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Indoor phthalate concentration and exposure in residential and office buildings in Xi'an, China

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HIGHLIGHTS

- We measured indoor phthalates in air and dust from 28 buildings in Xi'an, China.
- Di-n-butyl phthalate (DnBP) and di(2-ethylhexyl) phthalate (DEHP) are the most abundant phthalates indoors in Xi'an.
- Correlation analysis shows indoor diisobutyl phthalate (DiBP), DnBP and DEHP might come from the same sources.
- The daily exposure to indoor phthalates in Xi'an was estimated.

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ABSTRACT

Indoor phthalate levels were investigated in 28 buildings, including 14 office and 14 residential buildings in Xi'an, China. Phthalate esters in the gas-, particle-, and dust- phase were measured separately. Four phthalates including dimethyl phthalate (DMP), diisobutyl phthalate (DiBP), di-n-butyl phthalate (DnBP) and di(2-ethylhexyl) phthalate (DEHP) were detected. The detection frequency of DnBP and DEHP was more than 90%. The concentrations of total phthalate esters ranged from 0.20 to 8.29 μg m^{-3} for the gas-phase, from 0.09 to 14.77 μg m^{-3} for the particle- phase and from 123 to 9504 μg g^{-1} for the dust- phase. The individual phthalate with the highest concentrations of 6.17 μg m^{-3}, 7.97 μg m^{-3} and 7228 μg g^{-1} respectively for gas-, particle- and dust- phase in all investigated rooms is all DiBP. The median concentration of the gas- and particle-phase DiBP (0.52 and 0.72 μg m^{-3}) and dust-phase DEHP (582 μg g^{-1}) were the highest. It was also found that the average concentrations of individual phthalates in residential buildings were often higher than in office buildings, and correlation analysis indicated that DiBP, DnBP and DEHP might come from the same sources. Based on the gas- and particle-phase concentrations measured, the particle-air partition coefficients of phthalates were estimated, and their logarithm values were found to be linearly correlated with the logarithm values of their octanol-air partition coefficients. Finally, the total daily exposure to indoor phthalates in air and dust was calculated, and ranged from 2.6 μg kg^{-1} day^{-1} (for adults) to 7.4 μg kg^{-1} day^{-1} (for toddlers).

1. Introduction

In recent years, phthalate esters (PAEs) have been identified by research as an indoor air pollutant that may have potential negative health consequences. Commonly, indoor phthalates are widely used as plasticizers in polyvinyl chloride (PVC) products such as flooring materials, toys, electronic cables or other plastic products and also exist in personal care products as solvents or carriers. About 3.5 million tons of phthalate products are consumed globally (Cadogan and Howick, 1996). When these products are used indoors, the phthalates are released, as they are not chemically bound to the polymer matrix or other materials. Therefore, phthalates are ubiquitous in indoor environments.

The presence of phthalates indoors has been correlated with some adverse health effects. As typical endocrine-disrupting chemicals, exposure to phthalates may result in reproductive and developmental problems. Studies have shown that some phthalates are linked with problems in male reproductive development such as poor semen quality (Liu et al., 2012; Swan, 2008) and decreased

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anogenital distance (Swan et al., 2005), and also to problems in female fertility and development including pregnancy loss (Toft et al., 2012), shortened pregnancy duration (Latini et al., 2003), pre-mature breast development and precocious puberty (Wolff et al., 2010). Epidemiologic investigations have also revealed an association between exposure to indoor phthalates and childhood health. Numerous studies indicate that there are strong associations between phthalates and children's asthma and allergies (Bornehag et al., 2004; Jaakkola and Knight, 2008). In addition, some research suggests a relationship between phthalate exposure and infant neurodevelopment (Kim et al., 2011).

