Science of the Total Environment 639 (2018) 760–768

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

# The effect of air change rate and temperature on phthalate concentration in house dust

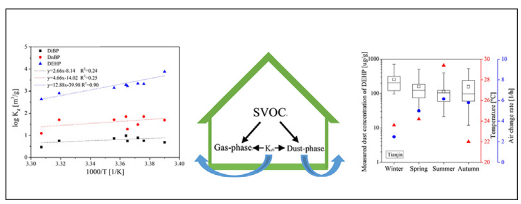
Jingjing Pei *, Yahong Sun, Yihui Yin

*Tianjin Key Laboratory of Indoor Air Environmental Quality Control, School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China*

## HIGHLIGHTS

- The indoor gas-phase SVOC concentrations in different seasons were predicted with varying temperature and ventilation.
- Concentrations of phthalates in dust through a year were measured in 40 resident apartments.
- The dust-gas partition $K_d$ was obtained and found to be significantly correlated with temperature.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 1 March 2018
Received in revised form 29 April 2018
Accepted 7 May 2018
Available online 26 May 2018

Editor: Kevin V. Thomas

*Keywords:*
Air change rate
Temperature
DEHP
House dust
Field measurement

## ABSTRACT

Semi-volatile organic compounds (SVOCs) are one of the main indoor pollutant categories. Six phthalates (dimethyl phthalate (DMP), diethyl phthalate (DEP), di(isobutyl) phthalate (DiBP), di(nbutyl) phthalate (DnBP), butyl benzyl phthalate (BBzP) and di(2-ethylhexyl) phthalate (DEHP)) in house dust samples were measured in forty residential apartments in Tianjin and Urumqi in four seasons throughout a year. The measured DEHP dust-phase concentration is in the range: 11.9–699.9 μg/g; and showed obvious differences in different seasons, and the maximum can be 2 times higher than minimum. The DiBP and DnBP showed similar phenomenon. The corresponding gas-phase concentration is estimated considering the influencing factors of indoor temperature, air change rate, particle concentration. Then the dust-gas partition coefficient $K_d$ under different season was obtained through the measured dust-phase concentration and estimated gas-phase concentration. From winter to summer, because the increased temperature leads to higher emission rate, the gas-phase concentration is obviously high in spite of the higher air change rate in summer. The estimated DEHP gas-phase concentration showed obvious differences in different seasons, and the maximum can be about 2 times higher than minimum. The DiBP and DnBP showed similar phenomenon. The lower dust-phase concentration in summer is observed due to the temperature-dependency of the dust-gas partition coefficient. Therefore temperature has the greatest impact on the dust concentration, not influence via emission rate, but influences the partition coefficient $K_d$.



## 1. Introduction

Through the 1980s, phthalate ester, which is a major category of semi-volatile organic compounds (SVOCs), has been recognized as major indoor pollutants (Weschler, 1980). In 2006, worldwide phthalate use was 6.65 million metric tons, and one-quarter of which was in China (Tao and Liang, 2008). Phthalates can diffuse within materials, leach out, and then suspend into air or be absorbed by particulate matters and available surfaces, and later settles as dust (Fujii et al., 2003). Exposure to phthalate esters occurs via ingestion, inhalation and dermal pathways. Phthalate ester levels in dust have been reported to be associated with asthma and allergies in children (Bamai et al., 2014). Prenatal phthalate exposure retarded male reproductive

* Corresponding author.
*E-mail address:* jpei@tju.edu.cn (J. Pei).

https://doi.org/10.1016/j.scitotenv.2018.05.097
0048-9697/

**Table 1**
Temperatures, infiltration and air change rates, and suspended particles concentrations in different seasons.

| Region | | Urumqi | | | | Tianjin | | | |
|---|---|---|---|---|---|---|---|---|---|
| Season | | Winter | Spring | Summer | Autumn | Winter | Spring | Summer | Autumn |
| Temperature (°C) | Range | 23.2 ± 6.8 | 24.3 ± 3.2 | 28.3 ± 6.8 | 25.0 ± 3.4 | 23.6 ± 6.8 | 24.2 ± 3.9 | 29.4 ± 3.3 | 22.0 ± 5.3 |
| Infiltration rate ($h^{-1}$) | Average | 0.54 | 0.34 | 0.31 | 0.23 | 0.42 | 0.33 | 0.37 | 0.40 |
| | Range | 0.1–1.55 | 0.09–1 | 0.09–0.79 | 0.11–0.43 | 0.02–1.14 | 0.07–1.37 | 0.01–1.26 | 0.03–1.7 |
| Total air change rate[a] ($h^{-1}$) | Average | 1.43 | 2.22 | 3.06 | 2.02 | 2.48 | 5.01 | 6.15 | 5.79 |
| | Min | 0.68 | 1.27 | 1.81 | 1.22 | 0.99 | 2.26 | 2.75 | 2.59 |
| | Max | 2.92 | 3.93 | 5.12 | 3.30 | 4.07 | 7.92 | 9.42 | 9.16 |
| TSP (μg/$m^3$) | Average | 53.92 | 21.62 | 16.32 | 28.41 | 71.35 | 56.54 | 56.34 | 80.97 |
| | Min | 5.86 | 1.86 | 1.54 | 1.72 | 3.049 | 6.48 | 0.76 | 2.55 |
| | Max | 140.23 | 45.64 | 68.50 | 42.82 | 191.51 | 130.63 | 189.13 | 174.08 |

[a] Total air change rate (n) is the daily air change rate considering both infiltration and window opening.

development and altered semen quality. Moreover, the Integrated Risk Information System (IRIS) has listed DEHP as a $B_2$ substance, that is, a possible human carcinogen (U.S. Environmental Protection Agency, 1999).

