Indoor Air 2014
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INDOOR AIR
doi:10.1111/ina.12096

Determination of volatile organic compounds and associated health risk assessment in residential homes and hostels within an academic institute, New Delhi

Abstract The purpose of this study was to investigate the concentrations of volatile organic compounds (VOCs) in different indoor microenvironments of residential homes and hostels in an academic institute, in New Delhi, during March–May 2011. Eleven VOCs (aromatic and halogenated) were assessed. Sampling and analytical procedure were based on National Institute for Occupational Safety and Health (NIOSH) standard method. The lifetime cancer and non-cancer risk were calculated for targeted VOCs using US Environmental Protection Agency guidelines. The mean concentrations of $\sum$ VOCs (sum of monitored VOCs) and individual VOC were found to be higher indoors as compared to outdoors at both types of premises. Indoor to outdoor (I/O) ratios of the targeted VOCs exceeded 1.0, suggesting the significant presence of indoor sources. Strong correlations between I/O concentrations of VOCs in the current study suggest the presence of common sources. Factor analysis (FA) was used for source evaluation separately at two premise types. The estimated lifetime cancer risks in the current study for all occupants at both premises exceeded 10^{-6}.

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Key words: Volatile organic compounds; Hostels; Indoor-outdoor ratio; Factor analysis; Lifetime cancer risk; Hazard quotient.

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Received for review 23 September 2013. Accepted for publication 11 January 2014.

Practical Implications

The present work describes the comparison between indoor VOC concentrations and those outdoors at two types of premises (homes and hostels) in an academic institute in India. The observed concentrations of VOCs were mainly associated with household products, building furnishing materials, and personal care products. It was found that benzene contributed the most among the VOCs monitored for cancer and non-cancer risks.

Introduction

Clean air is an essential requirement for healthy existence of humans. Emphasis on indoor air pollution research within the scientific community has been increasing due to its influence upon human health (Bruno et al., 2008). Research results suggest that indoor air is commonly more polluted than outdoor due to emissions from indoor sources and low ventilation rates in many indoor environments (Bruno et al., 2008; Tovalin-Ahumada and Whitehead, 2007). Indoor air quality is influenced by various pollutants such as volatile organic compounds (VOCs), formaldehyde, particulate matter, ozone, tobacco smoke, polyaromatic hydrocarbons and biological contaminants (Kulshrestha et al., 2008; Lü et al., 2010; Weschler, 2000). VOCs are one of the key group of indoor air pollutants and may be emitted from building furnishing materials, cooking, solvents, cleaning agents, and personal care products (Barro et al., 2009; Huang et al., 2011).

Several studies have been shown that indoor exposure to VOCs is associated with a variety of adverse health effects (Geiss et al., 2011; Salonen et al., 2009). Many VOCs are toxic, and among them, some are known or suspected to be carcinogenic (Civan et al., 2012). The potential health risks include a range of effects, including irritation of the eyes and respiratory tract and sensory, neurotoxic, and hepatotoxic disorders (de Blas et al., 2012; Guo et al., 2004a; Loh et al., 2006; Molhave, 2003; Zhou et al., 2011). Several studies have shown that outdoor concentrations of VOCs contribute only partially to total human risk associated with VOC exposure (Loh et al., 2006; Payne-Sturges et al., 2003; Sax et al., 2006). To reduce the hazards, many agencies have established exposure limits or guidelines for VOCs. The guideline values recommended by various agencies such as the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA), the Commission of European Communities, and the government of Hong Kong vary significantly for different VOCs. According to a European Union directive (December 2000), an acceptable concentration of benzene is 5 μg/m^3 on an annual average basis (Massolo et al., 2010). USEPA and WHO have established regulatory decision guidelines about VOCs for quantitative risk assessment (cancer risk and non-cancer risk) (Ramírez et al., 2012). In quantitative risk assessment, two parameters such as lifetime cancer risk (LCR) and hazard quotients (HQ) are used for cancer and non-cancer risk estimation.

Previous studies have reported indoor levels of VOCs in various cities around the world in different types of indoor environments such as homes, offices, schools, shopping malls, and hospitals (Brickus et al., 1998; Lü et al., 2006, 2010; Massolo et al., 2010; Ohura et al., 2006, 2009; Pegas et al., 2011; Roda et al., 2011; Tang et al., 2005). Few studies have reported VOC measurements in institutional campuses where a large population of students and employees (including teaching and non-teaching staffs) reside (Hori et al., 2012; Jo and Kim, 2010). The present study investigates VOCs concentrations in the indoor and outdoor environment of residential homes and hostels within a university campus in New Delhi, India. The data are further examined for understanding indoor/outdoor relationships and to ascertain the potential sources using factor analysis. The results obtained were compared with the USEPA guideline given for cancer and non-cancer risk.

