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Field study on indoor air quality of urban apartments in severe cold region in China

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ABSTRACT

An investigation on indoor air quality was carried out in urban apartments in Harbin, China. The indoor and outdoor concentrations of $PM_{2.5}$, PM_{10}, CO, CO_2, SO_2, NO_X, TVOC, HCHO and NH_3 were monitored. Simultaneously, questionnaire surveys on the indoor perception of air quality among occupants were conducted. In addition, a continuous measure on indoor air pollutants was performed during cooking period and the indoor air quality in newly-decorated urban apartments was also studied.

The results showed that the indoor $PM_{2.5}$ and PM_{10} during the space heating period, especially the haze weather period caused by heavy smog, were polluted seriously. Good linear relationships between indoor and outdoor concentrations of PM were identified in the condition of terrible outdoor air quality. In contrast, the concentrations of HCHO, CO, CO_2, NO_X and SO_2 approximately satisfied the requirements of national standard unless the serious haze weather occurred. According to the subjective surveys, occupants could evaluate the indoor ventilation correctly, but the indoor air quality was always overestimated. Moreover, the factor of illness history of the occupants had an obvious influence on the evaluation of indoor air quality. Furthermore, cooking increased the indoor concentrations of HCHO, CO and TVOC significantly, and the indoor air quality in newly-decorated urban apartments was heavily polluted by HCHO, NH_3 and TVOC.

1. Introduction

1.1. Research background

Indoor air quality (IAQ) has attracted increasing attentions and concerns recently since the living standard is improved obviously. Hundreds of indoor pollutants from various indoor and outdoor sources have been identified in indoor environments, which are associated with seriously adverse effects on human health (Jones, 1999; Tang et al., 2016). Undoubtedly, living and working in a poor indoor environment would make occupants uncomfortable and even lead to some sick building syndromes (SBS), such as sneezing, coughing, eye irritation and skin irritation (Massey et al., 2016). For example, particulate matter (PM) is likely to induce heart, lung disease and even lung cancer (Begum et al., 2009).

People spend most of time indoors and therefore healthy indoor environments can reduce the unhealthy risks and achieve a good living style accordingly. Many field studies on indoor air quality both at urban and rural houses are conducted in recent years (Deng et al., 2017; Fan et al., 2017; Kalimeri et al., 2016; Mainka et al., 2015). Wal et al. (1991) conducted a field study in urban houses in Netherlands and pointed out that ventilation could effectively reduce the indoor concentrations of CO, CO_2, NO, NO_2, PM and HCHO. Molloy et al. (2012) carried out a field study in urban houses in Australia and indicated that a reverse relationship was identified between the indoor concentrations of air pollutants and building construction time. Pereira et al. (2014) found that the concentration of CO_2 in Portuguese secondary classrooms frequently exceeded the national and international limits based on field studies. Branco et al. (2014) pointed out that the concentrations of PM were often higher than the corresponding limits in study rooms of urban nurseries at Porto city because of the poor ventilation. Wang et al. (2014) carried out a field study on indoor air quality of rural houses in winter in severe cold region in China. The indoor pollutants of PM, CO, NO_X and SO_2, which were mainly emitted by Chinese Kang, always exceeded the national standard values seriously. Zhang et al. (2015) investigated the indoor air quality during the heating and cooking periods in rural areas and pointed out that the influences of CO, NOx and inhalable particles polluted from rural areas on the air quality of the urban areas could not be overlooked. Jiang and Bell (2008) investigated the indoor air quality at rural and urban areas in northeast

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China and found that the indoor air quality at rural areas, which widely used the biomass, was worse than that at urban areas.

1.2. Motivation and challenge

For the severe cold region in China, the winter is very long and cold, and the space heating period lasts for around six months. In winter, coal is widely used in the centralized heating system in the urban area and straw is the main material for cooking and heating at the rural houses (Mestl et al., 2007). Due to the air pollutants released by the coal and straw (Wang et al., 2004; Zhang and Smith, 2007), the air pollution of urban area in winter in the severe cold region of China are always serious. What's worse, the haze weather with severe smog has occurred frequently in winter in China recently and the air quality issue is becoming a big challenge. For example, in October 2013, the heaviest haze weather caused by severe smog throughout history attacked Harbin, one of the biggest cities in the northeast of China. The terrible weather lasted for several days and the visibility was less than 10 meters, which resulted in serious inconveniences to citizens' living and health. In fact, many reasons lead to such poor air quality of urban areas in winter. The first and direct factor is that the continuous inversion and weak wind weather occurs frequently in winter. It is difficult for the air pollutant diffusion and raises the possibility of air pollution. Secondly, large amounts of straws are burnt by peasants for heating and cooking in winter at suburb. Combustion products of straws including many kinds of air pollutants would release into the environment. As a result, the urban areas will be influenced by serious air pollution coming from surrounded rural areas. Finally, widely using the coal boilers and furnaces for space heating in urban areas generates large amounts of air pollutants and causes the air pollution in winter.

