Indoor Environment Quality in Children’s Homes in Dalian, China

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Abstract. This study investigated residential indoor air quality of 10 families with children living in Dalian to better understand how the indoor living environment affects child health. According to the results of field campaigns, average indoor temperatures and relative humidity were 22.7°C and 40%, respectively; the mean level of CO₂ was 1034 ppm. The average mass concentration of indoor PM₂.₅ was 0.066 mg/m³ for all residents. Regarding chemical pollutants, formaldehyde averaged concentrations of 59.9μg/m³, which is lower than the standard value; nevertheless, Volatile organic compounds (VOCs) were always detected at levels far below the recommended limit of 600μg/m³. Semi-VOCs (SVOC) serve as an emerging indoor pollutant, and the mean level was 3164μg/g. Dibutyl phthalate (DBP) and di-(2-ethylhexyl) phthalate (DEHP) were the main SVOC pollutants, accounting for 32.5% and 38.2%. Planktonic fungi, accumulation fungi, and adherent fungi consisted in the main biological pollutants. The average mass concentration of planktonic fungi was 526cfu/m³. Accumulated fungi were 264cfu/mg in average and adherent fungi were 1.65cfu/cm² on average. In conclusion, particulate matter, VOC and formaldehyde lead to the major pollution in indoor environment while the remaining pollutants need further study.

Introduction

A large number of studies indicate that modern humans spend 80% of their time indoors [1]. Indoor building materials, furnishings, and appliances can emit a variety of airborne pollutants, which have the potential to cause health problems in occupants [2]. Children are considered more vulnerable to indoor air pollution given that their bodies are in a state of growth; thus children’s health problems receive great attention [3,4]. Evidence indicates that children’s health could be closely related to exposure to particles, formaldehyde, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOC), and fungi [5]. Exposure to these pollutants plays a significant role in the process of aggravated child allergic diseases [6]. A study in Netherlands suggests that children with asthma would be more likely to respond to air pollution than those without asthma [7], and an increase of particle concentration may aggravate asthma symptoms [8]. Other research also proved that asthma and allergy symptoms were closely related to decorating materials off-gassing VOCs [9]. After years of gradually attracting attention, the relationship between SVOC exposure and asthma has finally been acknowledged. For example, a relationship has been drawn between DEHP and children’s allergic conjunctivitis, asthma, and wheezing; DBP has a relationship with eczema and eye diseases [10,11]. In the field of biological pollutants, dust mites and...
fungi are the most common respiratory allergens and long-term exposure to air containing dust mites and fungal spores will induce the incidence of respiratory diseases [12,13].

The elevated morbidity rate resulting from allergic diseases in children in China has become a cause for great concern regarding indoor pollution. To Dalian, this regional climate consists of continental monsoons with maritime features therefore its climate behaves in a way that is characteristic of both Northeast China and coastal areas. This study explored the differences in major indoor pollutants through investigation of 10 children’s homes in Dalian.

Method

Before conducting the measurements, 120 children from fourth and fifth grade were surveyed. To further explore the relationship between indoor pollutants and children’s allergic symptoms during the hottest season of the Northeast, measurements were carried out in early March 2013. The experimental group (Group A) consisted of four families where children suffered from one or more respiratory and allergic symptoms. The remaining families exhibited no symptoms and were thus used classified as our control group (Group B). The measurement contained 10 items divided into five areas: 1) basic test parameters consisting of temperature and humidity; 2) CO₂ concentrations; 3) particulate pollution measuring PM₂.₅, PM₅, and PM₁₀; 4) chemical pollutants, including formaldehyde, VOCs, and SVOC; and 5) microbial pollutants, including planktonic fungi in the air, accumulated fungi, and adherent fungi on the floor.

Results and Analysis

Temperature and RH

As it was in the period heating time during the test, indoor air temperature was obviously higher and remained at around 20°C with few variations compared to the outdoor air temperature. On the other hand, indoor RH was a little lower and maintained a relatively smaller range compared to outdoor RH. Moreover, residents using different heating and humidifying methods created apparent differences in RH values between households, such as electric heating, gas heating, floor heating and radiator. RH values for DT2, DT3, DT6, DT7, and DT10 were lower than 40%, which might lead to eye irritation, dry skin, and so on [14], while average RH values were more than 50% in DT1 and DT4 due to the use of humidifiers in these households. Whereas, Zhang CX et al. [15] showed that the reduction of relative humidity could help to reduce indoor formaldehyde and biological pollutants. Therefore, the results indicate the necessity of humidification measures to alleviate dry climates indoors during the heating period in Dalian.

CO₂ Measurement and Analysis

The CO₂ data was lost for both DT07 and DT09 due to a power outage during the testing process. The mean concentrations for DT01, DT04, DT05, and DT08 households are higher than the limit (1000 ppm) proposed by the national standards for IAQ (GB / t18883-2002), extending beyond the limit by 63%, 53%, 36%, and 5%, respectively. CO₂ concentrations varied mainly between 279-2135 ppm, with 60% of the data under 1000 ppm, and 90% of the data under 2000 ppm. CO₂ concentrations in Group A were slightly higher than those found in Group B when it extended beyond 1400 ppm.
Results and Analysis of PM Concentrations

PM2.5 test results and the correlation analysis of indoor and outdoor particulate matter are shown in Fig. 1. It can be found that the average indoor PM2.5 mass concentration were 0.066 mg/m³, averaging at 0.110 mg/m³ for Group A, which was more than Group B’s average 0.037 mg/m³. The difference was significant between the two groups. Households DT05, DT06, and DT07 in Group A greatly exceeded the level 2 standard [16] for indoor PM2.5 mass concentration; however, on the test days weather conditions included sand and dust. Taking into account the influence of outdoor PM concentrations on indoor air quality, we cannot determine the true relationship between PM and allergic diseases.