Materials and methods

Sampling sites

The sampling sites were located in the campus of Jawaharlal Nehru University (JNU) in New Delhi, India's capital city, situated at 28.61°N and 77.23°E. New Delhi is a humid sub-tropical city with annual maximum temperatures of ~ 45–48°C in summer and minimum temperatures of ~ 1–2°C during winter. The university campus covers an area of 404 hectares, which is occupied by buildings and green areas, enriched with natural flora and fauna. The campus is devoid of any industrial activity; however, it is adjoined by a huge commercial zone in the west. Additionally, there are few vehicular emissions inside the campus, but major roads span three sides around its periphery. JNU is a residential university having student strength of over 7000 residing in different hostels within the campus. It also houses about 1500 employees, which include teaching and non-teaching staff with their families. Sampling was carried out at eighteen premises – nine residential homes and nine hostels – within the campus. The two different types of premises have certain characteristic differences in terms of age, occupants, room size, indoor furnishing materials, and activities. The age of the two types of premises ranged from 1 to 25 years. The main interior decorating materials used were plastered wall, tiles, and concrete flooring. Information concerning the sampling sites is shown in Table 1. Each residential home was occupied by a single family consisting of an average of five to seven people. In each hostel, approximately 350 people (students and workers) reside. Consequently, the kitchen of a hostel is different as compared to a residential home in which food is made in the hostel kitchen for approximately 350 people. Inside hostels, the dining hall is well connected to the kitchen. Kitchen ventilation in the two types of premises was provided by exhaust fans or open windows.

Sample collection

Sampling was carried out during the period of March–May 2011, and four sets of identical sampling equipment were assembled for this study. Three microenvironments were selected for sampling at homes (living room, bedroom, and kitchen) as well as in hostels (living room, kitchen, and dining hall) (Table S1). To measure indoor contaminants, indoor VOCs samples were collected from homes (N = 27) and hostels (N = 45). In indoor locations, VOCs samples were taken at a height of approximately 1.5 meters above the floor in the center of the sampled room. The outdoor samples (N = 18) were also taken simultaneously near the vicinity of the building. The distance between indoor and outdoor sampling sites varied from 1 to 5 m.

Sampling and analytical procedure were performed using standard NIOSH methods 1003 and 1501 for

Table 1 Physical characteristics and sampling conditions of the homes and hostels investigated

	Age of building (y)	Room volume (m^3)	Room Height (m)	Occupants	Indoor temp. (°C)	Outdoor temp. (°C)	Indoor RH (%)	Outdoor RH (%)	Cooking fuel	Frequency of cleaning
Home	5–25	34.8–785.5	2.4–4.2	Male, female, children	22.1 ± 1.23	21.3 ± 2.5	37.3 ± 2.4	40.5 ± 6.5	LPG	Daily
Hostel	1–25	36.2–65.5	2.4–3.6	Workers, students	26.6 ± 1.43	24.7 ± 3.5	41.2 ± 4.7	45.6 ± 5.4	LPG	Once or twice per day

RH, Relative humidity.

measuring VOCs. Eleven priority VOCs were investigated: benzene, toluene, m/p-xylene, o-xylene, methylene chloride (MC), chloroform ($CHCl_3$), carbon tetrachloride (CCl_4), trichloroethylene (TCE), tetrachloroethene (PERC), 1,4-dichlorobenzene (1,4-DCB), and 1,1,1-trichloroethane (1,1,1-TCE). Hazardousness of these eleven VOCs for humans was the main criterion for their selection (Ramírez et al., 2012; Zhou et al., 2011).For the collection of VOCs, we used Orbo^{TM}-32 charcoal tubes (7 cm in length × 6 mm o.d., from Supelco).The air was drawn through the sampling tube by an indigenous portable sampler (Satyam Scientific Instruments Company, New Delhi) at a flow rate of 100 ml/min for 3 h. After sample collection, the open sides of Orbo^{TM}-32 tubes were closed with Teflon tape to prevent further change. Then, the tubes were labeled, wrapped with aluminum foil, and stored in a refrigerator (<4°C) until analysis. In addition, measurements of thermal comfort parameters (temperature and relative humidity) were carried out during VOC sampling (Table 1).

Analytical procedure

Activated charcoal from Orbo^{TM}-32 tubes was transferred to 2-ml amber-colored glass vial. After that, 1-ml of low-benzene CS_2 (99% purity with less than 0.001% benzene, purchased from Supelco) was added as an extraction solvent, and it was put into an ultrasonication bath for 30 minutes. The extracted samples were stored in the freezer and analyzed using a gas chromatograph. The GC (Auto sampler AOC-20i, GC-2010, Shimadzu, Kyoto, Japan) equipped with capillary column RTX-VGC (75 m, 0.45 mm ID, and 2.55 μm film thickness) and FID detector was used to separate and analyze VOCs. The initial oven temperature was 40°C (hold time 6 min), which was then raised to 200°C at a rate of 6°C/min (hold time 6 min). Identification and quantification of targeted compounds was achieved by their retention time in relation to calibration VOC standards (JMHW VOC mix, 1000 μg/ml each in methanol, procured from Supelco) under the specified chromatographic conditions.

