A pilot study on VOCs and carbonyl compounds in Chinese residences

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ABSTRACT
The concentrations of volatile organic compounds (VOCs) and carbonyl compounds were measured at 40 residences in three cities of China (30 from Chengdu, five each from Changsha and Beijing). Indoor, outdoor and personal exposure samples were simultaneously collected at each site. The average concentrations of benzene, toluene, xylene, especially benzene, were significantly higher than those of other countries both indoor and outdoor. There is significant correlation between indoor concentration and personal exposure of VOCs and carbonyl compounds. Mean of indoor/outdoor ratios of VOCs and carbonyl compounds exceeded 1. The relevance between indoor air concentrations of VOCs and carbonyl compounds and interior decoration was studied, it showed that interior decoration materials were significant sources of VOCs and carbonyl compounds in Chinese indoor environment.

INDEX TERMS
Volatile organic compounds; Carbonyl compounds; Indoor; Outdoor; Personal exposure

INTRODUCTION
In recent years, indoor air quality has caught the attention of scientists and the public in China. Volatile organic compounds (VOCs) and carbonyl compounds are a group of major indoor air pollutants that have been associated with many health effects including cancer (WHO, 1987). It is suspected that VOCs and carbonyl compounds are a major factor for 'sick building syndrome' (SBS) (Molhave et al., 1986).

VOCs and carbonyl compounds in the indoor environment originate not only from vehicle pollution entering from outdoors but also from building materials, furniture, smoking, cooking and the use of solvents. Field surveys of VOCs and carbonyl compounds in buildings have been conducted by many researchers worldwide especially in the developed countries (Schneider et al., 2000; Skov et al., 2000; Edwards et al., 2001; Lee et al., 2001). Several outdoor air quality studies showed that the concentrations of VOCs in cities of China are significantly higher than other countries (Liu et al., 2000; Wang, et al., 2002). However, few measurements about VOCs and carbonyl compounds related to indoor air quality in China were performed. In this study, indoor air concentration, outdoor air concentration and personal exposure of VOCs and carbonyl compounds were measured to characterize personal exposure and indoor air concentration level of VOCs and carbonyl compounds

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in Chinese residences, and to examine the correlation between indoor air concentration and personal exposure, indoor air concentration and interior decoration.

SAMPLING AND METHOD

Sampling Site

The study was carried out in Beijing, Changsha and Chengdu (Figure 1). The samples were collected from 40 residences (30 from Chengdu, five each from Changsha and Beijing) of the three cities. The population in the three cities is presented in Figure 1.

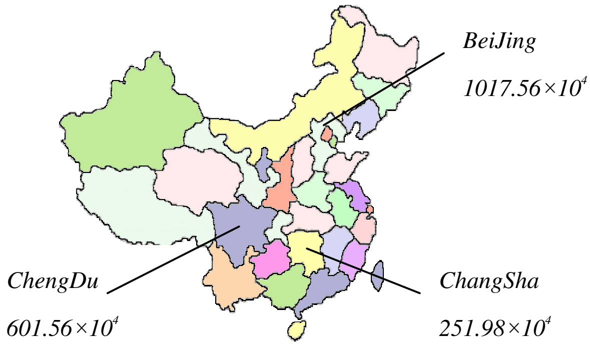

Figure 1 A background about the three cities of China (population in 2001).

Sampling

Passive sampling was applied in this study. Sampling was carried out within a week in all residences. Field blank samples were taken at every 10 residences.

Carbonyl compounds

Indoor, outdoor and personal exposure samples were simultaneously collected with 2,4-dinitrophenylhydrazine (DNPH) cartridges (Xpsoure, Waters Ltd, USA). Table 1 shows the sampling rate of the passive sampler. Each cartridge was sealed with Teflon caps immediately after sampling, then stored in an aluminum bag and refrigerated until analysis.

VOCs

Passive gas tubes (8015-066, Shibata, Kagaku, Japan) were used in this study. Palm charcoal (20–40 mesh) was used as adsorbent for VOC sampling. The sampling rate of the passive sampling is shown in Table 1. After sampling each sampler was put in aluminium bag and sealed until analysis.