Phthalates are semi-volatile organic compounds (SVOCs) and are especially easily adsorbed on indoor particular matters and surfaces due to low vapor pressure (Weschler and Nazaroff, 2010). The gas-, particle-, surface- and dust- phases of phthalates play important roles in the migration of indoor phthalates from their sources to human bodies through three main routes, which include inhalation, dermal adsorption, and dietary uptake (Weschler and Nazaroff, 2012). An investigation of indoor phthalates concentrations in different phases is the basis for an estimation of phthalate exposures. Indoor phthalate levels have been measured in several countries, such as China (Guo and Kannan, 2011; Lin et al., 2009; Pei et al., 2013; Zhang et al., 2013), Denmark (Langer et al., 2010), Germany (Becker et al., 2009), Norway (Rakkestad et al., 2007), Sweden (Bergh et al., 2011; Bornehag et al., 2005) and U.S. (Guo and Kannan, 2011; Hwang et al., 2008; Rudel et al., 2003). The comparisons show that indoor phthalate levels vary sharply in different locations. Because about a quarter of the total amount of phthalates used in the world are produced in China (Wang et al., 2010), there is an increasing tendency to be concerned about indoor phthalate pollution in China. However, the data for indoor phthalate concentrations in the western region of China is still rare. In this study, several typical phthalate esters in their gas-, particle-, and dust-phases were measured in indoor environments in Xi'an, a representative city of western China, and phthalate exposures were estimated based on that data.

2. Methods

2.1. Chemicals

17 common phthalate esters are selected as target compounds in the investigation and their related information is listed in Supplementary Information (S2), which are selected according to the standard mixture of phthalate esters with 1000 μg mL^{-1} from Chemservice Inc.

2.2. Building information

This study involved a total of 28 buildings, consisting of 14 office buildings and 14 residential buildings. All the buildings had interior decoration of basic levels and only common indoor materials were used. In the buildings, the floor was covered by ceramic tiles or wooden floorboards and the walls were coated with latex paint, gypsum or wallpaper. All residential buildings were constructed less than 5 years previously and office buildings less than 10 years.

2.3. Sampling

Gas- and particle-phase phthalates were collected by an active SVOC sampler (the detailed information can be found in the Supporting Information S3) as designed according to U.S. EPA method TO13-A (EPA, 1999). The gas-phase phthalates were adsorbed by polyurethane foam (PUF with size Φ 90 mm × 50 mm) and the particles with phthalates were trapped on a glass-fiber filter with effective diameter 80 mm and aperture diameter less than 10 μm. The sampling flow rate was 100 L min^{-1} and the sampling duration was 24 h for one sampling point. Prior to the sampling, the sampling media was pre-conditioned to decrease phthalate ester residues. The PUFs were dipped into the boiled water and was twisted back and forth several times. The glass fiber membranes were baked at 400 °C in a Muffle furnace for over 4 h and then were weighed by an electric balance with 1 mg precision before and after sampling. Before sampling, the PUFs were extracted by methylene dichloride in a Soxhlet extractor and then kept at 4 °C as operation described in "Measurement" part after sampling.

Indoor dust from non-walking surfaces in the selected buildings was swept on to a glass-fiber membrane. Then the glass-fiber membrane together with the collected dust was quickly transferred in a sealed glass bottles. Prior to the instrumental analysis, all samples were stored at 4 °C.

The sampling was conducted from September 9th, 2012 to January 9th, 2013. When starting sampling, the indoor temperature was recorded and ranged from 14.6 °C to 21.5 °C in the period (Seen in Supplementary Information S4).

2.4. Measurement

After sampling, the samples were extracted separately in 6 cycles per hour for total 8 h by methylene dichloride through a Soxhlet extractor. Then the sample was concentrated into a 1 mL volume through a stream of clean nitrogen at 40 °C. The final concentrated solution was kept at 4 °C until GC–MS analysis.

Phthalate concentrations were determined by a gas chromatography–mass spectrometry instrument (Thermo Scientific ISQ) through splitless injection on a 30 m HP-5MS column (Agilent Scientific Inc.; 30 m × 0.25 mm[inner diameter] × 0.25 μm [film thickness]; the column flow rate: 0.5 mL min^{-1}) carried by helium gas. The temperature program of the oven was 70 °C for 4 min, risen at 10 °C min^{-1} to 280 °C and maintained for 4 min. The coupled mass selective detector was operated in electron impact (EI) mode using selected ion-monitoring (SIM).