Risk calculation

To assess the hazards of VOC exposures, the lifetime cancer risk (LCR) and non-cancer risk (HQ) was calculated by using US Environmental Protection Agency conventional approaches (USEPA, 1997). The LCR and HQ were calculated from Equations (1) and (2), respectively.

$$\mathrm{LCR} = \mathrm{DI} \times \mathrm{SF} \tag{1}$$

$$\mathrm{HQ} = \mathrm{DI}/\mathrm{RfD} \tag{2}$$

where DI is the daily intake (mg/kg/d), SF is slope factor $(\mathrm{mg/kg/d})^{-1}$, and RfD is reference dose (mg/kg/d) of the chemical. Hazard index (HI) is a measure of the overall potential for non-carcinogenic effects posed by more than one chemical. HI is calculated by adding the hazard quotients of all individual organic contaminants (HI = $\sum$HQ). Equation (3) was used for calculating the daily intake (DI) for each compound:

$$\mathrm{DI} = \frac{\mathrm{CA} \times \mathrm{IR} \times \mathrm{ET} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT} \times 1000} \tag{3}$$

where CA is the VOC concentration (μg/m^3), IR is an inhalation rate (m^3/h), ET is the exposure time (h/day), EF is exposure frequency (day/y), ED is the exposure duration (y), BW is a body weight (kg), AT is averaging time (y), and 1000 is the conversion factor (μg/mg).

Inhalation rates of 0.83 and 0.87 m^3/h for adults and children and body weights of 70, 60, and 36 kg for male, female, and children were used, respectively. In this study, exposure time (ET) has been considered as 12 h for males and children because they spend at least half of the day in indoors, whereas women (housewives) spend the whole day (24 h) inside homes. Workers are assumed to spend on an average 12 h of the whole day in hostels.

Exposure frequency was considered 350 days in a year for homes and hostels because generally people take 15 days as vacation to outside. In our study, exposure duration (ED) was assumed to be 40 years. Averaging time (AT) of 70 years was applied to all groups of individuals. The inhalation reference doses (RfD) and slope factors (SF) used in this study are listed in Table 2.

Statistical analysis

Statistical analyses were performed by using SPSS (version 16.0.; SPSS Inc., Chicago, IL, USA) and MATLAB (R2011b; MathWorks, Natick, MA, USA) software. Concentrations below the detection limit were substituted by one-half of the detection limit. Indoor and outdoor levels were compared with

Table 2 Reference doses and carcinogenic slope factors (USEPA, 1998)

Chemical	Reference dose (mg/kg/d)	Carcinogenic slope factor $(\mathrm{mg/kg/d})^{-1}$
Benzene	0.00171	0.029
m/p-Xylene	0.0857	–
o-Xylene	0.2	–
$CHCl_3$	0.00571	–
CCl_4	0.000571	0.0525
TCE	–	0.006
PERC	–	0.00203
1,1,1-TCE	0.286	–

paired-sample *t*-test. Correlations between parameters were evaluated using Pearson correlation coefficients. To evaluate the sources of organic pollutants, factor analysis was used. A significance value of 0.05 was used in all statistical testing.

Results and discussion

VOC concentrations

The concentrations of VOCs in the indoor and outdoor air of homes and hostels are shown in Table 3. Total VOCs ($\sum$ VOC) refer to sum of all detected VOCs in current study. $\sum$ VOC in indoor sites for homes ranged from 33.6 to 107.2 μg/m^3, while concentrations for outdoor sites ranged from 21.7 to 37.9 μg/m^3. Higher concentrations of $\sum$ VOC were detected in living rooms, followed by kitchens and bedrooms for homes. Toluene had the highest concentration among the targeted VOCs in indoor (30.7 μg/m^3) and outdoor (9.2 μg/m^3) air. Benzene was the next highest organic contaminant in both indoor (7.8 μg/m^3) and outdoor (3.6 μg/m^3) air. Mean concentrations of toluene in kitchens, living rooms and bedrooms were 30.6, 32.9 and 28.7 μg/m^3, respectively. Chlorinated hydrocarbons were found to be significantly lower than the benzene, toluene and xylene-isomers (BTX) compounds. Mean concentrations of $\sum$ VOC in hostels were 119.5 and 83.1 μg/m^3 for indoors and outdoors, respectively. Trends of $\sum$ VOC concentrations were kitchens (170.9 μg/m^3) > dining halls (122.1 μg/m^3) > living rooms (65.6 μg/m^3). Similar to homes, toluene was the most abundant among VOCs in both indoor and outdoor sites at hostels. After toluene, m/p-xylene was present at the next highest concentration followed by benzene.

