to assess IAQ (Andersson et al. 1997). TVOC monitor various gases such as acetone, benzene, formaldehyde, isobutene, butanone, methyl propyl ketone, styrene, toluene, nonane, octane, and pentane to name but a few from a very wide range list. Although many VOC gases are detectable, the PhoCheck 5000 monitor cannot differentiate between the gases. The PID in the instrument uses an ultraviolet (UV) light source to break down VOCs in the air into positive and negative ions. Then, the PID detects or measures the charge of the ionized gas, with the charge being a function of the concentration of VOCs in the air. The concentration is displayed in the monitor window. Over 220 ml/min of air was drawn through the PhoCheck's internal pump into the instrument, and a 1-s measurement interval was set for the PID data logger. Calibration was performed before each sampling by 100 ppm isobutylene and zero air according to the manufacturer's instruction. Details of the PhoCheck 5000 TVOC monitor are shown in Table 2.

However, sampling and analysis for BTEX measurements were done according to the National Institute for Occupational Safety and Health (NIOSH) methods. Samples were taken by drawing air with a handy sampler (Satyam Scientific Instruments Company, New Delhi) through Orbo^{TM}-32 tubes (7 cm in length×6 mm o.d., provided by Supelco) having activated charcoal. The sampling period for BTEX was kept the same as TVOC for 8 h with the flow rate of 100 ml/min. Subsequently, each Orbo^{TM}-32 tube was wrapped with aluminum foil and resealed with a Teflon bag. Then, Orbo^{TM}-32 tubes were transferred back to the laboratory and stored in the refrigerator before further analysis.

Analytical procedure

Charcoal from Orbo^{TM}-32 was transferred to a 2-ml amber-colored glass vial, and then 1 ml of low-benzene CS_2 (99 % purity with less than 0.001 % benzene, purchased from Supelco) was added and put on agitation for 30 min. Further, prepared samples were analyzed with gas chromatography

Table 1 Summary of the characteristics of indoor environments

Indoor environments	Abbreviation	Volume(m^3)	Characteristics
Reading hall I[a]	RH I	2,133.0	Air conditioned, well decorated, plywood or particle board furniture
Reading hall II	RH II	680.4	Old furniture, acrylic wall painting, woody furniture
Helen Keller hall	HKR	1,385.1	Where a group of deaf and physically and visually challenged students read, few computers, plywood or particle board furniture
Cyber room[a]	CR	168.3	Server with around 200 computers
Photostat room	PR	89.8	Xerox machines, printers
Book section hall	BS	1,389.3	Books, journals, stationary, newspaper stands
Reception hall	RP	945.0	An entrance open indoor area
Basement	BM	1,944.0	Bookshelves (a lot of old books), plaster flooring, woody furniture

[a]Air conditioned in summer

(Auto sampler, Model AOC-20i, GC-2010, Shimadzu). An RTX-VGC capillary column (75 m, 0.53 mm, 2.55 μm) was used for GC. One microliter of the prepared sample was injected into the gas chromatograph assembled with a FID detector. The initial oven temperature was kept at 40 °C for 2 min, then increased 10 °C/min to 230 °C, and kept for 5 min. The compounds of interest were identified by their retention time of calibration VOC standards (HC BTEX/MTBE Mix, 2,000 μg/ml each in methanol, procured from Supelco) under a specified chromatographic condition.

