Science of the Total Environment 577 (2017) 73–83

Contents lists available at ScienceDirect

Science of the Total Environment

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

VOC characteristics and inhalation health risks in newly renovated residences in Shanghai, China

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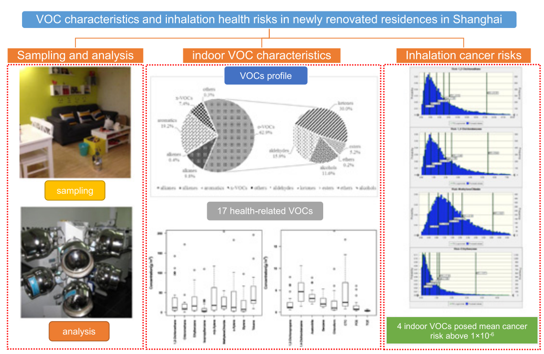
HIGHLIGHTS

- Measurements of up to 101 VOCs were made in 8 newly renovated homes in Shanghai, China.
- The dominant VOC groups by mass concentration were oxygenated VOCs, aromatics, alkanes and halogenated VOCs.
- The median individual concentrations of 17 health-related VOCs ranged from 0.35 μg/m^3 to 30.64 μg/m^3.
- The concentrations of 1,2-dichloroethane, 1,4-dichlorobenzene, methylene chloride, and ethylbenzene presented a mean cancer risk above the acceptable risk level of 1×10^{-6}.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 June 2016
Received in revised form 2 September 2016
Accepted 10 October 2016
Available online 4 November 2016

Keywords:
Volatile organic compounds
Renovation
BTEX
Chlorinated hydrocarbons (CL-VOCs)
Health risk assessment

ABSTRACT

Background: Exposure to indoor VOCs is expected to link to a variety of negative health outcome. The popularity of decorations and refurbishment in homes in China has given rise to indoor elevated VOC levels, potentially posing health threats to residents.

Methods: In this study, concentrations of 101 VOC compounds and associated health risks were investigated in newly renovated homes in Shanghai. The potential excess inhalation health risks from home exposure of 17 health-related VOCs were estimated by the Inhalation Unit Risk (IUR) and Reference Concentration (RfC) proposed by US EPA. Monte Carlo simulation and sensitivity analysis were used to assess the uncertainty associated with the estimates of health risks.

Results: The dominant groups by mass concentration were oxygenated VOCs (o-VOCs), aromatics, alkanes and halogenated VOCs (x-VOCs) .12 VOCs with IARC's confirmed or probable carcinogens ratings were detected with a >60% detection frequency in the total samples. The mean concentrations of BTEX (benzene, toluene, *m*/*p*-xylene, *o*-xylene, ethylbenzene) were 2.32 μg/m^3, 200.13 μg/m^3, 39.56 μg/m^3, 32.59 μg/m^3 and 26.33 μg/m^3 respectively, generally higher than those in older homes reported in previous studies except benzene. The mean concentration of methylene chloride (47.43 μg/m^3) and 1,2-dichloroethane (33.83 μg/m^3) were noticeably higher than the levels reported in previous studies in Hong Kong, Japan and Canada. Whereas the mean concentration of 1,4-dichlorobenzene (5.53 μg/m^3) were similar to the results of Canadian national survey but lower than those in Japan. The concentrations of 1,2-dichloroethane, 1,4-dichlorobenzene, and methylene chloride, ethylbenzene presented a mean cancer risk at 7.39×10^{-6}, 1.95×10^{-6}, 1.62×10^{-6}, 1.04×10^{-6} respectively, above the US EPA proposed acceptable risk level of 1×10^{-6}. Sensitivity analyses indicated that the VOC exposure concentration have a greater impact than the IUR values on the risk assessment.

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http://dx.doi.org/10.1016/j.scitotenv.2016.10.071

Conclusion: This study highlights the characteristics of VOCs in recently renovated homes and has implications for the adverse health effects that result from exposure to chlorinated hydrocarbons in indoor air.

1. Introduction

Indoor Air Quality (IAQ) has been a major public concern for several decades given that city dwellers spend approximately 80–90% of their time indoors. Volatile organic compounds (VOCs), as a common group of indoor air pollutants with large variety of species, continued to get worldwide attention due to their ubiquitous occurrence in indoor environments and their potentially important implications for human health. It has been widely reported that some VOCs may have both short- and long-term adverse health effects on occupants, including sensory irritation, allergies, sick building syndrome (SBS), decrements in lung function, asthma, and even leukemia, particularly in vulnerable groups such as children (Norback et al., 1995; Daisey et al., 2003; Rumchev et al., 2004; Cakmak et al., 2014; Gao et al., 2014).

Due to their potential health effects, studies on investigating the levels of indoor VOCs as well as screening the priority toxic pollutants have been carried out in many countries. In the United States, efforts on clarifying the exposure and source of VOCs were made since the late 1970s. Air toxins such as carbonyls (formaldehyde, acetaldehyde), chlorinated hydrocarbon (1,4-dichlorobenzene, chloroform, carbon tetrachloride), benzene, naphthalene have been identified as pollutants of potential concern indoors (POPCs) in view of several risk-based analyses (US EPA, 2004; Loh et al., 2007; Jia et al., 2008a). In Europe, European Commission's INDEX study classified BTXS (benzene, toluene, xylene, styrene), naphthalene, carbonyls (acetaldehyde, formaldehyde), terpene (limonene, α-pinene) as priority pollutants to be regulated in dwellings and public buildings. Other EU-funded studies (Sarigiannis et al., 2011, Karakitsios et al., 2015) revealed that for carcinogenic contaminants in EU countries, attributed risk is one to two orders of magnitude higher than the acceptable one of 10^{-6}. In Japan, recent nationwide survey (Azuma et al., 2016) on indoor chemicals exposure assessment showed that the highest risk pollutants included acrolein, benzene, propanal, acetaldehyde, and 1,4-dichlorobenzene.

