FIELD INVESTIGATION OF INDOOR AIR QUALITY IN VARIOUS CHINESE RESIDENTIAL BUILDINGS

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ABSTRACT

In recent years, the housing market in China has expanded tremendously due to economic development. Building envelopes have become more and more airtight because of improvements in building technology and concerns on energy conservation. But a lack of knowledge on domestic ventilation performance and difficulties in achieving suitable standards have led to more and more complaints from occupants, and reported cases of building related illness (BRI). For these reasons, we carried out an investigation on indoor air quality and building performance of various residential buildings in a northeast coastal city in China. Field measurement of indoor/outdoor parameters was conducted in combination with questionnaire survey during 2001~2002. Statistical analysis was performed to reveal the factors that influence indoor air quality in typical buildings. The relationships between pollutant levels, building characteristics and inhabitant's living patterns were also discussed. The conclusions can be summarized as follows: 1. Carbon Dioxide concentration measurements indicated that 1/3 of test rooms were suffering from inadequate ventilation in winter. 2. A total of 29.7% households reported that air in their homes is bad, especially when smoking, excessive occupancy or cooking occurs. 3. The formaldehyde concentration in older houses is lower than in new-built or newly decorated houses. 4. Occurrence of building related symptoms in new dwellings is higher than that in old buildings.

KEYWORDS

Indoor air quality, Domestic ventilation, Field investigation, Residential building

INTRODUCTION

In recent years, Chinese housing market has expanded tremendously because of rapid economic development. Newly-built residential units are increasing in number rapidly. Due to

concerns on energy efficiency and improvements in building techniques, the energy performance of residential building built after the 1996 regulation (B.C.D. 1996) should be generally better than those built before. Requirements of envelope U-value and air-tightness are indicated in the standard. Improvement of post-occupancy operation also contributes to energy conservation. But meanwhile, we have to pay attention to the emergence of more and more complaints, even cases of disease related to indoor air quality in recent years. The incidence of allergies such as asthma (especially in children) is increasing rapidly. A.P. Jones gave an extensive review on the risk of asthma in domestic environments (Jones 1998). Considering the large number of households which have moved into new-built or newly-decorated homes, which are more airtight than before, it is necessary to carry out a study on the evaluation of sick buildings and their influence on IAQ and people's health. From another point of view, we don't have building regulations which considering requirements for residential ventilation in China. But in Europe and USA, study on ventilation for acceptable IAQ has been a very important topic since the 1970s. ASHRAE standard 62 series, standards for EU and individual countries all provide statement of minimum ventilation requirements for different kinds of buildings. They are in constant development and revision following research progress in this area, but we even lack basic knowledge on local domestic ventilation performance and IAQ. So we carried out this field study to better understand the situation of residential indoor environments, and to explore the association between building features and IAQ.

Figure 1: Location of Dalian

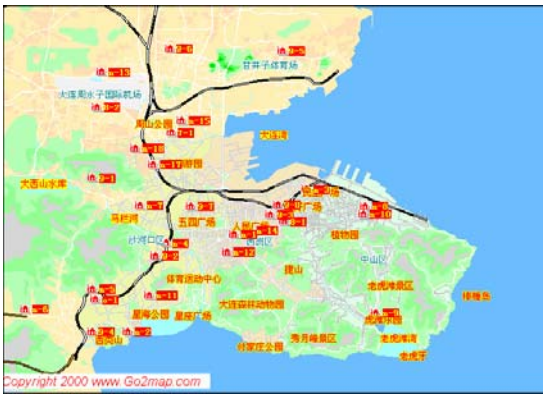

Figure 2: Location of the 30 dwellings

We selected Dalian, a coastal city in northeastern China, for the field investigation. Dalian is located between 38°43' to 40°10' north latitude and 120°58' to 123° east longitude, in the southernmost point of Liaodong Peninsula; with the Yellow Sea to its east and the Bohai Sea to its west (see fig.1). The climate is temperate continental monsoon with four distinct seasons. Average temperature is 8.4°C to 10.5°C with a high of 35°C and low of - 24°C. Annual precipitation is 600~790mm. As in other Chinese cities, the housing market of Dalian has seen vast development during past ten years. Up to 2000, the total built-up area in Dalian was

53.97 million ㎡, among which 29.98 million ㎡ is residence. It is increasing at the rate of 1.5 million ㎡ each year (2001).