Health risk calculation

As mentioned earlier, VOC compounds have adverse impact on human health, and few of them are known as carcinogens (Zhang et al. 2012). Based on the measured VOC data in this study, lifetime cancer risk (LCR) and non-cancer hazard quotient (HQ) were assessed. The daily exposure (E_D in μg kg^{-1} day^{-1}) of any compound due to the inhalation pathway is evaluated (Som et al. 2008; USEPA 1997) from Eq. 1. Effective yearly exposure (E_Y) in Eq. 2 and effective lifetime exposure (E_L) in Eq. 3 are used for the calculation of chronic non-cancer HQ and LCR, respectively (Som et al. 2008):

$$E_D = (CA \times IR \times ET)/BW \times 1,000 \quad (1)$$

$$E_Y = E_D \times EF/365 \quad (2)$$

Table 2 Technical specification of the Ion Science Phocheck 5000 TVOC monitor

	Description
Detector	10.6 eV Krypton PID lamp
Detection range	1 ppb to 10,000 ppm
Accuracy	±5 % displayed reading ±1 digit
Linearity	±5 %
Temperature	Operating: −20 to 60 °C, −4 to 140 °F
Humidity	Operating: 0–99 % RH (non-condensing)

$$E_L = E_Y \times ED/AT \quad (3)$$

where CA is the concentration of the air pollutant (μg/m^3), IR is the inhalation rate (0.83 m^3/h), ET is the exposure time (8 h day^{-1}), BW is the body weight (70 and 60 kg for men and women, respectively), EF is the exposure frequency (225 days/year, this study), ED is the exposure duration (30 years), AT is the average lifetime (70 years), and 1,000 is the conversion factor.

Non-cancer risk of VOCs is expressed as HQ which is defined as the ratio of yearly average daily doses received (E_Y) by the reference dose, RfD. However, LCR is assessed for benzene by multiplying effective lifetime exposure (E_L) with slope factor (SF):

$$HQ = E_Y/RfD \quad (4)$$

$$LCR = E_L \times SF \quad (5)$$

where RfD (mg/kg·day) is a level below which adverse health effects are unlikely to occur and SF is the slope factor or carcinogen potency slope (expressed in mg^{-1} kg day). All exposure parameters, RfD, and SF for each pollutant used in the analysis were obtained from USEPA (1997, 1998).

Results and discussion

TVOC concentrations

The mean concentration of TVOC was recorded as 465.8 μg/m^3 (145.3–1503.2 μg/m^3) in winter and 321.8 μg/m^3 (90.7–1,100.9 μg/m^3) in summer for indoor air. However, for outdoor air, the concentrations were 187.4 and 113.3 μg/m^3 in winter and summer, respectively (Fig. 1). Inside the library, concentrations of TVOC were higher as compared to the outdoor; this might be due to the insulating materials, adhesives, building materials, and office equipment (Ohura et al. 2009; Sarkhosh et al. 2012; Sofuoglu et al. 2010). Our results are comparable with the similar studies conducted in earlier

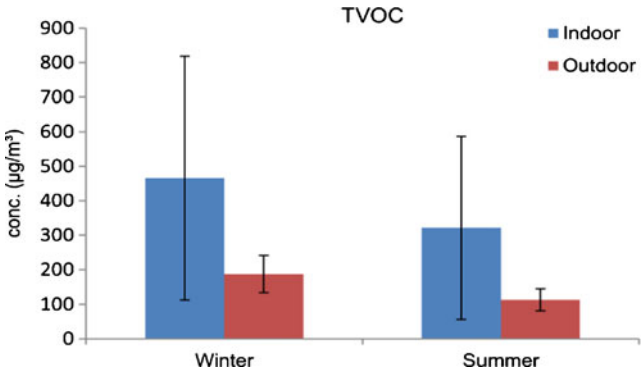

Fig. 1 Indoor and outdoor average TVOC concentrations in winter and summer

years. Recently, a range of 100 and 538 μg/m^3 for TVOC concentrations was reported in indoor air of Japanese University (Hori et al. 2012), while Sarkhosh et al. (2012) observed that concentrations ranged from 113.4 to 486.3 ppb (227–973 μg/m^3 isobutylene units) in photocopy centers. Chan et al. (2009) measured TVOC concentrations in new hotels' guest rooms of the factory region which varied between 416 and 2900 μg/m^3. The indoor air quality guideline for TVOC suggested by Molhave et al. (1997) and the Hong Kong Indoor Air Quality standard (Environmental Protection Department of HKSAR 2003) are used for comparisons. Mean concentrations of TVOC lie within the second group of the Molhave criteria, indicating a multifactorial exposure range, which can be a potential cause of mucous and skin irritation. After comparing with the Hong Kong Indoor Air Quality standard, it was found that the mean concentration of TVOC in indoors for both seasons could not achieve the "excellent class" level (below 200 μg/m^3).