2.5. Quality assurance and quality control

Before the investigation, two field blanks, two transportation blanks and two process blanks for each sampling point were analyzed together with the samples. And the concentrations of target PAEs were all lower than the LOD (see Supplementary Information S5). A recovery efficiency experiment was conducted ($n = 4$) using a 1 μg μL^{-1} standard mixture of 17 phthalate esters in hexane (Chemservice Inc.) added to the blank glass fiber membranes and PUF filters (10, 20, 30, 40 and 50 μL respectively). Through the same pretreatment and lab analysis procedure as the samples, the recovery efficiencies were obtained and ranged from 73% to 94%. The precision of the method was assessed by replicate experiments ($n = 6$) by adding a 1 μg standard mixture to a blank sampling medium. The relative standard deviation (RSD) was found to range from 7.5% to 19.7%.

2.6. Statistical analysis

IBM SPSS Statistics version 19.0 software was employed for data analysis. Mean, median, standard deviation, and ranges were given. Non-parametric independent-samples with the Mann–Whitney *U* test method were used to compare the difference between concentrations in homes and offices. Spearman's rank correlation was applied for analyzing correlations between phthalate concentrations in different phases.

3. Results and discussions

3.1. Phthalate ester concentrations in indoor air and dust

Table 1 presents the results of phthalate ester concentrations in indoor air (including the gas-phase and suspended particle-phase phthalates) and dust. Four types of phthalate esters were detected including DMP, DiBP, DnBP and DEHP. DMP was detected at the least frequency while DiBP, DnBP and DEHP were detected in most of buildings. Especially, DEHP in all three phases was detected in all of buildings. This indicates DiBP, DnBP and DEHP are the predominant indoor phthalate contaminants in Xi'an City. The concentrations of gas-phase DMP, DiBP, DnBP and DEHP are comparable while the concentrations of DiBP, DnBP and DEHP in particle and dust are much higher than the concentration of DMP in the same phase. The reason for this is that DMP tends to exist in a gas-phase due to a relative higher vapor pressure.

DnBP and DEHP appeared at the highest frequency in the literature, therefore, the concentrations of DnBP and DEHP in air and dust were compared with those reported in the literature as shown in Fig. 1. This comparison shows that the median concentrations of dust-phase DnBP and DEHP in Xi'an are on a moderate level, but the concentrations of DnBP and DEHP in the air are very high, especially the median concentration of DEHP in the air of Xi'an is the highest in the listed locations. In all listed results, DnBP concentrations in air lie in the magnitude order close to the ones of the concentrations of DEHP in air. In contrast, the concentrations of dust-phase DnBP are much lower than those of dust-phase DEHP in all listed zones, except for Bulgaria. A comparison between the concentrations of DnBP and DEHP in the air in previously investigated Chinese cities shows that the pollution level of DnBP and DEHP in the air in Xi'an is relatively high, while the concentrations of dust-phase DnBP and DEHP in Xi'an are on a moderate level within China. A possible reasons for this is that the composition of particles is different from other listed locations in China (Shen et al., 2008).

Comparing the average concentration of four types of phthalate esters in air and three types of phthalate esters in dust (because DMP was detected in dust at a very low frequency, the average concentration of dust-phase DMP contained little information) in office and residential buildings as seen in Fig. 2, it is found that the average concentration of phthalates in residential buildings is higher than that in offices except dust-phase DEHP. The statistical analysis showed that the concentrations of DiBP and DnBP in home air are higher than in office air in a significant level ($p < 0.05$). At the same time, the concentrations of other phthalates in offices and