METHOD

Questionnaire Survey

A questionnaire survey was conducted in two stages in summer and winter. Self-report questionnaires were submitted to families of senior school students, which were distributed in different areas around the city. All questions were explained to the students in advance and the householder of each family (normally parents) was responsible for the answers. Questions covered aspects of building features, facilities and operation, lifestyle of occupants, occupant's perception of indoor environment and their heath experience etc.

The summer survey was from 20th July 2001 to 10th August 2001, during which 650 questionnaires were handed out and 117 were fully answered (response rate 18%). The winter survey was carried out from 1st Jan to 3rd Jan 2002 using a modified questionnaire based on the summer one. Eventually 550 were collected from the 630 issued (response rate 87%) due to improved technique of interview. All valid data sets were processed by statistical analysis.

Field Measurement

Table 1: Measurement Summary

Measuring Parameters	Instrumentation	Ref. Criteria *
Temperature	TR-51A, TR-72S and RHLOG data logger	-
Relative Humidity	TR-72S and RHLOG data logger	-
Formaldehyde	TH-150 Air Sampler (0.5L/min, 30min) and 721-Spectrophotometer	0.08mg/m^3
Radon	Sun Nuclear Radon Monitor M 1027	200 Bq/m^3 for old buildings 100 Bq/m^3 for new buildings
CO_2	Testo Infrared CO_2 Probe and Monitor	1000 ppm
Radiation	Inspector (S.E. Intl, Inc)	

Note: National Standard China GB/T 16146-1995 for radon, GB/T 16127-1996 for formaldehyde and GB/T 17094-1997 for carbon dioxide.

Besides the questionnaire survey, 30 residential buildings were selected to do indoor environment monitoring and pollutant measurement. The locations of 30 dwelling are shown in Fig.2, in which each home is marked by a house symbol and a square containing a number. We divide samples into three groups according to the age of building, which is group A - 10

houses built in recent three years; group B – 10 houses age 4~10 years and group C – 10 houses more than 10 and up to 50 years old. Included are 27 (90%) multi-story apartments /flats, two detached houses and one bungalow. The fieldwork lasted about six weeks from January to February 2002. Temperature and relative humidity were recorded continuously in the living room and the main bedroom of each house for durations of 4 days to 1 week. Radon, formaldehyde, carbon dioxide and radiation were measured at the middle of one test room in each house. Parameters and instrumentation details are listed in Table 1. Questionnaires were completed by interviewer and occupants during the visit.

RESULTS AND DISCUSSIONS

Results Of Questionnaire Survey

Distribution of building characteristics

In the sampled households, 98.4% live in multi-story flat/apartments (93.7% are lower than 9 stories and 4.7% are high-rise). Just 1.6% live in detached town house. From the distribution of building age shown in Fig 3, about 2/3 dwellings were built in the recent 10 years, which is a large proportion compared with developed countries. Fig 4 shows features of window, which play important roles in insulation, infiltration and ventilation, including double or multiple glazing and new window frame materials.