Furthermore, smokers lived in DT05, DT06, and DT07 households according to the results of the preliminary questionnaire; thus it was presumed that smoking might also be a significant cause of elevated indoor PM concentrations. Enhanced indoor ventilation is an important measure to reduce indoor PM. However, household windows were often kept during the testing period given that it was in the heating period, which could have resulted in excessive PM levels.

Formaldehyde, VOCs, and SVOC

The household formaldehyde concentrations are shown in Fig. 2. The overall average residential formaldehyde concentration was 59.9μg/m³, with the Group A showing an average of 77.6μg/m³, higher than that of the Group B at 48.2μg/m³. According to the Indoor Air Quality (IAQ) standard of China (GB/T 18883-2002) [17] formaldehyde limits are 100μg/m³. Living room formaldehyde concentrations for all households were below the limit. However, bedroom formaldehyde concentrations found at DT03, DT07, and DT08 exceeded the limit, of which the DT07 bedroom did so by 25%. Furthermore, bedroom concentrations were generally found to be higher than those of the living rooms, a phenomenon encountered in similar studies.

The average VOC concentration of all households was 386.8μg/m³. The indoor air VOC concentrations were mostly within satisfactory limits (600μg/m³) according to IAQ Standards (GB/T18883-2002) [17], except for the DT09 household. The VOC concentration of DT09 was unusually high, and the main pollutant detected was P-dichlorobenzene. Further analysis showed that the household had placed pest control agents in the corner of the living room, children's bedroom bed, and tables, with the main active ingredient of the pest control agent being p-dichlorobenzene.
At present, there is no a standard against which to measure SVOC in China's indoor environment, therefore, we compared every respondent household’s SVOC concentrations against the measured average concentration. A statistical chart of detection results is shown in Fig. 3. The average concentration of SVOC was 3164μg/g, with the Group A having an average of 2432μg/g, and the Group B having an average of 3896μg/g. Among the SVOC, DEP, DBP, DEHP, BHT and DBA were detected, with DBP and DEHP being main pollutants accounting for 32.5% and 38.2%, respectively.

**Planktonic Fungi, Accumulation Fungi, and Adherent Fungi**

There are between 500~1000 microbial species that can appear in dust indoor [14]. This test focused on planktonic fungi, accumulation fungi and attached fungi, all of which may have a negative impact on human health.

Household measurements for planktonic fungal concentrations are shown in Fig. 4. The content of aspergillus spp, cladosporium spp, penicillium spp, and mycelium was relatively high and accounted for more than 90% of planktonic fungi. The average value of planktonic fungi was 526cfu/m³ in the measured household, which was far less than the national standard [17] value (2500cfu/m³). While DT02, similarly to other households showed relatively low airborne fungi concentrations. Penicillium spp and cladosporium spp were both high in the DT02 household. This is most likely not a result of indoor temperature and relative humidity given that there is little difference in these values between households. Therefore, the possible reason is that the presence or mildew from rotten produce may be extreme in this household. Fig. 5 shows the accumulation fungal concentration distribution of measured households. The average concentration of the measured households in the Dalian area was 264cfu/mg. In terms of the groups, the Group A averaged 498cfu/mg, and the Group B averaged 632cfu/mg, higher than that of the Group A. The accumulation fungal concentration of DT01, DT02, DT03, DT09, and DT10 was higher, especially in the case of DT03; this type of concentration was associated with floor cleanliness. Testing revealed that the content of aspergillus spp reached 99% in the DT03 bedroom accumulation fungi, although the content of Yeast was generally higher in other households, occupying about 50% of total concentrations.

![Figure 3. Distribution of SVOC concentrations in each household.](Image)

![Figure 4. Concentrations of planktonic fungi in each household.](Image)


The concentrations of adherent fungi are shown in Fig. 6. The average adherent fungi concentration of the measured household was 1.65cfu/cm². The concentrations of DT05 and DT08 were relatively high, which may be due to a lack of thorough cleaning, such as ignoring
the corner of the table and wall, resulting in an increase in concentration of indoor microorganisms. Compared with the measurement results, the average concentration of the Group A was 1.69cfu/cm², slightly higher than that of the Group B, 1.62cfu/cm². Analysis of the composition found that the content of Yeast and Penicillium spp were the highest, accounting for 45% and 19% of the total, respectively.

There is a certain correlation among planktonic fungi in air, accumulation fungi, and adherent fungi on floor surface. For example, the number of fungi on the floor will cause higher concentrations of fungi in the indoor air. Furthermore, their concentration is closely related to indoor condition.

Conclusions

This study investigated indoor environment quality in children’s homes in Dalian, China. The following conclusions were made:

1) During the heating period there was little difference in temperature among households. Indoor relative humidity was generally significantly less than outdoor relative humidity, but there were obvious differences in households with 50% of the households having less than 40% RH, which is a state of low humidity. CO₂ was generally present at satisfactory level, however, there were also times of excessive levels.

2) There was a serious particulate pollution issue prevalent in Group A, but Group B exhibited good condition. In general, households were not showing signs of formaldehyde and VOC pollution, except for individual measuring points. DBP and DEHP is the main component of SVOC pollutants.

3) The main types of detected planktonic fungi were Aspergillus spp and Penicillium spp, but the content did not exceed the national standard. Yeast and Aspergillus spp were detected mainly from accumulation fungi. Yeast and Penicillium spp occupied a large proportion of the adherent fungi. However, further research is needed to explore the relationship between biological pollutants and children's allergic symptoms.

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