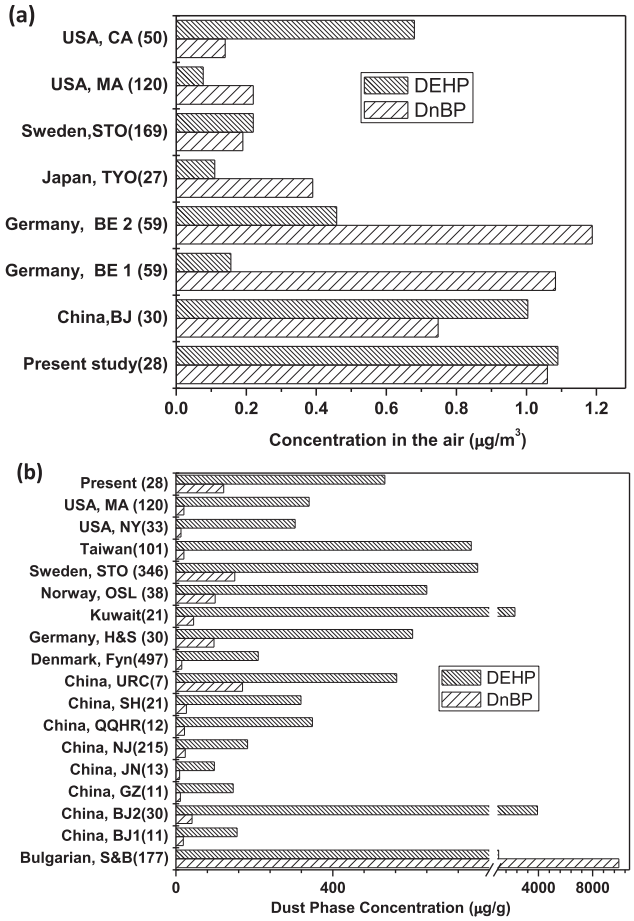

Fig. 1. Comparison of the median concentration of DEHP and DBP investigated by us and those in the literature. **(a)** Gas phase compared with those in Germany (Fromme et al., 2004), Japan (Otake et al., 2004), Sweden (Bergh et al., 2011), U.S.A. (Rudel et al., 2003; Rudel et al., 2010) and China (Lin et al., 2009; Shen, 2009); **(b)** Dust phase compared with those in, Bulgarian (Kolarik et al., 2008), China, Beijing1 (Guo and Kannan, 2011), China, Beijing2 (Lin et al., 2009) China, Guangzhou (Guo and Kannan, 2011), China, Jinan (Guo and Kannan, 2011), China, Nanjing (Zhang et al., 2013), China, Qiqihaer (Guo and Kannan, 2011), China, Shanghai (Guo and Kannan, 2011), China, Urumchi (Guo and Kannan, 2011), Denmark (Langer et al., 2010), Germany (Abb et al., 2009), Kuwait (Gevao et al., 2013), Norway (Oie et al., 1997), Sweden (Bornehag et al., 2005), Taiwan (Hsu et al., 2012), U.S.A., New York (Guo and Kannan, 2011), U.S.A., MA (Rudel et al., 2003).

Table 1
Concentrations of phthalate esters indoors ($n = 28$).

Phthalates	Phase	Mean	Median	Min	Max	Standard deviation	Detection frequency %
DMP	Gas (μg m^{-3})	0.51	0.22	LOD[a]	2.46	0.69	57
	Particle (μg m^{-3})	0.10	ND	LOD	1.75	0.36	14
	Dust (μg g^{-1})	5.66	ND	LOD	68.84	15.49	14
DiBP	Gas (μg m^{-3})	1.00	0.52	LOD	6.17	1.52	82
	Particle (μg m^{-3})	1.62	0.72	LOD	7.97	2.12	79
	Dust (μg g^{-1})	900.98	233.80	LOD	7228.34	1723.31	82
DnBP	Gas (μg m^{-3})	0.59	0.28	LOD	2.15	0.68	93
	Particle (μg m^{-3})	1.06	0.55	LOD	4.92	1.36	96
	Dust (μg g^{-1})	447.78	134.77	3.64	4357.32	912.30	100
DEHP	Gas (μg m^{-3})	0.47	0.34	0.05	1.86	0.42	100
	Particle (μg m^{-3})	1.04	0.56	0.09	4.16	1.10	100
	Dust (μg g^{-1})	798.61	581.50	67.06	3475.73	810.60	100
Total phthalates	Gas (μg m^{-3})	2.58	1.77	0.20	8.29	2.20	100
	Particle (μg m^{-3})	3.83	2.85	0.09	14.77	3.48	100
	Dust (μg g^{-1})	2153.03	1149.20	122.88	9504.38	2282.16	100

[a] LOD means below limit of detection.

