Concentration levels and impact factors of benzene series in Chinese dwellings

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Abstract. In this study, a nation-wide field measurement has been carried out in Chinese residence to obtain BTEX (benzene series) concentration levels and characteristics. Concentrations of benzene series (benzene, toluene, xylene and ethylbenzene) indoor were sampled in 223 dwellings covering 5 climate zones in China during 2016.12-2017.12. The arithmetic mean concentrations of benzene, toluene, xylene and ethylbenzene were 6.78 μg/m³, 17.4 μg/m³, 17.68 μg/m³ and 9.87 μg/m³, respectively. Higher concentration of BTEX and higher standard limit were founded in China than that in other countries and organizations. We identify some reasonable sources for specific data group, impact factors on decoration year, frequency of smoking and cooking of benzene series concentration were studied. Toluene concentration decreased with increase of decoration year, and concentration of benzene concentration in smoking families were higher than that in non-smoking families. No direct correlation between cooking frequency and indoor benzene concentration were founded. This study also provided statistical data on benzene exposure in new decorated residences and a discussion on setting limit values for standard.

1. Introduction

WHO 2002 has reported that indoor air pollution, hypertension, high cholesterol and obesity were clearly listed as the top 10 threats to human health. Benzene has been classified as a carcinogenic compound to humans by IARC (International Agency for Research on Cancer), and also toluene, ethylbenzene, xylene (BTEX) has been recognize increasingly because of its multiple sources and high health risks. Harmful gas pollutants emission from interior decoration and building materials are the main sources of indoor air pollution such as formaldehyde and benzene series. Du et al. [1] reported that new decoration materials, solvents and new furniture are the main sources of indoor benzene series. Human activities such as smoking and cooking indoor are also important indoor pollution sources in Chinese residences. Several researchers have studied indoor BTEX concentrations but only focus on one city or one region, which can be specific in terms of climate environment, building characteristics, living habit and economy level; and most of such studies focus on the new decorated houses. There is still no nation-wide BTEX survey in China and few studies analysed their associations with indoor human activities.

2. Methods

2.1. Experimental design

From December 2016 to December 2017, 223 Chinese residences in 9 cities covering 5 climate regions were selected, indoor air samples were collected for multiple on-site measurement in different seasons, including the living room, bedroom and kitchen. The climate region, average temperature and average relative humidity of each city during one year were shown in Table 1. Indoor temperature and humidity were measured using a sensor (Ikair) with 1 min record interval to monitor long-time indoor temperature and humidity, and the annual data were analysed statistically.
1. Comparison on BTEX Indoor Concentrations

Table 1. Indoor temperature, relative humidity and climate region of the tested cities.

| City       | Climate region       | Spring T(°C) | Spring RH (%) | Summer T(°C) | Summer RH (%) | Autumn T(°C) | Autumn RH (%) | Winter T(°C) | Winter RH (%) |
|------------|----------------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|
| Guangzhou  | Hot summer warm winter | 20.7          | 54.0          | 30.4         | 49.7          | 29.5         | 53.0          | 22.6         | 54.1          |
| Kunming    | Mild                 | 20.8          | 42.9          | 25.3         | 64.0          | 20.4         | 52.9          | 18.1         | 45.1          |
| Changsha   | Hot summer cold winter | 27.7          | 58.4          | 26.2         | 74.0          | 22.0         | 59.0          | 15.9         | 65.9          |
| Chongqing  |                      | 21.4          | 69.8          | 29.5         | 59.7          | 21.6         | 77.3          | 14.3         | 66.2          |
| Shanghai   |                      | 22.2          | 59.3          | 29.1         | 59.6          | 23.1         | 67.3          | 17.7         | 61.9          |
| Xi'an      | Cold                 | 25.6          | 49.3          | 28.1         | 61.6          | 19.3         | 50.9          | 21.6         | 37.8          |
| Tianjin    |                      | 24.2          | 46.9          | 29.3         | 61.6          | 22.5         | 52.6          | 23.6         | /             |
| Urumqi     | Severe cold          | 24.3          | 46.6          | 28.3         | 48.3          | 25.2         | 38.4          | 22.9         | 34.3          |
| Shenyang   |                      | 25.0          | 48.1          | 29.7         | 61.9          | 21.8         | 50.5          | 23.4         | 24.4          |