Figure 1 shows the indoor VOC concentrations in homes compared with those in hostels. The results of $\sum$ VOC and individual VOCs were found to be higher for indoors at hostels as compared to homes. The hostel to

Table 3 Summary of concentrations (μg/m^3) of VOCs for indoor and outdoor air in homes and hostels

	Kitchen (n = 9)		Living room (n = 9)		Bedroom (n = 9)		Outdoor (n = 9)				
Homes	Mean ± s.d.	Range	Mean ± s.d.	Range	Mean ± s.d.	Range	Mean ± s.d.	Range	I/O Corr.[b]	I/O[c] ± s.d.	I/O P value[d]
Benzene	7.9 ± 3.5	3.9–14.1	8.2 ± 3.7	3.5–15.6	7.3 ± 3.2	4.3–14.1	3.6 ± 1.4	2.0–5.6	0.92[a]	2.2 ± 0.3	0.000
Toluene	30.7 ± 13.7	11.6–54.5	32.9 ± 18.6	11.6–59.6	28.8 ± 13.9	11.5–49.8	9.2 ± 4.1	4.2–16.6	0.72[a]	3.5 ± 1.0	0.028
m/p-Xylene	4.2 ± 1.3	2.5–6.1	5.4 ± 2.0	3.2–9.5	4.7 ± 2.6	2.8–11.3	2.3 ± 0.7	1.3–3.4	0.59	2.2 ± 0.7	0.001
o-Xylene	1.8 ± 0.9	0.8–3.4	2.3 ± 1.4	1.1–5.4	1.9 ± 0.9	0.9–3.8	1.1 ± 0.5	0.8–2.3	0.52	1.8 ± 0.6	0.012
MC	4.4 ± 2.4	1.3–8.1	3.7 ± 2.1	nd–5.7	2.9 ± 2.0	nd–5.9	2.5 ± 1.2	1.7–5.4	0.34	1.7 ± 1.6	0.032
$CHCl_3$	2.0 ± 0.8	0.9–3.3	1.7 ± 1.0	nd–2.6	1.0 ± 0.5	nd–1.3	1.5 ± 0.8	0.6–3.1	0.26	1.4 ± 0.6	0.529
CCl_4	0.7 ± 0.3	0.4–1.4	1.0 ± 0.5	nd–1.6	1.0 ± 0.6	nd–1.6	1.3 ± 0.5	0.7–2.2	0.29	0.8 ± 0.3	0.073
TCE	2.6 ± 1.3	0.8–4.7	2.2 ± 1.2	nd–3.4	2.2 ± 1.1	nd–2.6	1.8 ± 0.9	0.5–3.5	0.82[a]	1.4 ± 0.5	0.016
PERC	4.2 ± 1.5	1.5–6.3	2.9 ± 1.5	nd–3.7	1.9 ± 0.8	nd–3.2	1.7 ± 0.8	0.9–2.9	0.64	2.1 ± 0.8	0.000
1,4-DCB	3.7 ± 1.5	1.7–5.9	3.3 ± 2.1	nd–6.4	1.6 ± 1.1	nd–3.7	2.2 ± 1.0	0.9–4.1	0.94[a]	1.5 ± 0.3	0.001
1,1,1-TCE	1.3 ± 0.6	0.4–2.1	1.7 ± 1.0	nd–2.9	1.2 ± 0.7	nd–1.7	1.2 ± 0.3	0.9–2.0	0.52	1.3 ± 0.3	0.205
Sum of measured VOCs ($\sum$ VOC)	61.6 ± 8.5	38.9–89.7	70.9 ± 9	39.4–107.2	53.1 ± 8.2	33.6–87.3	28.3 ± 2.3	21.8–37.9			

	Kitchen (n = 9)		Dining hall (n = 9)		Living room (n = 27)		Outdoor (n = 9)				
Hostels	Mean ± s.d.	Range	Mean ± s.d.	Range	Mean ± s.d.	Range	Mean ± s.d.	Range	I/O Corr.[b]	I/O[c]±s.d.	I/O P value[d]
Benzene	36.0 ± 20.3	11.1–78.0	15.3 ± 5.0	6.7–23.4	9.9 ± 9.6	1.6–42.1	21.4 ± 23.8	7.5–84.2	0.78[a]	1.4 ± 0.6	0.875
Toluene	55.2 ± 19.6	29.0–84.0	41.1 ± 21.0	14.4–80	27.7 ± 14.5	7.1–56.3	23.3 ± 9.3	12.1–40.8	0.92[a]	1.8 ± 0.4	0.000
m/p-Xylene	37.2 ± 13.7	19.6–55.6	30.0 ± 17.3	15.8–69.4	11.1 ± 6.7	1.6–25.6	17.1 ± 4.6	11.8–26.9	0.88[a]	1.5 ± 0.2	0.000
o-Xylene	14.7 ± 4.1	8.4–20.4	11.0 ± 4.5	7.2–22	4.4 ± 2.7	0.9–11.2	5.2 ± 1.8	3.1–8.2	0.41	2.1 ± 0.7	0.000
MC	9.6 ± 6.0	2.4–23.1	6.4 ± 2.1	3.4–9.6	2.6 ± 1.4	nd–3.7	6.3 ± 4.4	1.3–14.7	0.80[a]	1.6 ± 1.6	0.619
$CHCl_3$	2.6 ± 1.0	1.4–4.6	2.1 ± 0.9	1.0–3.7	1.1 ± 0.6	nd–1.6	1.4 ± 0.7	0.5–2.3	0.27	2.0 ± 1.4	0.031
CCl_4	1.9 ± 0.9	0.9–3.6	1.5 ± 0.4	0.9–2.2	0.7 ± 0.3	nd–0.8	1.0 ± 0.3	0.6–1.6	0.37	1.5 ± 0.5	0.011
TCE	2.8 ± 1.3	1.2–4.5	3.4 ± 1.9	1.3–7.6	1.3 ± 0.7	nd–1.7	2.0 ± 1.0	0.5–3.6	0.89[a]	1.5 ± 0.6	0.002
PERC	4.2 ± 1.8	1.9–7.4	3.0 ± 1.4	1.4–5.7	1.6 ± 0.6	nd–2.6	1.9 ± 1.1	1.0–4.2	0.73[a]	1.9 ± 0.7	0.004
1,4-DCB	4.8 ± 2.9	1.7–9.7	3.9 ± 2.1	1.2–7.5	1.4 ± 0.5	nd–2.2	2.4 ± 1.6	1.0–4.0	0.66[a]	1.7 ± 0.8	0.009
1,1,1-TCE	1.8 ± 0 .4	1.1–2.5	1.8 ± 0.7	0.9–2.9	0.9 ± 0.2	nd–1.1	1.1 ± 0.4	0.5–1.7	0.26	1.7 ± 0.9	0.004
Sum of measured VOCs ($\sum$ VOCs)	170.9 ± 18.5	94.3 ± 227.2	122.1 ± 13.1	75.5–212.3	65.6 ± 8.0	34.4–83.2	83.1 ± 8.7	58.8–129.3			