Household microenvironments have been shown to be the driving factor determining personal exposure to VOCs (Guo et al., 2004; Stocco et al., 2008; Delgado-Saborit et al., 2011; Du et al., 2014a, 2014b, Karakitsios et al., 2015). Previous studies (Lee et al., 2002a; Zhou et al., 2011; Maisey et al., 2013; Wheeler et al., 2013; Gao et al., 2014) identified that recent renovation was an important factor influencing indoor VOC levels due to emission of the building materials, furniture, paints, glues, floor covering and other decorating materials (Hodgson et al., 2002; Ni et al., 2005; Jarnstrom et al., 2008; Guo, 2011; Liu et al., 2014). By utilizing low-emission building materials and eco-friendly consumer products, the indoor air quality appeared to have been improved over time in some developed countries (US EPA, 2011; Zhu et al., 2013). However, in most cases, homes undergone recent renovation had significantly higher VOC concentrations than those in non-renovated homes. These compounds may go through various changes in relation to time, some studies (Park and Ikeda, 2006; Liu et al., 2012; Shin and Jo, 2013; Liu et al., 2013) have shown that VOCs in new or recently renovated dwellings remain elevated for a range from 1 to 5 years.

Over the past two decades, because of rapid urbanization in China, the popularity of decoration and renovation in homes has led to elevated levels of indoor VOCs (Liu et al., 2012). Thus, adverse health effects associated with these compounds has become a major public concern (Zhang et al., 2013). A number of studies (Zhao et al., 2008; Guo et al., 2013; Dong et al., 2013, 2014; Gao et al., 2014) carried out in cities across China reported that recent renovation or use of new furniture in homes were associated with increased likelihood of sick building syndrome, respiratory symptoms, allergic rhinitis, asthma and leukemia in occupants, especially in children and women. Furthermore, a recent survey in city of Changsha (Deng et al., 2015) revealed that early life exposure to new furniture and home decoration contribute the rapid development of childhood asthma in China.

Thus far, the characteristics of VOCs and their inhalation-related health risks in newly renovated homes have not been well studied in China (Kulmala, 2015). Most studies of indoor air pollution in China (Wang et al., 2007; Weng et al., 2010; Huang et al., 2013; Liu et al., 2013; Zhu and Liu, 2014; Liu et al., 2014; Du et al., 2014a, 2014b) have focused on benzene, toluene, xylene and ethylbenzene (BTEX) or carbonyls (formaldehyde), and little is known about the levels of other VOCs and their potential health impacts. Thus, it remains important to better understand the profile and potential health impacts of VOCs in newly renovated residences.

The objective of this study was to understand the concentration of VOCs in newly renovated homes in Shanghai and the health risks related to inhalation exposure to VOCs. 101 VOCs were measured and their compositions were analyzed. The inhalation cancer risk and chronic toxicity for specific VOCs were calculated using the inhalation unit risk (IUR) and Reference Concentration (RfC) from US EPA as well as OEHHA of CalEPA. Uncertainty and sensitivity analyses were also conducted using a Monte Carlo simulation to determine the overall uncertainty associated with the predicted risks.

2. Methods

2.1. Sampling area and study design

Shanghai is one of the largest cities in China, with an area of over 6340 km^2 and with population of over 24 million people. It has a humid subtropical climate and experiences four distinct seasons. Home interior decoration and renovation are very popular in Shanghai due to the boom in the urban real estate industry in this megacity.

This study was carried out in May 2015 in Shanghai, China. Eight residences that had been renovated within the past year were studied. Information was collected regarding the construction area, type of decoration materials, and time of decoration.

2.2. Sampling method and analysis

The sampling process followed the national standard Technical Specifications for Monitoring of Indoor Air Quality (HJ/T167-2004). Three sampling sites were used in each participating residence: the living room, bedroom, and study. The latter two areas generally had a high amount of pressed-wood furniture. 3.2-Liter Summa canisters (Entech Instruments, Inc.) were used to sample indoor air VOCs. The sampling time of the Summa canisters was set to 45 min by controlling the QT valve. The relative sampling height was 0.5 to 1.5 m, which represents the breathing zone. Before sampling, the rooms were closed for approximately 12 h to simulate bad ventilation during daily life. The rooms were also closed during sampling. No smoking or cooking occurred during the measurements. The temperature, air pressure and other weather conditions were recorded during sampling.

VOC samples were analyzed using a gas chromatograph with a mass spectrometer and a flame ionization detector (GC–MS/FID). The VOC samples were first pumped into a cryogenic pre-concentrator (TH_PKU-300, Tianhong, China) and then concentrated at −150 °C in two traps. The concentrated VOCs were desorbed at 100 °C and injected into the gas chromatograph (7820A, Agilent, USA). The C2–C5