A Study on Indoor Air Quality of Urban Residential Buildings in China

Hiroshi Yoshino*,1, Junhong Zhao1, Yasuko Yoshino2, Kazukiyo Kumagai3, Yueyong Ni1, Zhenhai Li4, Jing Liu5, Takayuki Shigeno6, Hiroyuki Miyasaka1 and Yukio Yanagisawa3

1 Graduate School of Engineering, Tohoku University, Japan
2 Junior College of Nihon University, Japan
3 Graduate School of Frontier Sciences, University of Tokyo, Japan
4 Tongji University, China
5 Harbin Institute of Technology, China
6 Tokyo Electricity Corporation, Japan

Abstract
The purpose of this survey was to examine the actual conditions of residential indoor air quality in urban areas in China. In this survey, the concentrations of about 16 volatile organic compounds (VOCs) and two carbonyl compounds were measured at 75 apartments in seven Chinese cities, viz., Urumqi, Harbin, Beijing, Shanghai, Changsha, Chongqing, and Kunming. In this paper, the measurement results for six VOCs and two carbonyl compound concentrations are summarized. It was found that the average concentrations of benzene, toluene, and formaldehyde were relatively high.

Keywords: china; urban residential building; indoor air quality; field measurement

1. Introduction
During the past several decades, China has made great progress in terms of economic growth and development. However, various environmental problems have been generated at the same time that the standard of living has been rising. Recently, the problem of indoor air pollution has attracted considerable attention because the pollutants (volatile organic compounds (VOCs) and carbonyl compounds) in indoor air have a significant impact on the health of occupants. VOCs and carbonyl compounds are a group of major indoor pollutants that have been associated with many adverse health effects including cancer (WHO, 1987). It is suspected that VOCs and carbonyl compounds are major factors in “sick building syndrome” (SBS) (Molhave et al. 1986).

Now, at the time when a huge number of new residential buildings are being constructed in China, luxurious interior decorations have become the basic source generating indoor air quality (IAQ) problems. On the other hand, due to the enhancement of residential performance, such as high airtightness and high thermal insulation, IAQ problems have become more serious. In order to find a solution to such problems, it is necessary to understand the context within which they arise. The purpose of this study is to look into the actual conditions in urban residential buildings in China.

2. Outline of survey
2.1 Location of the cities surveyed (Fig.1.)
The apartment houses investigated were located in the seven urban areas: Urumqi, Harbin, Beijing, Shanghai, Changsha, Chongqing and Kunming.
Harbin and Urumqi are located in a very cold region according to the climatic classification provided by the government of China. Beijing is in a cold region. Shanghai, Changsha and Chongqing are located in regions characterized by hot summers and cold winters. Kunming is in a warm region.

2.2 Subject apartments of the survey (Table 1.)

The measurements of indoor and outdoor chemical concentration together with a questionnaire survey were carried out in 75 apartments in seven Chinese cities from August 2002 to January 2004.

2.3 Methods of investigation

a) Field measurement approach (Table 2.)

Concentrations of carbonyl compounds and VOCs were simultaneously measured by passive sampling in all apartments. The sampling period was five days. Meanwhile, personal exposure was measured by selecting an occupant from each subject apartment. The indoor temperature and humidity were recorded for the same measurement period. Table 2 shows the measurement and analysis methods used to ascertain chemical concentrations.
b) Questionnaire approach (Table 3.)
A questionnaire was distributed to each apartment. Occupants of these subject apartments were asked to answer the questionnaire, in which the basic information on their buildings, living environment and lifestyle were included.

3. Results of survey
3.1 Questionnaire results
a) Building age and years elapsed since interior decoration (Fig.2.)
Among the 75 investigated apartments, there were about 30% where the building age was less than three years. There were approximately 60% of apartments where less than three years had elapsed since interior decoration had taken place.
b) Type of interior decoration (Fig.3.)
Based on the answers to the questionnaire, the interior decoration was divided into three types: “luxurious” (decorating expenses more than 30,000 RMB yuan); “ordinary” (decorating expenses less than 30,000 RMB yuan); and “skeleton” (not yet decorated). The results showed that about 45% of the subject houses could be categorized as having luxurious interior decoration.

3.2 Results of field measurement
Seventeen chemicals were analyzed for this investigation. In this paper, the concentrations of the following chemicals were measured: formaldehyde, acetaldehyde, benzene, toluene, ethylbenzene, xylene, alpha-pinene and p-dichlorobenzene. The indoor air quality was measured at different times of the year and in different cities.

Notes:
1) In: indoor; out: outdoor
OT: Mean outdoor temperature
RH: Mean outdoor relative humidity
2) Each plot in the graph represents the chemicals’ concentrations in one subject house, and the same mark indicates the same residence. Bars are the average of the concentrations.