The research on indoor SVOC pollution has been focused on building material emission characteristics and test method (Liang and Xu, 2014), indoor total airborne or dust-phase SVOC concentration level (Bi et al., 2015), phthalate exposure and risk assessment (Bu et al., 2016). The control of indoor SVOC pollution has not been discussed widely. Ventilation as an important way to improve indoor air quality, have been proved by many studies that increased ventilation can reduce indoor volatile organic compounds (VOCs) concentration (Hodgson et al., 2004; Zuraimi et al., 2006). In contrast, the effect of ventilation on indoor SVOC concentration is not thoroughly studied. Xu et al. (2009) developed a two-room model to predict residential exposure to phthalate plasticizer emitted from vinyl flooring. The research showed increasing air exchange rate will increase the DEHP emission rate from the vinyl flooring significantly while it also causes a substantial decrease in the gas-phase concentration. Liu et al. (2015) develop a mass balance model to describe the effect of ventilation on indoor exposure to SVOCs. When air exchange rate increased from 0.6/h to 1.8/h, the steady-state SVOC (gas-phase plus particle phase with log($K_{oa}$) varying from 9 to 13) concentration in the idealized model decreased by about 60%. These researches all showed that ventilation can reduce total airborne concentration of SVOC, but its effect on dust-phase concentration was not discussed. In addition, these researches all had established models to explore the impact of ventilation on SVOC, which need the support of field measurement data.

Besides ventilation, the temperature is also an important factor for indoor phthalate pollution. Fujii et al. (2003) investigated temperature dependence of the emissions of phthalate esters from plastic materials in a passive flux sampler. They observed nearly 100 times increase of maximum emissions of phthalates as the temperature from 20 °C to 80 °C without exchange of air. In indoor environment, both the air change rate and temperature can vary in a considerable range, for example, in different seasons. Clausen et al. (2012) used both experimental and CFD modeling techniques to study the effect of temperature on emissions of DEHP from vinyl flooring in the Emission Cell FLEC at air flow rate of 450 ml·$min^{-1}$, and found that the amount of DEHP in the gas- and particle-phase combined is predicted to increase almost 10-times with an increase of temperature in a home from 23 °C to 35 °C. And the amount in the gas-phase increases by a factor of 24 with a corresponding decrease in the amount on the airborne particles. However, the experiments above were carried out in laboratory is not in a realistic residential environments. Wei et al. (2018) measured the concentrations of DEHP and BBP in the air, settled dust, in an indoor environment with floor area of 110 $m^2$ at 21, 25, 30 °C. They found that the indoor air concentrations (sum of gas and particle phases) of BBP and DEHP at steady state at 30 °C were higher than those at 21 °C by a factor of 3. However, the temperature was not observed to significantly influence the concentration of DEHP and BBP in the settled dust. The ventilation condition was as not specifically discussed. To sum up, indoor gas-phase concentrations of phthalates have a relatively consistent conclusion in the literature, but there is controversy over the change of dust phase concentration in temperature. So it is necessary to study the effect of temperature on indoor dust-phase concentration.

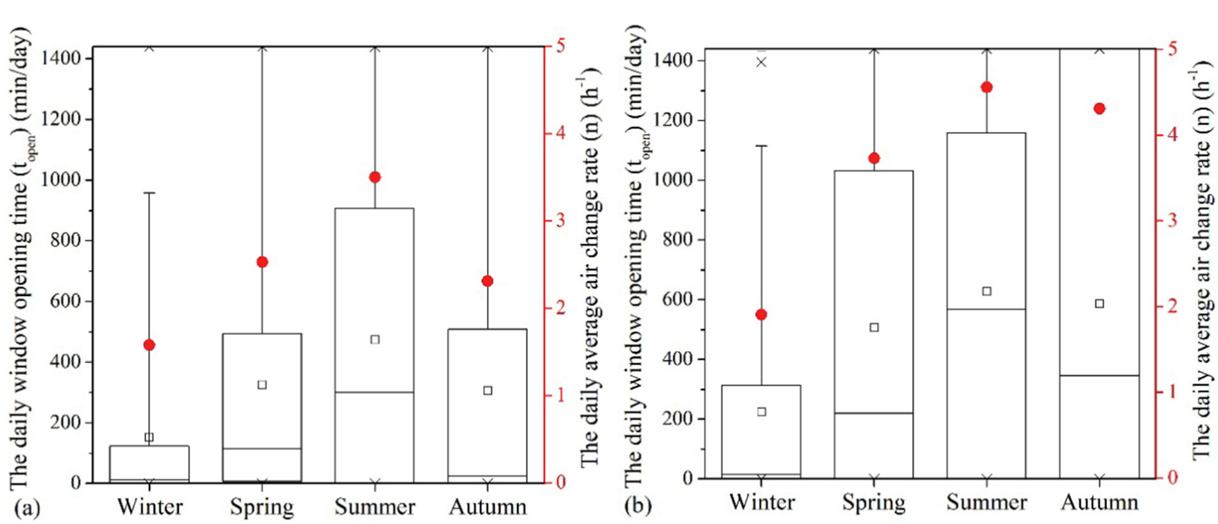



**Fig. 1.** Window opening time and daily average air change rate in different seasons in (a) Urumqi and (b) Tianjin. Box-whisker plots representing the 5th, 25th, 50th, 75th and 95th percentiles, as well as the mean (open squares).