Analysis

DNPH cartridges were eluted with 10 ml of HPLC-grade acetoneitrile (Wako Pure Chemicals Co. Ltd., Japan), and 20 μl aliquots were injected into a High Performance Liquid Chromatograph (Hewlet Packard 1100). VOCs were ultrasonic-extracted form the passive gas tubes for 10 min in 1-ml carbon disulphide (Wako Pure Chemicals Co. Ltd., Japan). The VOCs were determined by gas chromatography–mass spectrometry (GC–MS, HP6890-HP5973, Hewlett-Packard, USA). The details of the analytical conditions are shown in Tables 2 and 3.

RESULTS AND DISCUSSION

A total of 240 samples (120 samples for VOCs, 120 samples for carbonyl compounds) were collected and 12 VOCs and three carbonyl compounds were identified in this study.

General Results

The overall results of this study are shown in Table 4. The data were presented as mean, median, maximum, minimum and standard deviation. Toluene, benzene, xylene dominated the VOCs. A comparison of benzene, toluene, xylene concentrations in indoor environments and outdoor environments with other urban sites are presented in Tables 5 and 6. This is especially obvious for benzene; the concentration of benzene in this study, for both indoor and outdoor, is significantly higher than in other countries. Benzene is a known carcinogen (Hayes et al., 1994). The source of benzene is mainly considered to be from automobile emissions in outdoor environments. Motor vehicles increased by up to 10% in the recent 15 years in major cities of China. On the other hand, benzene is used as a solvent in China. It is suggested that the indoor air source of benzene is from building materials, furniture and the use of solvents indoor.

Correlation between Indoor Air Concentration and Personal Exposure

Table 7 shows the mean of personal exposure/indoor concentration (P/I) ratios. In general, almost all of them were about 1. It suggested that there is significant correlation between indoor concentration and personal exposure of VOCs and carbonyl compounds.

Correlation between Indoor Air Concentration and Outdoor Air Concentration

As shown in Table 7, the mean of indoor air concentration/outdoor air concentration (I/O) of VOCs and carbonyl compounds is form 0.82 to 9.22. The data mean that there are major sources of acetone, *p*-dichlorobenzene, alpha-pinene, formaldehyde, styrene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene in the indoor environment; the sources of benzene, butanol, toluene, xylene, ethylbenzene, acetaldehyde from not only indoor environment but also outdoor environment; the source of heptane from outdoor environment.

Table 1 Sampling rate of VOCs and Carbonyl compounds

	Compounds	sampling rate(ml/min)
VOCs	benzene	35.38
	butanol	21.72
	heptane	28.00
	toluene	33.29
	ethylbenzene	25.19
	m,p-xylene	24.56
	styrene	20.90
	o-xylene	23.70
	alpha-pinene	21.65
	1,3,5-trimethylbenzene	21.63
	1,2,4-trimethylbenzene	22.64
	p-dichlorobenzene	25.79
carbonyl compounds	Formaldehyde	1.47
	acetaldehyde	1.25
	acetone	1.09

Table 2 Analytical conditions of GC/MS

Column	HP5 30m x 0.25mm x 0.25um
Column Temp.	40° (4min)→ 10° /min. →280°
Solvent Delay	1.2min.
Injector Temp.	250°
Injection	Pulse split
Interface Temp.	220°
Carrier	He
Ion Souce Temp.	230°

Table 3 Analytical conditions of HPLC

Column	ZORBAX Eclipse XDB-C18(5um)4.6mm*250r
Fluent	CH3CN:H2O = 65:35
Flow rate	1.0ml/min
Injection volume	20ul
Column temp	35°
Detector	Diode Array Detector(DAD)365nm