Fig.2. Building Age and Years Elapsed since Decoration
Fig.3. Type of Interior Decoration
Fig.4. Indoor and Outdoor Concentrations of Eight Chemicals
quality standards in China are 110μg/m³ for benzene, 200μg/m³ for toluene, 200μg/m³ for xylene and 100μg/m³ for formaldehyde.

3.2.1 Summer investigation (Fig.4.)

a) Harbin: Indoor concentrations of xylene and formaldehyde, which were relatively high, exceeded the Chinese standards in two and four apartments out of ten, respectively.
b) Beijing: The indoor concentration of formaldehyde in three apartments out of six exceeded the Chinese standard. The highest level detected was 893.3 μg/m³, which is nine times higher than the standard. The highest indoor concentration of benzene was 404.8 μg/m³, which is four times higher than the standard.
c) Shanghai: Average outdoor temperature during the measurement period was 32.3°C, which was the highest among the four cities. The mean indoor concentration of p-dichlorobenzene was the highest among the four cities. Indoor concentrations of xylene and formaldehyde exceeded the Chinese standards in two houses.
d) Changsha: The concentrations of carbonyl compounds were higher than those for VOCs. However, the mean concentrations of each compound were the lowest among the four cities.

3.2.2 Winter Investigation (Fig.4.)

a) Urumqi: The average outdoor temperature during measurement period was −12.1°C, which was the lowest among the four cities except for Beijing. The indoor concentrations of benzene, toluene, ethylbenzene and xylene in Urumqi were much higher than in the other cities because the windows were usually closed due to the low outdoor temperature. In one apartment, whose neighbor was carrying out interior decoration, concentrations of benzene, toluene, ethylbenzene and xylene were 777.3, 609.8, 458.4 and 785.7 μg/m³, respectively.
b) Beijing: The mean indoor concentration of three compounds, toluene, alpha-pinene and formaldehyde, were relatively high. In particular, the average value for formaldehyde concentration exceeded the Chinese standard. The highest levels of benzene, toluene and alpha-pinene were found in an apartment where interior decoration had just been finished.
c) Chongqing, Changsha and Kunming: In these three cities, the indoor concentrations of benzene, toluene, xylene and formaldehyde were lower than the Chinese standard. This is attributable to the fact that many apartments keep their windows open due to the relatively high outdoor temperatures.

3.3 Relationships between concentrations and living environmental factors (Figs. 5 and 6)

Fig.5. shows the relationship between formaldehyde concentration and four living environment factors. As building age and the years after decoration increase, the formaldehyde concentration tends to decrease. On the other hand, the concentration increases with a rise in indoor temperature. However no clear relationship between the formaldehyde concentration and indoor relative humidity could be established through this survey.
Fig. 6. shows that toluene concentration decreases with increasing building age and years elapsed since interior decoration, but a relationship between the concentration and indoor temperature/relative humidity was not evident.

3.4 Correlation between personal exposure and indoor concentration

a) Formaldehyde (Fig. 7.): Relationship between personal exposure and indoor concentration is high. The correlation coefficient for the winter investigation is 0.84. On the other hand, the correlation between these two parameters for the summer investigation was not so high. One of the reasons for this finding is that the exposure concentration for the subject of apartment A was very low due to the short length of his stay in the apartment.

b) Toluene (Fig. 8.): In the summer investigation, the correlation coefficient was low because some organic solvent was used at the workplace of the subject in apartment B. This fact was discovered through the questionnaire. In the winter investigation, due to some organic solvent usage in the workplace of the subject in apartment C and the short length of subject’s stay in apartment D, the correlation coefficient was low.

c) Benzene (Fig. 9.): In the summer investigation, the correlation coefficient was 0.87. The relationship between personal exposure and indoor concentration is high. In the winter investigation, the correlation coefficient is relatively low. The personal exposure of the subject in apartment E is extremely high because some organic solvent was used at the workplace of the subject. On the other hand, it was found that the personal exposure concentration of the subject in apartment F was low because of the short length of time spent at home everyday.

3.5 Multiple regression analysis on indoor chemical concentration with living environment factors (Table 4.)

By taking nine factors of the living environment as variables, the influence of the living environment on indoor chemical concentration was studied using multiple regression analysis. However the data of one apartment in Urumqi (whose neighbor was carrying out interior decorating) and another apartment in Beijing (where interior decorating had just been finished) were excluded. The results for formaldehyde and toluene are as follows.

a) Formaldehyde: In the summer investigation, it was found that “new furniture purchased within one year” (hereafter, “new furniture”), “mean indoor relative humidity”, “interior decoration types” and “the length of time window was open per day” had an influence on concentration. However, the standard partial regression coefficient (β) for two factors (“new furniture” and “interior decoration types”) were negative, though this result had not been expected. “Indoor temperature”, “building age and years elapsed since interior decoration”, “interior decoration types” and “the mean length of time window was opened per day” had an influence on the concentration of formaldehyde.