BTEX concentrations

The studied BTEX were detected in all samples. Table 3 summarizes the mean indoor and outdoor concentrations for BTEX during the measurement period. Indoor mean concentrations were in order of toluene>*m*/*p*-xylene>*o*-xylene>ethylbenzene>benzene for winter. In summer, on the other hand, the order for BTEX concentrations was toluene, *m*/*p*-xylene, ethylbenzene, benzene, and *o*-xylene. The mean concentrations of toluene and *m*/*p*-xylene were 94.0 and 28.7 μg/m^3 in winter and 66.7 and 22.2 μg/m^3 in summer, respectively. Benzene was found relatively lower (7.2 and 12.2 μg/m^3 in winter and summer, respectively) compared to others. The compound with the highest winter concentration outdoors was toluene (34.9 μg/m^3), followed by benzene (11.9 μg/m^3), and then *m*/*p*-xylene (9.8 μg/m^3). Similar trends were observed in summer for outdoors with different concentrations. Benzene has been widely used in a variety of industrial solvents and household products such as paints, furniture wax, lubricants, and glues (Sarigiannis et al. 2011). While sources of toluene, ethylbenzene, and xylenes (TEX) include adhesives, floor covering, paints, cleaning agents, coating, dyes, ink, and printing products (Chan et al. 2009; Watson et al. 2001). Therefore, BTEX compounds are detected in almost all indoor environments.

Comparison of indoor and outdoor BTEX concentrations during both seasons among different cities around the world has been shown in Table 4. Indoor concentrations of benzene and toluene were observed to be higher compared to those found elsewhere (Esplugues et al. 2010; Gallego et al. 2008; Lee et al. 2011). Similarly, the concentrations of xylenes were reported to be higher than those found elsewhere (Liu et al. 2013; Ongwandee et al. 2011) and lower in the study carried out by Righi et al. (2002). On the other hand, indoor concentrations of ethylbenzene in this study were lower than those in China (Lü et al. 2010). Outdoor concentrations of BTEX in this study were also comparable to those found elsewhere (Esplugues et al. 2010; Gallego et al. 2008; Hoque et al. 2008; Ongwandee et al. 2011; Sarkar et al. 2013; Son et al. 2003; Tang et al. 2005).

Table 3 revealed that the mean concentration of benzene in both seasons for indoor and outdoor environment exceeded the

Table 3 Summary of concentration (μg/m^3) of targeted BTEX in winter and summer

	Winter				Summer			
	Indoor		Outdoor		Indoor		Outdoor	
	Range[a]	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)
Benzene	1.9–19.2	7.2 (4.2)	4.9–25.4	11.9 (5.6)	3.5–35.7	12.2 (7.9)	2.3–32.1	14.0 (8.5)
Toluene	13.2–274.1	94.0 (70.1)	16.4–65.1	34.9 (11.3)	8.5–205.4	66.7 (54.4)	11.2–108.6	39.3 (20.9)
Ethylbenzene	3.2–31.4	10.1 (6.6)	2.1–19.4	6.5 (4.7)	4.4–42.1	13.9 (8.6)	2.9–19.6	10.9 (5.2)
m/*p*-xylene	6.2–127.3	28.7 (31.7)	2.5–21.3	9.8 (5.1)	3.7–94.7	22.2 (25.8)	5.1–33.9	12.2 (7.0)
o-xylene	3.2–54.7	13.1 (12.6)	1.2–15.1	5.8 (3.7)	1.8–48.2	9.4 (11.8)	1.1–17.4	5.7 (4.2)
∑ BTEX	44.9–477.8	153.2 (113.4)	31.7–104.8	69.1 (18.2)	42.9–411.4	124.7 (100.3)	35.3–172.9	77.3 (34.7)