Facing the above challenges, it is meaningful and necessary to investigate the indoor air quality of urban apartments in winter in the severe cold region, especially under the heavy haze weather caused by severe smog. However, limited researches were conducted to investigate the indoor air quality in the severe cold region of China under aforementioned weather conditions. Therefore, field studies on indoor air quality were carried out in urban apartments in Harbin, a typical city located in the severe cold region in China. The studies were conducted between September 2013 and May 2014. During the test period, serious haze weather with heavy smog pollution occurred. .

In each field study, the indoor and outdoor air pollutants of $PM_{2.5}$, PM_{10}, CO, CO_2, SO_2, NO_X, TVOC, HCHO and NH_3 were monitored. In addition, the influences of cooking and decorating on indoor air quality were also investigated and studied. According to the field measurements and questionnaires, the indoor air quality in urban apartments was analyzed. Also, the relationships between the indoor and outdoor PM were identified.

2. Methodology

The objective test and questionnaire survey were conducted simultaneously for the field studies.

2.1. Sampling sites and sampling events

Harbin, with a quite long and cold winter, is a typical city located in the severe cold region in China. The space heating period lasts for around six months in winter. To investigate the indoor air quality of urban apartments in the severe cold region of China (especially in winter), the field studies were selected to be carried out in Harbin. The field tests were carried out about every two weeks between September 2013 and May 2014. The sites for the study were ten apartments from nine residential buildings in five residence communities in Harbin. The appearances of these five residence communities are shown in Fig. 1 and the basic information of the selected ten apartments is shown in Table 1.

In Table 1, these ten apartments were with relatively long construction time so as to remove the influence of decorating on indoor air quality. Among these ten apartments, apartment 1 was chosen to conduct a continuous test to study the influence of cooking on indoor air quality. In addition, another six apartments, which experienced repair or decoration within six months, were selected to investigate the indoor air quality in newly-decorated apartments. These two studies were carried out in November 2013.

The indoor pollutants were measured between 19:30pm and 21:30pm every field study except the study of cooking. This period was the main time that the occupants stayed at home after work and could also ensure a sufficient time interval after cooking activities which may potentially influence the accuracy of measurements.

The indoor and outdoor concentrations of nine air pollutants were measured on sites simultaneously, including $PM_{2.5}$, PM_{10}, CO, CO_2, SO_2, NO_X, TVOC, HCHO and NH_3. The information of instruments for tested parameters is shown in Table 2. $PM_{2.5}$ and PM_{10} were monitored by a portable instrument (TSI 8532), with an accuracy of ± 5% within the range of 0.001–150 mg/m^3. CO_2 was measured by a portable instrument (Tal 7001), with a resolution of 1 ppm within the range of 20–10000 ppm. CO, SO_2, NO_X, TVOC and HCHO were measured by portable instruments (GT901 series) with a resolution of 0.01 ppm within the range of 0–100 ppm. NH_3 was measured by a portable instrument (MIC) with a resolution of 0.01 ppm within the range of 0–100 ppm. The instruments for the measured pollutants are shown in Fig. 2. To guarantee the accuracy of the measurement, the calibration of each instrument was conducted for the field study. Normally, the calibration of each instrument was needed every twelve months using either a zero concentration gas or with a gas with a specific concentration. In this study, all the instruments were factory calibrated prior to the field tests. Considering the harsh conditions for outdoor measurements, another calibration of each instrument was carried out with the help of each instrument's factory during the field study. In addition, the PM portable instruments performed zero calibration with a zero filter prior to every use.

Fig. 3 shows the indoor location of the sampling site in one of the field-study urban apartments. The sampling site in each apartment was located in the central of the living room, which was the main activity place for the occupants. Considering human respiratory zone introduced in the indoor air quality standard, the height of each sampling site was set as about 1.0 m above floor level (ASHRAE Standard 62.1-2007). The concentration of each indoor pollutant was recorded as the average value measured within one hour. In addition, the outdoor concentration of each air pollutant was measured for each apartment. The outdoor measuring site was located about 30 m in front of each residential building. Due to the seriously cold weather of Harbin in winter (i.e., the temperatures always kept at −20 ~ -30 °C), effective methods were necessarily adopted in case the instruments were failure caused by the very low temperature. According to the operational condition of each instrument shown in Table 2, the instruments of PM and CO_2 were beyond the acceptable working conditions for the outdoor measurements. In such a case, thermal insulation packages were equipped with the instruments and the sampling time was set to be shorter than that for the indoor tests, i.e., the average values measured within half an hour.

2.2. Questionnaire survey

Questionnaire surveys were carried out in each field study, simultaneously with the objective investigation. 20 subjects stayed at 10 apartments with long construction time participated in the questionnaire surveys every time. The questionnaire contained objective and subjective questions, as presented in Table 3. The objective questions included the gender and age of occupants, the frequency of cleaning and the time interval after cooking, etc. The subjective questions included the evaluations on air ventilation and perceived indoor