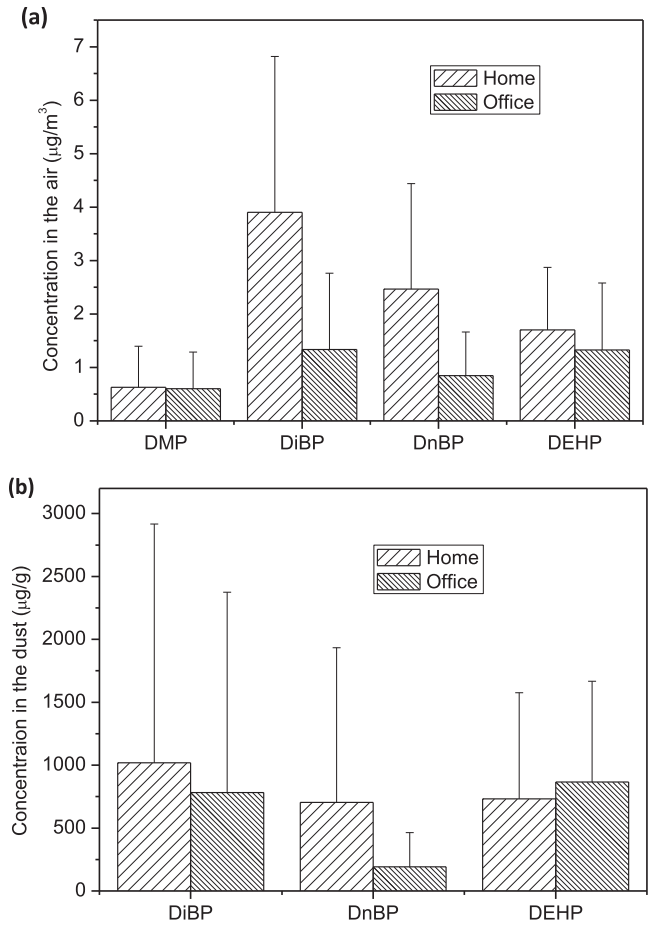

Fig. 2. Comparison of the average concentration of phthalate esters in office and residence buildings: (a) in the air; (b) in the dust.

homes do not show a significant difference ($p > 0.05$). A possible reason for the difference between phthalate concentrations in office and residential buildings is that more decoration materials are used in homes than in these offices. In addition, differences in ventilation may be a factor. Most of the offices in the study are ventilated mechanically through air ducts, while the residential buildings are only naturally ventilated through windows. Because mechanical ventilation is more effective than natural ventilation, indoor phthalate esters may be diluted and exhausted more easily in offices than in homes.

3.2. The association of different types of phthalates

Tables 2–4 present the correlations between different phthalates in air and dust. The analysis results show that there are obvious positive correlations ($p < 0.05$) between the paired concentration of DiBP and DnBP in air, the paired concentration of DnBP and DEHP in air, and the paired concentration of DiBP and DnBP in dust. After the paired concentrations with the maximum or minimum values of DiBP and DEHP in air are excluded, the paired concentrations of DiBP and DEHP in air also show a significant correlation ($p < 0.05$) and the correlation coefficient changes from 0.131 to 0.518. With the same procedure, the filtrated paired concentrations of DiBP and DEHP in dust also show a significant correlation ($p < 0.05$) and the correlation coefficient changes from −0.035 to 0.460. Because DiBP and DnBP are isomeric compounds, the correlation results indicate that indoor DiBP and DnBP

Table 2
Correlation coefficient matrix of different phthalate esters in air.