n, Number of samples; s.d., Standard deviation; nd, not detected, Detection limit range for all compounds: 0.2–0.3 μg/m^3.

[a] $P < 0.05$.

[b] Indoor/outdoor correlation coefficient.

[c] Indoor/outdoor concentration ratios.

[d] P values were calculated from paired-sample *t*-test, for comparing indoor and outdoor concentrations.

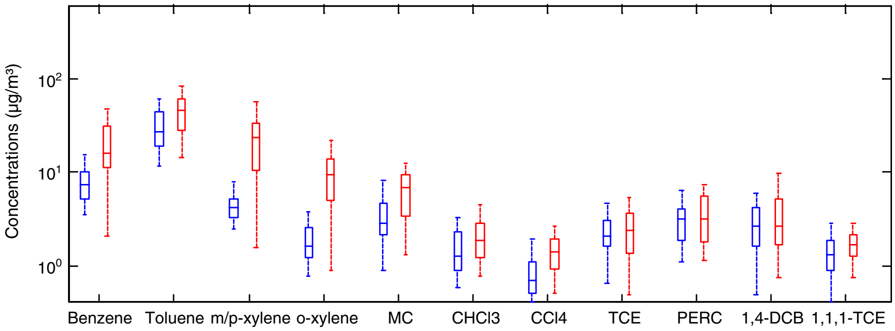

Fig. 1 Comparison of VOC concentrations (μg/m^3) in homes and hostels. Boxes show 25–75th percentiles. The upper and lower bars show the maximum and minimum values. Lines inside boxes show the median values. Concentrations in homes and hostels are presented with blue and red, respectively

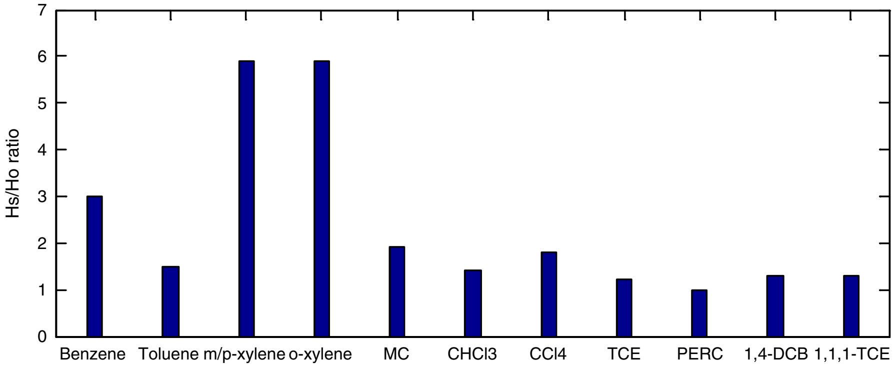

Fig. 2 Distribution of hostel to home concentration ratios for VOCs

home ratio (Hs/Ho) is depicted for all compounds in Figure 2. The observed Hs/Ho ratio ranged from 0.99 to 5.85 suggesting the presence of stronger indoor emission sources inside the hostels. There was no significant difference observed for most of the compounds in the three microenvironments of homes (paired-sample *t*-test, $P < 0.05$). However, kitchen and dining hall concentrations were significantly higher than the living room for most of the compounds inside the hostels. The relatively high concentrations of VOCs in the kitchen might be due to large scale cooking practices (baking, frying, roasting, broiling, etc.) being done for students and workers. In hostels, dining halls were well connected with kitchens; therefore, concentrations were also observed to be higher in the dining hall. Low concentrations of VOCs in living rooms were observed; it could be due to living rooms frequently being independent of kitchen and dining hall. Previous studies reported that fuel combustion and cooking activity results in higher levels of aromatic hydrocarbons (Baek et al., 1997; Huang et al., 2011; Lee et al., 2001). Moreover, several sources such as household products, consumer products (e.g., detergents and air fresheners), furnishing materials, paints and decorations are contributing agents of VOCs in indoor environments (Jia et al., 2008; Massolo et al., 2010; Sofuoglu et al., 2010).