Table 4 A summary of VOCs and carbonyl compounds concentrations in Chinese residences

	indoor air concentration(ug/m^3)					outdoor air concentration(ug/m^3)					personal exposure(ug/m^3)				
Compounds	median	max	min	mean	S.D.	median	max	min	mean	SD	median	max	min	mean	SD
benzene	36.8	97.9	11.1	40.3	21.5	26.3	48.9	11.6	27.2	10.0	36.8	224.6	12.0	41.5	34.2
butanol	22.5	66.3	3.4	26.4	17.9	12.6	158.5	3.4	19.6	26.1	21.2	154.5	3.4	27.6	26.2
heptane	N.D.	26.9	N.D.	3.8	4.7	N.D.	23.0	N.D.	4.7	5.1	N.D.	11.5	N.D.	3.5	3.0
toluene	63.9	404.8	23.2	83.8	68.9	39.9	84.6	23.3	43.9	15.4	63.3	302.9	24.9	71.0	48.3
ethylbenzene	21.6	81.3	10.7	26.4	14.9	18.6	45.2	11.3	19.2	5.9	20.9	52.7	11.1	24.5	10.8
m,p-xylene	28.6	104.3	5.1	35.4	22.7	16.6	63.3	4.2	18.2	10.8	29.7	88.5	6.2	34.1	19.5
styrene	4.8	35.0	4.8	11.7	11.6	4.8	12.3	4.8	5.3	1.7	4.8	36.9	4.8	10.3	11.0
o-xylene	13.1	50.5	4.0	18.5	13.2	10.5	34.7	4.2	12.3	7.4	13.5	51.4	3.9	18.5	12.3
alpha-pinene	25.7	313.9	N.D.	24.7	49.3	N.D.	28.5	N.D.	6.0	8.8	26.4	222.2	N.D.	25.9	35.4
1,3,5-trimethylbenzene	28.4	42.4	N.D.	23.1	13.5	N.D.	35.0	N.D.	10.9	12.5	28.7	37.4	N.D.	21.5	13.4
1,2,4-trimethylbenzene	32.3	43.6	N.D.	23.4	15.9	N.D.	37.7	N.D.	9.5	13.3	34.6	44.0	N.D.	26.6	14.9
p-dichlorobenzene	19.5	181.7	N.D.	28.7	38.8	N.D.	35.2	N.D.	3.2	5.7	35.2	280.5	N.D.	48.2	65.7
formaldehyde	49.0	898.3	20.3	112.3	164.0	30.2	66.4	12.3	30.7	11.4	56.1	431.0	23.0	84.8	13.8
acetaldehyde	49.0	88.5	3.1	49.0	18.8	33.1	49.0	9.6	30.8	11.6	47.6	606.8	12.7	60.7	91.2
acetone	34.6	664.9	3.0	76.7	129.6	7.4	25.3	3.0	8.3	4.9	33.6	501.5	3.6	60.3	96.9

N.D.: not detected

Table 5 Comparison of BTX concentrations in Chinese indoor environments with other studies (μg/m^3)

Sites	Period	Benzene	Toluene	m,p-xylene	Authors
Helsinki	1996-1997	2.33	20.35	7.84	Rufus D.Edwards et al.(2001)
Copenhagen	1997-1998	4.3			Henrik Skov et al.(2000)
Hamberg	1995-1996	1.48	20.46	2.92	Peter Schneider et al.(2000)
Erfurt	1995-1996	2.17	37.29	4.17	Peter Schneider et al.(2000)
Japan	1998	7.2	98.3	24.3	Japanese ministry of health(1999
HongKong	1999	3.6	31.4	11.6	Shun Cheng Lee et al.(2001)
BeiJing	2002	43.2	165.5	46.2	
ChangSha	2002	12.8	25.0	9.2	
ChengDu	2002	43.0	71.2	33.1	

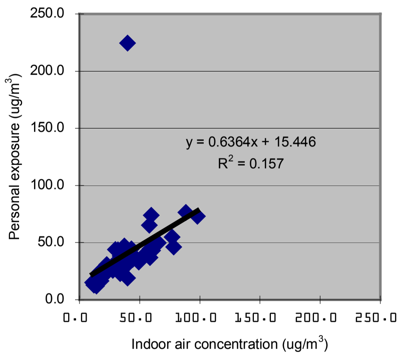

Figure2 The relevance between indoor air concentration and personal exposure of benzene.