SD standard deviation

[a] Range: min–max

Table 4 Comparison of mean concentrations of measured BTEX (μg/m^3) in this study with previous studies

City	Benzene	Toluene	Ethylbenzene	Xylenes[a]	Reference
Indoor location					
JNU, New Delhi	7.2	94.0	10.1	20.9	Present study (winter)
JNU, New Delhi	12.2	66.7	13.9	15.8	Present study (summer)
Modena, Italy	17.1	20.2	–	23.5	Righi et al. (2002)
Korea	4.7	32.4	6.3	7.3	Lee et al. (2011)
Spain	2.7	16.2	1.3	1.7	Esplugues et al. (2010)
Guangzhou, China	10.8	98	61.1	63.8	Lü et al. (2010)
Beijing, China	9.0	32.2	–	12.2	Liu et al. (2013)
Bangkok	8.08	110	12.1	10.9	Ongwandee et al. (2011)
Barcelona	5.8	67.0	–	51.4	Gallego et al. (2008) (rural)
Barcelona	4.3	64.8	–	47.6	Gallego et al. (2008) (urban)
Outdoor location					
JNU, New Delhi	11.9	34.9	6.5	7.8	Present study (winter)
JNU, New Delhi	14.0	39.3	10.9	8.9	Present study (summer)
Spain	1.2	6.8	0.9	1.3	Esplugues et al. (2010)
New Delhi	48	85	7	22.5	Hoque et al. (2008)
Bangkok	2.9	43.6	5.5	4.7	Ongwandee et al. (2011)
Guangzhou, China	28.8	51.8	9.4	12.4	Tang et al. (2005)
Mohali, India	51	150.7	–	–	Sarkar et al. (2013)
Barcelona	1.4	9.2	–	9.2	Gallego et al. (2008) (rural)
Barcelona	3.5	34.2	–	31.3	Gallego et al. (2008) (urban)
Asan, Korea	21.6	18.1	1.7	8.9	Son et al. (2003)
Seoul, Korea	39.8	147.8	1.6	44.7	Son et al. (2003)

[a] Xylenes = sum of xylene isomers

value of 5 μg/m^3 guideline provided by the European Union (Stranger et al. 2007). Further, by comparing with China's indoor air quality guideline, results showed that the observed mean benzene, toluene, and xylene (BTX) concentrations were far lower than the guideline values (Lü et al. 2010).

Variation of TVOC and BTEX among microenvironments

The relative concentrations of TVOC and BTEX varied significantly in the sampled indoor environments for two seasons (Table 5). The average concentrations of TVOC and BTEX were generally found to be higher in winter as compared to summer. It might be due to poor ventilation, because during winter, most of the time windows or doors are closed (de Blas et al. 2012). Almost all the indoor environments are characterized by the presence of BTEX because they are largely present in commonly used household cleaning products, paints, and adhesives (Sarigiannis et al. 2011). The indoor concentrations of TVOC and BTEX were relatively higher in the photostat room (PR), basement (BM), and book section

Table 5 Mean concentrations of total volatile organic compounds (TVOC), benzene (B), toluene (T), ethylbenzene (E), and xylenes (X) in different microenvironments (μg/m^3)

Indoor environments	Winter					Summer				
	TVOC	B	T	E	X[a]	TVOC	B	T	E	X
RH I	178.7	2.5	54.7	9.5	11.5	154.7	5.0	35.7	12.8	5.3
RH II	293.1	9.9	54.4	9.5	12.0	184.8	12.5	35.0	23.1	6.4
HKR	386.8	5.6	109.6	9.8	8.5	152.9	8.3	54.1	16.1	6.7
CR	321.4	7.2	60.3	14.5	10.4	221.4	9.9	44.1	11.8	7.3
PR	1,194.9	15.1	242.0	16.4	67.1	900.4	29.0	189.5	21.8	58.1
BS	394.2	5.1	70.1	7.0	15.6	315.5	10.9	69.1	7.3	11.2
RP	192.4	4.4	24.7	5.2	6.9	112.8	8.3	19.6	7.8	6.2
BM	765.3	8.1	136.5	9.1	34.9	532.1	14.2	86.8	10.3	25.6