	DMP	DiBP	DnBP	DEHP
DMP	1.000			
DiBP	−0.055	1.000		
DnBP	0.252	0.485[a]	1.000	
DEHP	0.179	0.131	0.538[a]	1.000

[a] Correlation is significant at the 0.01 level (2-tailed).

come from the same sources. The results also imply a high possibility that DiBP, DnBP and DEHP may be released from the same sources. At the same time, there seem to be no significant correlations between the concentrations of DMP and other phthalate esters, wherever in the air or the dust. The results suggest that DMP sources may be different from DiBP, DnBP and DEHP. Therefore, the indoor sources of phthalates in Xi'an are diverse.

3.3. Estimation of the particle-air partition coefficients of phthalate esters

The particle-air partition coefficient of phthalate is an important parameter for describing a phthalate ester's distribution between the particle and the gas phase, which is defined as Eq. (1) (Weschler et al., 2008). A larger K_p indicates that more phthalate is adsorbed on particles.

$$K_p = \frac{C_p}{TSP \times C_g} \quad (1)$$

where C_p is the particle-phase concentration of phthalate, TSP is the particle concentration and C_g is the gas-phase concentration of phthalate.

In our estimation, the concentration of particles can be obtained by the mass of particles filtrated by the glass fiber membrane divided by the sampling volumes and gas- and particle-phase phthalates concentrations can be estimated by analyzing the phthalates adsorbed by PUFs and the filtrated particles on the glass fiber membrane, respectively. Thus K_p can be estimated based on Eq. (1) as shown in Fig. 3. Because the glass fiber membranes adsorbed phthalates, the concentrations of gas-phase phthalates were underestimated, while the concentrations of particle-phase phthalates were overestimated. The lower the vapor pressure, the larger the deviation. Thus, K_p was possibly overestimated in comparison with the real value and bias in the estimation needs to be studied further.

As the sampling sites are in the same city and the main source of particles is from the atmosphere, the composition of particles is expected to be similar in all the buildings, which means K_p should be the same for the same phthalate in all the buildings. Therefore, the average values of K_p for DiBP, DnBP and DEHP were calculated from available data, except for DMP because its detection frequency was too low. In theory, K_p is expected to be proportional to the octanol-air partition coefficient, K_{oa} (Weschler and Nazaroff, 2010). However, based on the data from our in-site investigations, log K_p

Table 3
Correlation coefficient matrix of different phthalates in dust phase.

	DMP	DiBP	DnBP	DEHP
DMP	1.000			
DiBP	−0.198	1.000		
DnBP	−0.081	0.381[a]	1.000	
DEHP	0.119	−0.035	0.182	1.000

[a] Correlation is significant at the 0.05 level (2-tailed).

Table 4
Equations used for estimating the daily intakes of PAEs through different routes.

Exposure routes	Equation		Parameters
Inhalation exposure (IE) (EPA, 2011; Guo and Kannan, 2011)	$E_{inhalation} = \frac{C_{air} \times f_1 \times f_2}{M}$	(4)	C_{air} is the concentration of PAEs in air including gas phase and particle phase, μg m^{-3}; f_1 is the indoor exposure time, h day^{-1}; f_2 is the inhalation air volume per day, m^3 day^{-1}; M is the mass of the body, kg.
Dermal adsorption exposure (DE) (EPA, 2011; Guo and Kannan, 2011; Little et al., 2012)	$E_{dermal} = \frac{C_{dust} \times f_1 \times A \times m \times f_3}{M} + \frac{C_g \times k_{p\_g} \times f_1 \times A \times f_4}{M}$	(5)	C_{dust} is the concentration of dust phase PAEs, μg g^{-1}; A is the skin area, m^2; m is the dust mass adsorbed by the skin, g m^{-2}; f_3 is the fraction of dust adsorbed by the skin; C_g is the concentration of gas phase PAEs, μg m^{-3}; k_{p_g} is the overall permeability from bulk air to dermal capillaries, m day^{-1}; f_4 is the fraction of gas phase PAEs adsorbed by the skin
Oral ingestion exposure (OE) (EPA, 2011; Guo and Kannan, 2011)	$E_{ingestion} = \frac{C_{dust} \times f_1 \times f_5}{M}$	(6)	f_5 is the mass of oral ingested dust per day, g day^{-1}

and log K_{oa} do not satisfy Eq. (2), but fit Eq. (3) in a surprising level as shown in Fig. 4. Certainly, because only three types of phthalates were studied, and there are large standard deviations, Eq. (3) may not be universal and further verification is needed.