Table 6 Comparison of BTX concentrations in Chinese outdoor environments with other studies (μg/m^3)

Sites	Period	Benzene	Toluene	m,p-xylene	Authors
Helsinki	1996-1997	1.66	5.62	3.12	Rufus D.Edwards et al.(2001)
Copenhagen	1997-1998	2.9			Henrik Skov et al.(2000)
Hamberg	1995-1996	1.33	4.46	1.2	Peter Schneider et al.(2000)
Erfurt	1995-1996	1.62	4.98	1.77	Peter Schneider et al.(2000)
Japan	1998	2.9	20.3	4.7	Japanese ministry of health(1999
HongKong	1999	4.85	28.81	3.98	Shun Cheng Lee et al.(2001)
ChangChun	1997-1998	31.3	69.8		Chunming Liu et al.(2000)
BeiJing	2002	23.1	42.3	16.5	
ChangSha	2002	13.6	26.0	9.2	
ChengDu	2002	27.7	44.9	18.1	

Table 7 The mean of I/O and P/I

Compounds	I/O	P/I
benzene	1.48	1.03
butanol	1.35	1.04
heptane	0.82	0.92
toluene	1.91	0.85
ethylbenzene	1.37	0.93
m,p-xylene	1.94	0.96
styrene	2.23	0.88
o-xylene	1.51	1.00
alpha-pinene	4.08	1.05
1,3,5-trimethylbenzene	2.13	0.93
1,2,4-trimethylbenzene	2.45	1.14
p-dichlorobenzene	8.90	1.67
formaldehyde	3.66	0.76
acetaldehyde	1.59	1.23
acetone	9.22	0.79

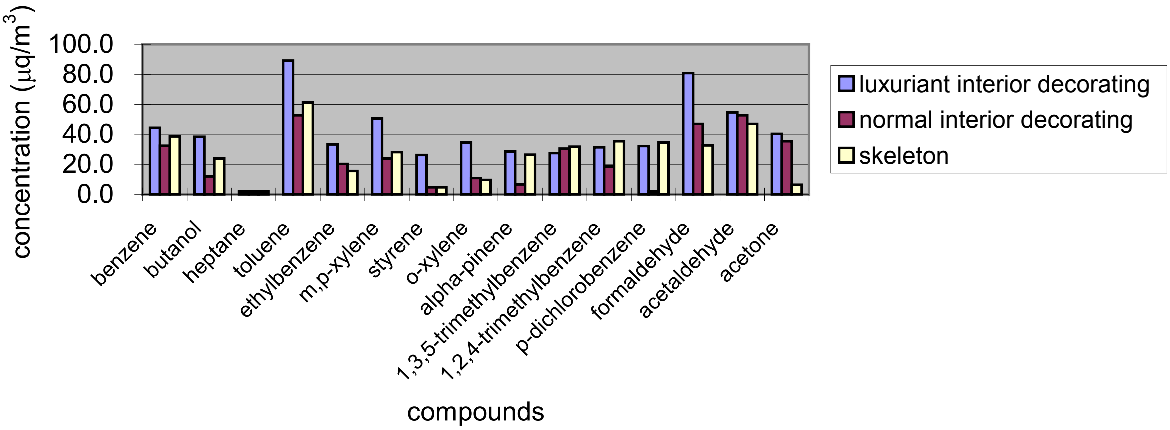

Figure 3 Relevance between indoor air concentration and interior decoration.