[a]X is the sum of xylene isomers

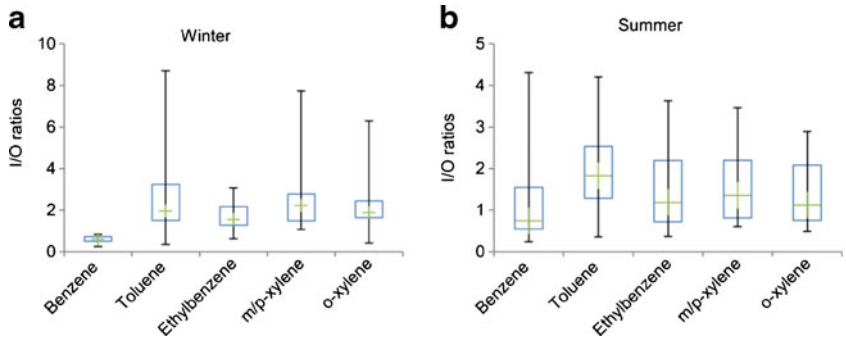

Fig. 2 Indoor/outdoor (I/O) concentration ratios of BTEX in **a** winter and **b** summer

(BS). Instead, the reading hall I (RH I), reading hall II (RH II), and reception hall (RP) showed lower levels of VOCs. Analysis of the data showed that the photostat room was the most polluted among the all indoor environments. This suggests that there were strong possible emission sources of these organic pollutants. It may be due to emissions from photocopier operations. It has been reported that more than 60 VOCs may be emitted during photocopier operations (Sarkhosh et al. 2012). The levels of organic compounds in the BM ranked second and might be due to cleaning activities, degradation of lignin and cellulose from older books, and poor ventilation (Fenech et al. 2010). Following the basement, the BS had large concentrations of organics. Toluene was found to be significantly higher in the BS but lower in the PR, BM, and HKR probably due to the presence of ink in newspapers. Volatiles such as toluene are used to increase the fluidity of inks (Bruno et al. 2008). The results showed that the cyber room (CR) also had significantly higher concentrations of TVOC and toluene. This may be due to computers kept inside the cyber room. Takeuchi and Ozaki (2009) reported that emission rates of VOCs from the computers were higher when computers are on than off. The reading hall I (for common people) and Helen Keller hall (for deaf and blind students) were well decorated with marble flooring, furniture (wood or particle or plywood), and furniture coating. Therefore, emission from luxurious decorations and building furnishing materials may have higher source strength (Missia et al. 2010).

Source characteristics of BTEX

To elucidate possible emission sources, statistical analysis of BTEX was performed. The indoor–outdoor (I/O) ratios were calculated by dividing the mean indoor concentrations with the mean outdoor concentrations for BTEX compounds (Fig. 2). An I/O ratio of ≤1.0 specifies influence of outdoor sources (Edwards et al. 2001). A ratio between 1 and 4 with no significant difference can be considered as mixture of indoor and outdoor sources. Furthermore, significant differences between the indoor and outdoor levels of compounds indicate presence of mainly indoor sources (de Blas et al. 2012; Geiss et al. 2011). The results showed that the I/O ratios for BTEX ranged from 0.2 to 8.7 and 0.2 to 4.3 in winter and summer, respectively.