Literature comparison

Mean indoor concentrations of two premises in the current study were compared with the results of other indoor places around the world and a significant difference was observed between the concentrations as shown in Table 4. In general, the mean concentrations of BTX and chlorinated hydrocarbons in the current study that we observed were higher than those found elsewhere (Godwin and Batterman, 2007; Ohura et al., 2006; Parra et al., 2008; Weisel et al., 2008; Wu et al., 2011). However, the mean concentrations of BTX were comparable with those studies carried out in different indoor buildings (Baek et al., 1997; Chan et al., 2009; Jia et al., 2008; Jo and Kim, 2010; Ongwandee et al., 2011). Indoor concentration of 1,4-DCB in this study was much lower (3.1and 2.9 μg/m^3 at home and hostel, respectively) than those found elsewhere (Ohura et al., 2006; Weisel et al., 2008). Moreover, the mean concentrations of benzene in both types of premises exceeded the standard limit 5 μg/m^3 prescribed by the European Union (Massolo et al., 2010). The indoor levels of BTX and chlorinated hydrocarbons in the present study were found to be within the limits adopted by the Hong Kong Government (Srivastava and Devotta, 2007).

Table 4 Comparison of the mean concentrations of VOCs in indoor air with other studies (μg/m^3)

Sampling sites	Reference	Benzene	Toluene	Xylenes	MC	$CHCl_3$	CCl_4	TCE	PERC	1,4-DCB	1,1,1-TCE	
Homes	Present study	7.8	30.8	3.4	3.6	1.6	0.9	2.3	3.0	2.9	1.4	AM
Hostels	Present study	20.4	41.3	18.1	6.2	1.9	1.4	2.5	2.9	3.4	1.4	AM
Homes (summer)	Ohura et al. (2006)	0.99	11.50	1.50		0.25	0.53	0.22	0.16	29.6	0.29	GM
Homes (winter)	Ohura et al. (2006)	2.69	25.90	4.08		0.92	0.75	0.36	0.16	42.8	0.35	GM
Homes	Winkle and Scheff (2000)	4.1	15.3	23.1	140	1.8	0.51	0.48	2.6	2.97	24.9	AM
Homes	Jia et al. (2008)	2.84	15.56	5.21		0.72	1.00	0.06	0.93	4.51	0.47	AM
New hotel	Chan et al. (2009)	9.90	81.42	15.84	6.16	0.91	0.75	9.15	1.74		0.33	AM
Commercial. buildings	Wu et al. (2011)	0.69	4.47	1.25	0.83	0.3	0.46	0.02	0.18	0.05		GM
Office	Ongwandee et al. (2011)	8.08	110	10.8		1.10		0.56	0.92			AM
School	Godwin and Batterman (2007)	0.09	2.81	1.26		0.09		0.02	0.02			AM
Pubs and cafes	Parra et al. (2008)	2.25	8.96	1.75					0.44			AM
Restaurant	Baek et al. (1997)	12.0	52.0	17.4								AM
Research laboratories	Jo and Kim (2010)	9.4	31.0	6.6			0.6	8.3	4.3	2.0	6.1	AM

Xylenes, sum of Xylene-isomers.

Indoor/outdoor ratios and correlations

Indoor/outdoor ratios with standard deviation and related correlation coefficients (*r*) were evaluated for the targeted VOCs measured in homes and hostels (Table 3). Additionally, to determine the differences between indoor and outdoor levels; an indoor-outdoor paired-sample *t*-test was also calculated.

Firstly, the I/O ratio was calculated for each sample and then the average ratio was calculated. The I/O ratio is an indicator of whether indoor levels are influenced by significant indoor sources or penetration from outdoor sources (Tang et al., 2005). In this study, I/O ratios for VOCs varied between 0.77 to 3.5 and 1.35 to 2.1 for homes and hostels, respectively. For most of the VOCs, indoor mean concentrations were found to be significantly higher (paired-sample *t*-test, $P < 0.05$) than the outdoor mean concentrations at two types of premises. For most of the VOCs, the mean I/O ratios exceeded 1.0, suggesting the significant presence of indoor sources (Pekey and Arslanbas, 2008; Son et al., 2003). Our study is comparable with the work carried out by Lü et al. (2010) and Pekey and Arslanbas (2008). They reported that indoor concentrations were significantly higher than outdoors for most of the VOCs.