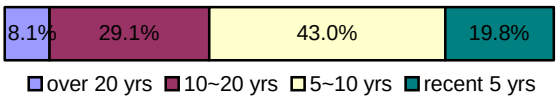

Figure 3: distribution of building ages

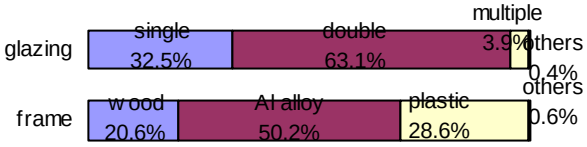

Figure 4: characteristics of windows

Residential Ventilation Styles And Occupant Ventilating Habits

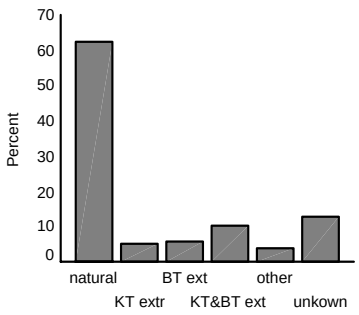

Fig 5: ventilating styles

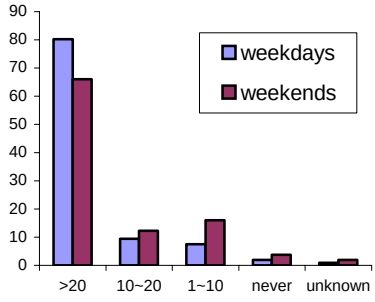

Fig 6: summer window open hrs

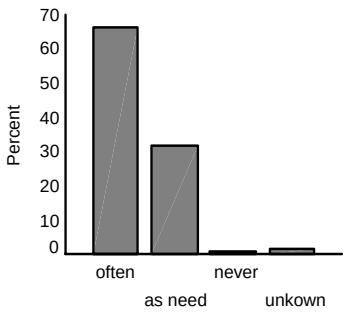

Fig 7: winter window open freq

Fig 5~7 show information about how occupants ventilate their home in summer and winter. Most residential buildings are naturally ventilated by opening windows, with about 1/5 having extract fan in kitchen (KT) or bathroom(BT) or both. In summer, most households have their windows continuously open for more than 20 hours per day while in winter they are briefly open but frequently, or when need.

The Perceived Indoor Air Quality

When asked the question “Do you think indoor air quality of your home is good or bad?” 29.7% occupants’ answer was “Bad”. The ranked reasons causing bad IAQ are smoking, excessive occupancy, and cooking. Considering the degree of discomfort, 22.4% regarded their living environment as slightly uncomfortable, about 2% were uncomfortable and people who felt very uncomfortable and unbearable were 1% respectively.

Indoor Air Pollutant Levels

Summary Of Measurement Results

The results of pollutant measurements are summarized in table 2.

Table 2: Concentration of indoor air pollutants in 30 dwellings

Pollutant	Minimum	Maximum	Mean	Std. Deviation
CO_2_LR (ppm)	446	1650	840	330.56
CO_2_BD (ppm)	465	1552	760	278.54
CO_2_KT (ppm)	404	1795	772	368.81
HCHO (mg/ m3)	0*	0.50	0.13	0.1335
Radon (Bq/m3)	3.7	92.5	41.8	29.634
Radionuclide Level (μSv/hr)	0.02	0.19	0.11	4.228E-02

Note: “0” means undetected. The minimum detected range for formaldehyde is 0.04 mg/m^3.

Carbon Dioxide

Carbon dioxide concentration in fig 8 indicates that although most families have acceptable levels of CO_2, 1/3 of measured homes are suspected of suffering from inadequate ventilation in winter. To estimate ventilation rate from carbon dioxide concentrations (Persily 1997; Beisteiner and Coley 2003), continuous measurement is required. CO_2 level can also be used as the indicator of IAQ. Gas cooking probably causes higher concentrations in kitchens.

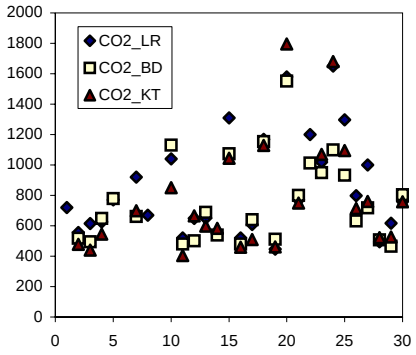

Figure 8: CO_2 concentration in 30 dwellings

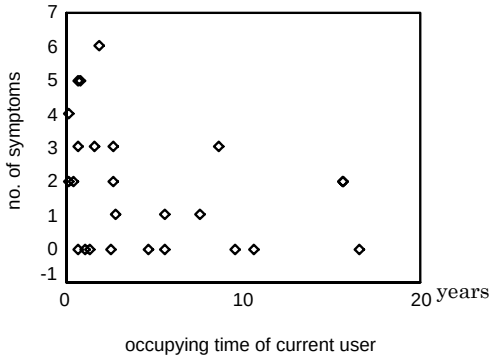

Figure 9: symptom occurrence vs. occupying time

Radiation – Radon and Radionuclide

Radon concentrations and radionuclide level indicate the risk of radiation exposure, which is normally unperceivable but can cause severe health problems e.g. cancer. Radon results in our survey are all lower than the recommended level. However, the highest concentration case was a new apartment with electrical ceiling radiant heating system. The householder reported that he almost never opened windows during winter because of the high electricity bills.

Radionuclide level is the only parameter we measured which is not influenced by ventilation. It comes from building materials made from industrial waste or natural materials, e.g. marble and granite, which are widely used in Chinese decoration. Different form Radon, which damages human body by inhalation, the exposure pathway of radionuclides is direct (external) exposure. Being aware of radiation pollution, the General Administration of Quality Supervision, Inspection and Quarantine of China (GAQSIQ) has issued National Standard to classify building materials into three grades according to the radioactive level of radionuclides (GAQSIQ 2001). The applying boundaries of different materials are also regulated.