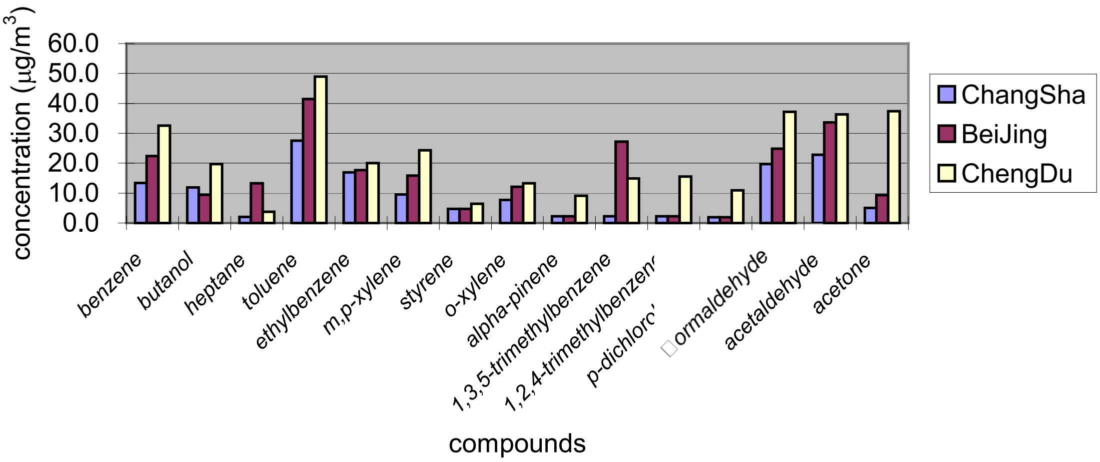

Figure 4 Comparison of outdoor concentrations of VOCs and carbonyl compounds among different urban sites.

Relevance between Indoor Air Concentration and Interior Decoration

To understanding the relevance between indoor air concentration and interior decoration, sampling sites were divided into three groups by different types of interior decoration, luxuriant interior decoration (expenses of interior decoration above $4000); normal interior decoration (expenses of interior decoration below $4000); skeleton (without interior decoration). Figure 3 illustrates the relevance between indoor air concentration and interior decoration. As shown, the mean concentrations of toluene, ethylbenzene, *o*-xylene, acetaldehyde indoor were in the order luxuriant interior decoration > normal interior decoration > skeleton. Although the mean concentrations of the other compounds in indoor environment are not in the order as given above, it is obvious that the highest indoor air concentration of almost all compounds is in luxuriant interior decorated residences. It suggested that the indoor air pollution of VOCs and carbonyl compounds is related to interior decoration, but interior decoration materials are not the unique source of VOCs and carbonyl compounds. The indoor air concentrations of VOCs and carbonyl compounds are also contributed by other factors such as furniture, smoking, outdoor air.

Comparison of Outdoor Concentrations of VOCs and Carbonyl Compounds Among Different Urban Sites

Figure 4 shows the comparison of the mean concentrations of VOCs and carbonyl compounds in outdoor environment among Beijing, Changsha and Chengdu. The mean concentrations of almost all VOCs and carbonyl compounds are the most abundant in Chengdu excluding hepane and 1,3,5-trimethylbenzene, which can be explained by the geographic location of Chengdu. Because it is located in the SiChuan basin, diffusion of pollutants in atmosphere is difficult than other cities. The difference in concentrations of VOCs and carbonyl compounds in outdoor environment also suggested a difference of vehicle and industrial activity. As shown in Figure 4, there are greater concentrations of VOCs and carbonyl compounds in outdoor environment in Beijing the capital of China than Changsha.

CONCLUSION

1. This study presented the first available data of indoor air concentration and personal exposure of VOCs and carbonyl compounds in China. It was found that the average concentrations of BTX, especially benzene, are significantly higher than other countries both indoor and outdoor.
2. In general, mean of I/P ratios for VOCs and carbonyl compounds were about 1. The results showed that there is significant correlation between indoor concentration and personal exposure of VOCs and carbonyl compounds.
3. Mean of I/O ratios of VOCs and carbonyl compounds were above 1, it suggested that indoor concentrations are significantly greater than outdoor concentrations.
4. The relevance between indoor air concentrations of VOCs and carbonyl compounds and interior decoration was studied in this paper. The results indicated that interior decoration materials are significant sources of VOCs and carbonyl compounds.

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