Pearson correlation coefficients (*r*) were also evaluated to investigate the relationship between indoor and outdoor datasets for both premises (Table 3). In general, targeted indoor concentrations of VOCs showed strong correlation with outdoor concentrations in hostels as compared to homes. Except benzene, toluene, TCE and 1,4-DCB, the rest of the compounds showed no statistical significant correlation between I/O values inside homes. This finding confirms that indoor sources have stronger impact than outdoor sources on indoor concentrations. A study performed at a residential area in Korea (Son et al., 2003) and in child care centers in Singapore (Zuraimi and Tham, 2008) observed strong correlations for indoor and outdoor VOCs.

Source identification

Factor analysis with varimax rotation was performed on the whole data set at two types of premises to assess the sources and possible relationships among the variables. Factor analysis has been widely used as a multivariate statistical method for identifying sources of indoor VOCs (Guo et al., 2004b; Lü et al., 2010). Eigen values greater than 1 were fixed for extracting factors, and factor loadings >0.5 were considered as significant contributions from the organic pollutants. An association of VOCs with more than one factor suggests emissions from more than one source (Guo et al., 2004b). Table 5 describes loadings of the factors, communalities of VOCs, fractions of variances explained by each factor, and total variances for two data sets.

For the indoor dataset of two premises (homes and hostels), the analysis identified four factors which accounted for 84.6% and 79.5% of the total variance, respectively. After varimax rotation, factor 1–4 for homes retained 27.7%, 26.4%, 18.9%, and 11.5% of the variance, respectively. However, for hostels, it accounted for 30.3%, 19.4%, 15.4%, and 14.3% of the total variance. The first factor (F1) for homes was associated with benzene, toluene, m/p-xylene, and o-xylene. Similarly, F1 for hostels was also associated with benzene, toluene, m/p-xylene, o-xylene, and 1,4-DCB. These VOCs are likely to be related to gasoline vapor and combustion products (Jia et al., 2008). Office equipment and building-related materials emit toluene, xylene-isomers, and 1,4-DCB (Jo and Kim, 2010). Additionally, 1, 4-DCB is emitted from essential oils and mothballs used for clothing storage (Chin et al., 2012; Ohura et al., 2006).

The second factor (F2) for homes was correlated with $CHCl_3$, CCl_4, TCE, and 1,1,1-TCE. Similarly, F2 for hostels was associated with $CHCl_3$, PERC, and 1,1,1-TCE. These VOCs are mainly emitted from using chlorine bleach household products, industrial

Table 5 Factor analysis (FA) of targeted indoor VOCs in homes and hostels

	Homes					Hostels				
	F1	F2	F3	F4	Comm.	F1	F2	F3	F4	Comm.
Benzene	0.89				0.93	0.69				0.68
Toluene	0.85				0.87	0.86				0.86
m/p-Xylene	0.86				0.89	0.84				0.80
o-Xylene	0.83				0.89	0.91				0.93
MC				0.90	0.90				0.85	0.83
$CHCl_3$		0.69			0.67		0.89			0.85
CCl_4		0.93			0.89			0.78		0.74
TCE		0.87			0.77			0.87		0.80
PERC			0.89		0.90		0.82			0.78
1,4-DCB			0.88		0.86	0.53			0.80	0.88
1,1,1-TCE		0.74			0.70		0.66			0.56
Eigen value	3.05	2.91	2.08	1.27		3.33	2.13	1.69	1.57	
%age variance	27.8	26.5	18.9	11.5		30.3	19.4	15.4	14.3	
%age cumulative variance	27.8	54.2	73.2	84.7		30.3	49.7	65.2	79.5	

Table 6 The estimated non-cancer risk for different occupants in two premises

	Homes			Hostels	
	Adult male	Adult female	Children	Male worker	Female worker
Benzene	0.38	0.89	0.52	0.85	0.91
m/p-Xylene	5×10^{-3}	0.01	6×10^{-3}	0.02	0.02
o-Xylene	8×10^{-4}	2×10^{-3}	1×10^{-3}	3×10^{-3}	4×10^{-3}
$CHCl_3$	0.02	0.06	0.03	0.03	0.03
CCl_4	0.13	0.30	0.17	0.19	0.21
1,1,1-TCE	4×10^{-4}	9×10^{-4}	5×10^{-4}	4×10^{-4}	5×10^{-4}
Hazard Index	0.5	**1.3**	0.7	**1.1**	**1.2**

Hazard index values > 1.0 are shown in bold.