Formaldehyde

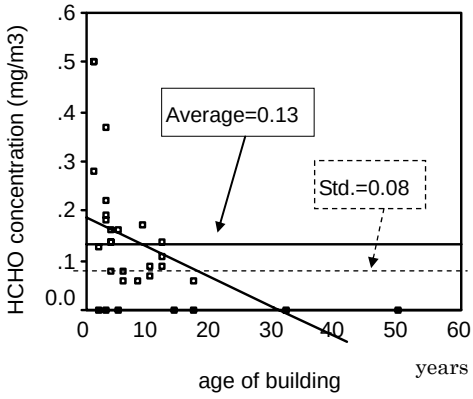

Figure 10: HCHO vs. building age

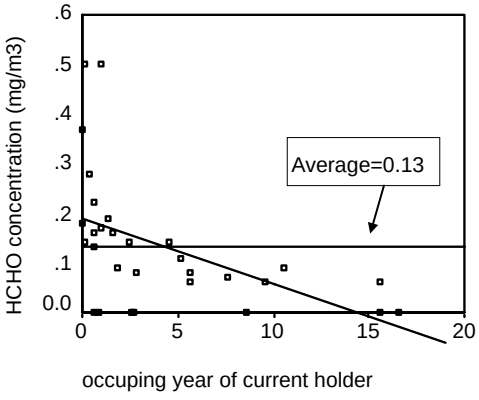

Figure 11: HCHO vs. occupying time

Fig 10 indicates serious formaldehyde pollution especially in new homes. Performing Pearson correlation analysis, the correlation of building age and HCHO concentration is significant at 0.05 level (Fig 10), and correlation of occupied time and HCHO concentration is significant at 0.01 level (Fig 11). HCHO concentration decreases when building age or occupied period increases. Sakaguchi and Akabayashi (2003) show similar results in their study. Significant correlation of HCHO and room temperature was not found in our study.

Opening windows is the most practical strategy to remove pollutants for the majority of naturally ventilated homes. To investigate its effect on HCHO removal, we conducted extra tests in two newly-completed apartments, which had the highest HCHO concentration (0.5 mg/m^3) in the 30 dwellings. After 20 minutes opening window in test rooms, HCHO concentration in one unit decreased to 0.27 mg/m^3; HCHO in the other unit was undetected (lower than 0.04 mg/m^3). So opening a window has a positive and rapid effect, but cannot ensure good level of IAQ continuously, especially in cold winter. To achieve optimum effect, further study is required on the interaction between HCHO emission rate, local conditions and the arrangement of ventilation strategies.

Occupants' Symptoms and Perceived IAQ

We asked 11 questions considering building-related symptoms (acute or chronic) such as headache, fatigue, depression, dry eyes, irritation of eyes or nose, arthritis and so on. In calculating the responses, 26.7% people had more than three symptoms. But it is somewhat difficult to conclude that indoor pollution is the only cause of the symptoms. When we examine numbers of symptoms occurring in various households versus the duration of their living in their current home which is shown in fig 9, we find that people living in new homes seem at higher risk of health problems. We also learn that the perceived IAQ level and the measurement results are not compatible. For example, among 17 people who evaluate their home as comfortable, 10 are living in homes with HCHO concentration above recommended criteria including one case of maximum concentration (0.5 mg/m^3); six are living in homes in which CO_2 levels are higher than 1000ppm.

CONCLUSIONS

From the results of the investigation, we obtained better knowledge of residential ventilation and IAQ. Changing building components, household lifestyle etc has led to more problems to be considered. 62.2% of surveyed dwellings are ventilated by natural means, which is easily influenced by occupant behaviour. A total of 29.7% of households reported that air in their

house is bad, especially when smoking, over-occupied or cooking. According to the field measurements, HCHO concentrations in new-built or new-decorated houses are higher. There was no relation found between HCHO concentration and room temperature. Opening windows has a rapid effect on removal pollution but the effect is influenced by HCHO emission rate, local conditions and the arrangement of ventilation strategies. It is important to ensure adequate ventilation in new and airtight house. People living in new homes seem at higher risk of building related health problems. The perceived IAQ levels reported by households are not compatible with the measurement results. So the assessment of IAQ level should be based on both occupant perception and parameter measurement.

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