$$K_p = \frac{f_{om-part}}{\rho_{part}} K_{oa} \quad (2)$$

$$\log K_p = a \log K_{oa} + b \quad (3)$$

where, $f_{om\text{-}part}$ is the organic fraction of particle, ρ_{part} is the density of the particle, a and b are the fitting parameters.

3.4. Exposure estimation

People are exposed to phthalate esters through inhalation, dermal uptake, ingestion and dietary intake. Because there is no available data, dietary intake and the adsorption of phthalates from other phthalate sources such as soil and personal care products were not be estimated in this study. Recent studies (Weschler and Nazaroff, 2012; Little et al., 2012) showed direct transport of gas phase phthalates through skin to dermal capillaries may play an important role in dermal exposure to phthalates. Therefore, this study investigated phthalate exposures through inhalation, dermal adsorption from indoor particle- and gas-phase phthalates, and dust ingestion. Exposure estimates were based on the measured median concentrations in residential buildings through the equations in Table 4 and the related parameters in the literature (Guo and Kannan, 2011) were adopted except those concerning dermal exposure to gas-phase PAEs which were estimated based on the method in the literature (Little et al., 2012). All parameters are listed in Supporting Information S6.

The daily intake of DMP, DiBP, DnBP and DEHP was estimated as shown in Table 5 for five age groups including infants (<1 year), toddlers (1–3 years), children (4–10 years), teenagers (11–18 years) and adults (>18 years) based on measured median concentration of different phase phthalates. The total daily intakes of indoor phthalate esters in air and dust ranged from 2647.3 ng kg^{-1} day^{-1} for adults to 7379.9 ng kg^{-1} day^{-1} for toddlers. DiBP is the most abundant phthalate in terms of exposure for all age groups, except toddlers. For toddlers, DEHP has the highest phthalate exposure risk. Table 5 shows that the inhalation exposure of phthalates decreases with age, while oral and dermal exposure is higher for toddlers than for other age groups. It is found that the three pathways including oral ingestion, dermal adsorption and inhalation are all important for phthalate exposure. Especially for adults, dermal adsorption exposure contributes more to the total DnBP exposure than oral ingestion exposure. Therefore, if other phthalate sources such as personal care products were considered in the estimation, the dermal adsorption exposure from these sources

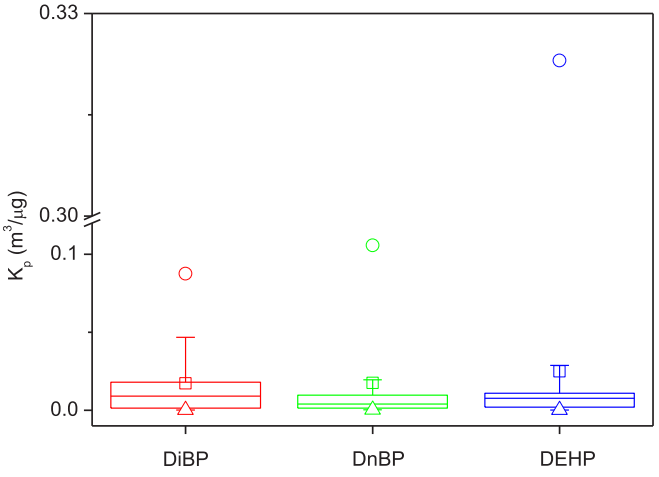

Fig. 3. The plot of the estimated particle-air partition coefficients.