* Includes some residences in cities surrounding Guangzhou

2.2. Survey

A questionnaire survey about building & decoration information and occupants living habits has been conducted for further analysis. Main content of the questionnaire includes the completion year of building, decoration year, main decoration materials and furniture materials in living room, bedroom and kitchen. Human activities include cooking habits (cooking frequency, cooking method, fuel, etc.) and smoking habits (smoking amount per day, smoking location indoor, etc.) also have been recorded.

2.3. Sampling and analysis

The samples are all taken under “closed condition”, means all the windows and doors in each room had been closed for more than 12h before samples were taken. This is the condition specified in the Chinese national indoor air quality standard (GB/T 18883-2002). BTEX concentration were sampled at a flow rate of 0.5L/min for 20min using Tenax-TA tubes. Samples were sealed by aluminium foil after sampling and sent back to laboratory for analysis immediately. Analysis of BTEX was conducted by gas chromatography mass spectrometry (GC/MS) method. Blank sample and periodic sampling inspection of BTEX recovery rate were conducted for quality control. SPSS 24.0 statistical software was used for data statistical analysis, correlation analysis and t-test test analysis.

3. Results and discussions

3.1. BTEX concentrations

Table 2 showed statistical BTEX indoor concentrations in 223 residences. The arithmetic mean concentrations of benzene, toluene, xylene and ethylbenzene were 6.78μg/m³, 17.4μg/m³, 17.68μg/m³ and 9.87μg/m³, respectively. Data showed that the indoor concentration of benzene series in residential buildings ranged from 0 to 300μg/m³ and with a high standard deviation (SD). Toluene was the most abundant compounds among BTEX.

Table 2. Statistical BTEX indoor concentrations

| Compound       | Arithmetic mean | Geometric mean | SD | Median | Min. | Max. |
|----------------|-----------------|----------------|----|--------|------|------|
| Benzene        | 6.78            | 4.00           | 8.08| 3.96   | 0.24 | 64.14|
| Toluene        | 17.40           | 11.43          | 20.12| 11.66  | 0.29 | 214.37|
| Xylene         | 17.68           | 8.87           | 32.62| 8.73   | 0.33 | 300.00|
| Ethylbenzene   | 9.87            | 3.51           | 29.92| 3.41   | 0.18 | 300.00|

Comparison on BTEX concentration between previous studies [1-13] and this study was shown in Figure 1. Except for ethylbenzene, indoor BTEX concentration in China were higher than the results in this study and other countries. The possible reason is that most studies in China focus on new decorated apartments rather than selected randomly. Decoration year of residence in this study distributed in 1~20 years, which could reflect the general situation of Chinese houses. While BTEX concentrations in this study were consistent with the level indoors in other countries, indicating that the benzene series concentrations indoor were still higher than that in other countries if under the same decoration period.
Figure 1. Comparison of indoor average concentration of benzene series in different countries.

Sources of BTEX included both indoor sources (decoration materials and human activities) and outdoor sources. In some developed countries (such as Britain, Canada and Germany), the indoor concentration of benzene, toluene and xylene is basically same as outdoor concentration, and outdoor BTEX mainly comes from automobile exhaust emissions and industrial fuel combustion. In China, relevant studies have shown that the concentration of outdoor benzene, xylene and ethylbenzene in China is lower than 10 μg/m³, the concentration of toluene is lower than 15 μg/m³, and the I/O ratio of benzene series often larger than 1 [14], which indicates that indoor sources of benzene series in Chinese residential buildings cannot be ignored.

3.2. Comparison on limit value for BTEX settled in standards

Table 3 summarized the limit value of benzene series settled in Chinese standards and other foreign health organizations. Only short-term (1h average) indoor BTEX limit value has been settled in China, while international organizations give long-term exposure limit value based on chronic health assessment, which were much lower than Chinese standards. Moreover, WHO proposed “no safe level” for indoor benzene concentration. Compare with the benzene limit set in Chinese Indoor Air Quality Standard (GB/T 18883-2002), almost all of the samples were below-limit; while compare with 3 μg/m³ limited in OEHHA for benzene long-term exposure, the over-limit rate is high up to 62%. In order to ensure a healthy indoor environment, China's IAQ standards should also consider the effect of long-term BTEX exposure on human beings.