Table 7 The estimated cancer risk for different occupants in two types of premises

	Homes			Hostels	
	Adult male	Adult female	Children	Male worker	Female worker
Benzene	$\mathbf{2 \times 10^{-5}}$	$\mathbf{4 \times 10^{-5}}$	$\mathbf{3 \times 10^{--5}}$	$\mathbf{4 \times 10^{-5}}$	$\mathbf{5 \times 10^{-5}}$
CCl_4	4×10^{-6}	9×10^{-6}	5×10^{-6}	6×10^{-6}	6×10^{-6}
TCE	1×10^{-6}	3×10^{-6}	2×10^{-6}	1×10^{-6}	1×10^{-6}
PERC	5×10^{-7}	1×10^{-6}	7×10^{-7}	5×10^{-7}	6×10^{-7}
Total risks	$\mathbf{2 \times 10^{-5}}$	$\mathbf{6 \times 10^{-5}}$	$\mathbf{3 \times 10^{-5}}$	$\mathbf{5 \times 10^{-5}}$	$\mathbf{5 \times 10^{-5}}$

Risks > 1×10^{-6} are shown in bold.

solvents, and pesticides (Mukund et al., 1996; Odabasi, 2008; Ohura et al., 2006; Roda et al., 2013). In indoor air, $CHCl_3$ can have different sources including chlorinated tap water and cleaning with bleach products or with products that use chloroform as a solvent (Ongwandee et al., 2011). The third factor (F3) for homes was associated with PERC and 1,4-DCB, while for hostels, it was correlated with CCl_4 and TCE. These VOCs are markers of adhesives, paints, and insecticidal fumigants (Jia et al., 2008; Roda et al., 2013). The fourth factor (F4) for homes was associated only with methylene chloride. For hostels, this factor was linked with methylene chloride and 1,4-DCB. These compounds are mainly emitted from aerosol consumer products, dyes, and air fresheners (Chin et al., 2013; Weisel et al., 2008).

Health risk assessment

From the obtained concentrations of VOCs, non-carcinogenic (HQ) and carcinogenic risks (LCR) were assessed with conventional approaches. The estimated risks in the current study were based on the assumption of lifetime exposure to indoor VOCs. The obtained results are not actual risk values and are generally regarded as being for screening purposes and for preliminary assessment. The calculated HQ and LCR for different occupants at two premises are presented in Tables 6 and 7, respectively.

At homes, the hazard quotients ranged from 8×10^{-4} to 0.9. None of the values exceeded the threshold of 1 (Hoddinott and Lee, 2000). Moreover, the hazard index (sum of individual HQ) exceeded the threshold value only for adult females (1.3). At the hostels, hazard indices (HI) estimated for male workers and female workers were 1.1 and 1.2, respectively, which exceeds slightly the threshold value. Benzene showed the highest contributions to the total non-cancer hazard among organic contaminants. Hazard indices evaluated in the current study were also comparable with those found elsewhere (Durmusoglu et al., 2010; Kumar et al., 2013; Vilavert et al., 2012). It has been reported that HQ values >0.1 indicate a potential concern (Ramírez et al., 2012).

Benzene contributed the most to the overall cancer risk (LCR) for all occupants of the two premises. The evaluated LCR at homes was estimated to be 2×10^{-5}, 6×10^{-5}, and 3×10^{-5} for adult male, adult female, and children, respectively. At hostels, LCR estimates were found to be 5×10^{-5} for workers of both genders. Therefore, the estimated total risks in the current study at both premises exceed 10^{-6}, a guideline limit value in some circumstances (Dutta et al., 2009). Estimated cancer risk in the current study is similar to those identified by Guo et al. (2004a), Hoddinott and Lee (2000), and Ohura et al. (2006) with distinct differences. However, Majumdar et al. (2008) and Lerner et al. (2012) estimated significantly higher LCR in different occupational environments.

Conclusions

In this study, the concentrations and source characteristics of VOCs in indoor and outdoor air for two types of premises (homes and hostels) in an institutional area in New Delhi were characterized. Results showed that the indoor concentrations of VOCs generally exceeded the outdoor concentration at both premises. The observed concentrations of $\sum$ VOC (sum of detected VOCs) at homes and hostels were 61.9 and 119.5 μg/m^3, respectively. Toluene was found to be the contaminant at the highest concentration in the two types of premises. Statistical analysis of the data indicates that generally indoor air concentrations were found to be significantly higher than outdoors. Pearson correlation highlights the strong correlation between indoor and outdoor concentrations of VOCs at hostels, while weak correlations were found at homes. The source characterization of VOCs was examined by factor analysis, and it was found that building-related materials, consumer products, and human activities are the major sources of VOCs in two types of premises. Cancer risk and non-cancer risk caused by inhalation for VOCs were estimated. Benzene accounted for maximum health hazard in the indoor air of homes and hostels. LCR and HQ for adult females were observed to be higher than those of adult males and children inside homes.

To prevent adverse health impact by VOCs inside the building, adequate measures should be taken to reduce indoor emission sources. Emission reductions can be done by using low VOC-emitting household products, good selection of decorating materials, and furniture. Apart from emission reductions, proper mechanism and management should be developed to maintain the quality of indoor air. This should include appropriate ventilation in areas of high continuous or intermittent source activity, for example, in kitchen/dining halls or where office equipment is used.

Acknowledgements

The study is supported by Research Grant (Junior Research Fellowship) from Council for Scientific and Industrial Research (CSIR), New Delhi, and Department of Science and Technology (DST), New Delhi. The authors would like to thank senior technical assistant Mr. R. Bhardwaj for his technical support.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Basic information about the sampling status at homes and hostels.

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