b) Toluene: In the summer investigation, according to standard partial regression coefficient (β), it can be concluded that three factors “the mean length of time window was opened per day”, “building age and
Table 4. Multiple Regression Analysis on Indoor Chemical Concentration

| Explanatory variables | Standard partial regression coefficient (β) |  |
|-----------------------|---------------------------------------------|--|
|                       | Formaldehyde (Summer (29*), Winter (42))    | Toluene (Summer (29), Winter (42)) |
| 1. Building age (years) | -0.002                                      | -0.256                                      | -0.256                                      | -0.157                                      |
| 2. Years elapsed since interior decoration (years) | -0.134                                      | -0.338                                      | -0.286                                      | -0.395                                      |
| 3. Interior decoration types (dummy variable; 0: ordinary decoration and skeleton, 1: luxurious decoration) | -0.279                                      | 0.268                                       | -0.200                                      | 0.085                                       |
| 4. Mean indoor temperature (degree C, during the period of measurement) | 0.024                                       | 0.579                                       | 0.144                                       | 0.341                                       |
| 5. Mean indoor relative humidity (RH%, during the period of measurement) | -0.302                                      | 0.101                                       | -0.302                                      | -0.274                                      |
| 6. Floor materials (dummy variable; 0: wood, 1: not wood) | -0.212                                      | -0.124                                      | 0.117                                       | 0.121                                       |
| 7. New furniture purchased within one year in the room measured (dummy variable; 0: no, 1: yes) | -0.328                                      | -0.011                                      | -0.187                                      | 0.303                                       |
| 8. The number of pieces of furniture in the room measured | 0.009                                       | 0.108                                       | 0.094                                       | 0.152                                       |
| 9. The mean length of window opening within a day (h) | -0.229                                      | -0.155                                      | -0.380                                      | -0.045                                      |

Multiple correlation coefficient (R): Formaldehyde: 0.612 (summer); 0.745 (winter); Toluene: 0.616 (summer); 0.598 (winter)
*Number of apartments used for analysis.

years elapsed since interior decoration” and “interior decoration types” influenced the indoor concentration of toluene. However, the standard partial regression coefficient value for “interior decoration types” was negative, which was the same as the result for formaldehyde, viz., contrary to expectation. In the winter investigation, it was shown that “years elapsed since interior decoration”, “mean indoor temperature and relative humidity”, and “new furniture” influenced indoor concentration.

4. Conclusions
Field measurements together with a questionnaire survey on indoor air quality were carried out for 75 residences located in seven Chinese cities. The conclusions are as follows:
1) It was found that the concentration of formaldehyde and some VOCs, such as toluene and benzene, were relatively high in the Chinese city residences investigated.
2) With increasing building age and years elapsed since interior decoration, indoor chemical concentrations decreased.
3) There is a strong correlation between personal exposure and indoor chemical concentration although the length of time subject stayed in the home, and the workplace situation influenced personal exposure.
4) According to the results of multiple regression analysis, the interior decoration type, indoor temperature and humidity, and window opening influenced the chemical concentrations.

Acknowledgement
This study was supported by a [grant][subsidy] from the Ministry of Education, Culture, Sports, Science and Technology of Japan under contract No.13574007. The authors would like to thank Assoc. Prof. Akashi Mochida (Tohoku University, Japan), Prof. Qingyuan Zhang (Tsukuba College of Technology, Japan) and Prof. Nianping Li (Hunan University, China) for their advice and great help during the investigation.

References
1) WHO, Indoor Air Quality, Organic Pollutants, EURO Reports and Studies 111, 1987
2) Molhave L, Bach B, and Pedersen O F. (1986) Human Reactions to Low Concentrations of Volatile Organic Compounds. Environment International, Vol. 12, pp. 167-165.
3) Hiroshi Yoshino, Qingyuan Zhang, Yasuko Yoshino, Takayuki Shigeno, Shan Guan, Hiroyuki Miyasaka, Zhenhai Li, Kazukiyo Kumagai and Yukio Yanagizawa, (2004) Summer Investigation on Indoor Environment of Residential Buildings in Beijing and Four Other Cities, Journal of Asian Architecture and Building Engineering, Vol. 3 No. 1, pp. 47-54
4) Zhipeng Bai, Zongshuang Wang, Tan Zhu, Jim Zhang (2002) Developing Indoor Air Quality Related Standards in China, Proceedings of the 2nd International Workshop on Energy and Environment of Residential Buildings in China, pp. 228-234.
5) Z. Tonghua et al: The Investigation and Analysis of Indoor Air Pollution in China, Proceedings: Indoor Air 2002, pp. 607-611
6) Y. Zhao et al (2002): Indoor Air Environment of Residential Buildings in Dalian, China, The 2nd International Workshop on Energy and Environment of Residential Buildings in China, pp. 86-90.
7) China Indoor Air Quality Standard, 2003, 3