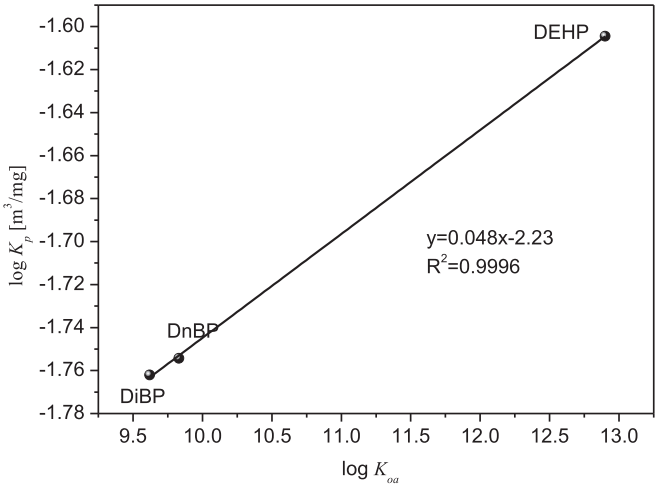

Fig. 4. The correlation between K_p and K_{oa}, here K_{oa} comes from the literature (Weschler and Nazaroff, 2010).

Table 5
Daily intakes of indoor four phthalate esters for different age groups (ng kg^{-1}-bw day^{-1}).

Age (years)		<1	1–3	4–10	11–18	>18
DMP	OE[a]	0.0	0.0	0.0	0.0	0.0
	DE[a]	4.4	6.0	4.7	3.4	3.6
	IE[a]	131.4	94.4	88.7	69.4	55.5
	total	135.8	100.3	93.4	72.9	59.1
DiBP	OE	533.2	1133.8	371.4	226.4	190.4
	DE	208.2	283.4	222.1	162.9	170.3
	IE	1611.9	1157.6	1087.8	851.6	680.6
	total	2353.3	2574.8	1681.3	1240.9	1041.4
DnBP	OE	342.1	727.4	238.3	145.2	122.2
	DE	165.3	225.0	176.3	129.4	135.2
	IE	835.0	599.7	563.5	441.1	352.6
	total	1342.4	1552.1	978.1	715.8	610.0
DEHP	OE	1036.1	2202.9	721.6	439.8	370.0
	DE	378.6	515.3	403.8	296.3	311.4
	IE	605.0	434.5	408.3	319.6	255.5
	total	2019.6	3152.7	1533.8	1055.8	936.9
Total PAEs	OE	1911.4	4064.0	1331.3	811.4	682.6
	DE	756.4	1029.7	806.9	592.1	620.6
	IE	3183.3	2286.2	2148.2	1681.8	1344.1
	total	5851.2	7379.9	4286.5	3085.3	2647.3

[a] OE is the exposure through oral ingestions; DE is the exposure through dermal adsorption; IE is the exposure through inhalation.

may be a more important route compared with the other two routes.

4. Conclusions

Four PAEs including DMP, DiBP, DnBP and DEHP were found in phases of gas, particle and dust. DiBP, DnBP, and DEHP were ubiquitous in the indoor environments of Xi'an, China. The concentrations of DnBP and DEHP in Xi'an are at a moderate level compared with those of other cities reported in the literature. The results showed that the average concentrations of DiBP, DnBP and DEHP in residential buildings were often higher than those in office buildings. Some obvious correlations between the concentrations of DiBP, DnBP and DEHP were found, which indicated that these three types of phthalates might come from the same sources. The particle-air partition coefficients of phthalates were also estimated from the measured concentration of gas-phase and particle-phase phthalate esters, and there was a clear linear correlation between the particle-air partition coefficients and the octanol-air partition coefficients. In addition, human exposures to phthalates in indoor gas and dust through oral ingestion, dermal absorption and inhalation were also estimated. It is found that the three routes are all important for phthalate exposures. At the same time, phthalate exposures for toddlers were higher than for other age groups. Therefore, it is important to study ways to decrease daily phthalate exposure in young children.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.atmosenv.2014.01.018.

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