To determine the differences between the indoor and outdoor sources, Wilcoxon rank sum test, a non-parametric test, was conducted. Normality of the raw data was tested by the Kolmogorov–Smirnov one sample test at the significance level of 0.05. It was observed that indoor and outdoor levels for BTEX in winter were statistically different at the 0.05 level, indicating indoor main sources (Bae et al. 2004; Ward et al. 2009). Gallego et al. (2008) showed that I/O ratios of the same aromatic compounds in this study in urban residences were greater than 1 with the significant difference at 0.05 levels. However, p values for BTEX (except toluene) in summer were greater than the significance level of 0.05; this could be accounted either from outdoor or mixture of indoor

Table 6 Pearson correlation coefficient for BTEX in indoors for winter and summer

		Benzene	Toluene	Ethylbenzene	m/p-xylene	o-xylene
Winter	Benzene	1				
	Toluene	0.645**	1			
	Ethylbenzene	0.432*	0.325	1		
	m/p-xylene	0.796**	0.784**	0.445*	1	
	o-xylene	0.726**	0.684**	0.412*	0.961**	1
Summer	Benzene	1				
	Toluene	0.827**	1			
	Ethylbenzene	0.503*	0.409*	1		
	m/p-xylene	0.919**	901**	0.347	1	
	o-xylene	0.922**	0.831**	0.341	0.969**	1

*p <0.05; **p <0.01 (correlation coefficient and significance test)

and outdoor sources (Saarela et al. 2003). They investigated on the basis of the Wilcoxon rank sum test that the indoor BTEX compounds were not statistically different to the outdoor. Sources of toluene were more likely to be indoors, probably owing to building materials, newspaper, copiers, and printers (Gallego et al. 2008; Sarkhosh et al. 2012; Watson et al. 2001).

Further, to investigate the relationships among the BTEX in indoor microenvironments, correlation analysis was done. Table 6 shows the Pearson correlation coefficient (r) and the strength of correlation based on a two-tailed test for BTEX in the two seasons. It is noted that most of the BTEX (except ethylbenzene) were correlated in both seasons, suggesting that they had similar sources and activities. On the other hand, the strength of association among BTEX compounds was higher in summer as compared to winter. The high concentrations of BTEX in indoor air of the library mainly from indoor sources might be due to cleaning, building materials, furniture, and office equipment. Ohura et al. (2009) reported that there were good correlations among the BTEX compounds observed in a residential indoor environment. However, the study performed at residential homes in China (Liu et al. 2013) and Michigan schools in the USA (Godwin and Batterman 2007) observed that there was no correlation among benzene, toluene, and xylene isomers.

Exposure risks

Table 7 shows the average daily exposure (E_D), yearly exposure (E_Y), lifetime exposure (E_L), HQ, and LCR of the adult male and female during both seasons. Estimated HQ for BTEX compounds was observed to be below 1 (ranging from 10^{-1} to 10^{-3}) for adults. Some related non-cancer risk findings have been reported around the world. Peng et al. (2012) and Sarigiannis et al. (2011) estimated HQ values which were far below 1 for benzene, toluene, and xylene isomers. However, the health risk assessment of exposure from an integrated iron and steel plant by Chang et al. (2010) estimated HQ to be significantly higher. It has also been reported that HQ values greater than 0.1 indicate a potential concern (McCarthy et al. 2009; Ramírez et al. 2012).

A LCR value of 1×10^{-6} recommended by the USEPA (Ramírez et al. 2012) was used for comparison and observed that females are at significant risk. According to a study carried out by Sexton et al. (2007), compounds with attributable cancer risk can be subdivided into three broad ranges wherein a cancer risk of over 10^{-4} can be considered as a "definite risk," between 10^{-5} and 10^{-4} as a "probable risk," and between 10^{-5} and 10^{-6} as a "possible risk." LCR for benzene of females in the library was 1.40×10^{-5} (probable risk) in winter and 1.04×10^{-5} (probable risk) in summer. LCR was slightly higher for females as compared to males because of less body mass. The estimated LCR for males was 5.27×10^{-6} and 8.93×10^{-6}