### Table 3. Summary of limit value for BTEX settled in standards

| Standard       | Remarks | Benzene (μg/m³) | Toluene (μg/m³) | Xylene (μg/m³) | Ethylbenzene (μg/m³) | Exposure averaging time |
|----------------|---------|-----------------|-----------------|----------------|-----------------------|-------------------------|
| GB/T 18883-2002| Indoor  | 110             | 200             | 200            | -                     | 1 hour                  |
| CA OEHHA REL   | -       | 27              | 37000           | 22000          | -                     | 1 hour (Acute)          |
| EC INDEX (2005)| Indoor  | No safe level   | 1500            | 2000           | -                     | Short-term exposure limit|
| OSHA           | Workplace| 3500            | 435000          | -              | -                     | 8 hours                 |

3.3. Impact factors on indoor BTEX concentrations
3.3.1. Decoration year and BTEX concentrations. Figure 2 showed the variation of indoor BTEX concentrations with decoration year. Concentration of benzene, toluene and ethylbenzene decreased obviously in the first three years after decoration. After 3 years’ decoration, toluene concentration decreased while concentrations of benzene, xylene and ethylbenzene had no discernible trend changed with decoration year. And there may be other specific sources of xylene and ethylbenzene indoor caused peak concentrations occurred in individual samples.

![Figure 2](image.png)

*Figure 2. Variation of indoor BTEX concentration with decoration year.*

3.3.2. Smoking and BTEX concentrations. Indoor BTEX concentrations in smoking/non-smoking dwellings were shown in Figure 3. Higher average benzene concentration was found in smoking families, while concentrations of toluene, xylene, and ethylbenzene were lower in smoking families than that in non-smoking families. Japanese researchers [15] found that harmful VOCs would emission from body 45 minutes after smoking and attach to clothing and environment, forming third-hand smoke. Third-hand smoke not only remains for a long time, but also forms carcinogenic teratogenic substances. Charles et al. [16] measured the emission of three standard cigarettes: 1R5F (ultra-low nicotine), 2R4F (low nicotine), and 1R3F (standard nicotine). The results showed that the emission of benzene and toluene in these three types of cigarettes were 296-535μg·cigarette⁻¹ and 541-1003μg·cigarette⁻¹, respectively. The emission of toluene during smoking is higher than that of benzene, while during the sampling period of this study, there was no ongoing smoking activities, only the occupants has smoking behaviors in the dwelling for a long time, which may indicate contribution rate of benzene in the effect of third-hand smoke is greater than that of toluene.
3.3.3. Cooking frequency and BTEX concentrations. The concentration of benzene, toluene, xylene and ethylbenzene corresponding to different cooking frequencies are shown in Figure 4. Concentration of benzene increased slightly with the increase of cooking frequency, while the concentration of toluene, xylene and ethylbenzene did not change clearly. Wang et al. [17] studied VOCs emitted from cooking, and the results showed that alkanes (51.26% ± 23.87%) and o-VOCs (24.33 ± 11.69%) played a dominant role. This may reflect that the main VOCs emitted by cooking were alkanes, aldehydes and ketones, the concentration of benzene series indoor has little correlation with cooking frequency.

Figure 3. Comparison of BTEX concentrations in smoking/non-smoking dwellings

Figure 4. Variation of indoor BTEX concentration with cooking frequency.
4. Conclusion
A nation-wide field measurement has been carried out in 223 Chinese residences to obtain BTEX (benzene series) concentration levels and characteristics, the data showed that most BTEX concentrations indoor were lower than the limit value (GB/T 18883-2002). For impact factors analysis, toluene concentration decreased with increase of decoration year, and concentration of benzene concentration in smoking families were higher than that in non-smoking families. No direct correlation between cooking frequency and indoor benzene concentration were founded.

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