Table 7 Individual pollutant exposure, associated with non-cancer hazard and cancer risk in winter and summer

	VOC pollutant	Adult male					Adult female				
		Average daily exposure (E_D) (mg kg^{-1} day^{-1})	Yearly exposure (E_Y) (mg kg^{-1} day^{-1})	Lifetime exposure (E_L) (mg kg^{-1} day^{-1})	Individual hazard quotient	Lifetime cancer risk	Average daily exposure (E_D) (mg kg^{-1} day^{-1})	Yearly exposure (E_Y) (mg kg^{-1} day^{-1})	Lifetime exposure (E_L) (mg kg^{-1} day^{-1})	Individual hazard quotient	Lifetime cancer risk
Winter	Benzene	1.02E−04	4.55E−04	1.95E−04	2.48E−01	5.27E-06	1.08E−03	6.53E−04	2.84E−04	6.57E−01	1.40E−05
	Toluene	9.57E−03	5.90E−03	2.53E−03	3.93E−03		6.15E−03	3.79E−03	1.62E−03	4.58E−03	
	Ethylbenzene	1.03E−03	6.37E−04	2.73E−04	2.81E−03		6.64E−04	4.09E−04	1.25E−04	2.42E−03	
	m/*p*-xylene	2.92E−03	1.80E−03	7.71E−04	1.96E−02		1.88E−03	1.16E−03	4.95E−04	2.28E−02	
	o-xylene	1.33E−03	8.22E04	3.52E−04	3.83E−03		8.57E−04	5.28E−04	2.26E−04	4.47E−03	
Summer	Benzene	1.24E−03	7.71E−04	3.33E−04	4.2E−01	8.93E−06	8.03E−04	4.95E−04	2.12E−04	4.90E−01	1.04E−05
	Toluene	6.79E−03	4.18E−03	1.79E−03	2.78E−03		4.36E−03	2.68E−03	1.15E−03	3.25E−03	
	Ethylbenzene	1.37E−03	8.47E−04	3.63E−04	2.76E−03		8.82E−04	5.44E−04	2.33E−04	3.22E−03	
	m/*p*-xylene	2.26E−03	1.39E−03	5.99E−04	1.52E−02		1.453E−03	8.97E−04	3.85E−04	1.77E−02	
	o-xylene	9.64E−04	5.94E−04	2.55E−04	2.77E−03		6.19E−04	3.82E−04	1.64E−04	3.23E−03	

in winter and summer, respectively, which means males were at possible risk.

Conclusions

We have determined the TVOC and BTEX concentrations in the indoor microenvironments and outdoors for two seasons in the library of a university. The main objective of this study was to measure IAQ in terms of VOCs. Mean concentrations of TVOC indoors were higher in winter (465.8 μg/m^3) as compared to summer (321.8 μg/m^3). Among BTEX, toluene had greater mean concentrations of 94.0 and 66.7 μg/m^3 in winter and summer, respectively. The photostat room was the most polluted microenvironment in both seasons.

The mean I/O ratios for TVOC and BTEX compounds were greater than 1; it confirms that ambient environment had less influence than indoor sources inside the library building. After correlation analysis, a significant correlation between the BTEX compounds was observed, suggesting they have common sources. The assessment of LCR based on the data investigated in this study to benzene exceeded the value (1×10^{-6}) recommended by USEPA for both males and females. On the other hand, HQ of non-cancer risk to BTEX was found to be within the acceptable range.

To avoid any health hazards caused by air pollution, urgent preventive measures for the reduction of effective sources are needed. To reduce VOC levels in the indoor environment, it will be necessary to eliminate the sources of chemicals through a better choice of construction and building/furnishing materials. Ventilation can have a considerable influence on the levels of VOCs in indoor air. So, there must be good ventilation conditions in the building. In order to achieve a healthy environment, it is necessary not only to have clean outdoor air but also to restrict the use of consumable products and chemicals containing VOCs in the indoor environments and to use alternative safe solvents in consumable products.

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