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Environmental conditions in homes with healthy and unhealthy schoolchildren in Beijing, China

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A B S T R A C T

In 2013, a comprehensive investigation of environmental conditions was carried out in schoolchildren's houses during winter and summer in Beijing, China. The houses were divided into two Groups (Group A: unhealthy children's houses; Group B: healthy children's houses). According to the field measurement, inappropriate thermal environment contributed by indoor low temperatures and RHs in winter and dampness in summer could affect childhood health. The beyond standard (1000 ppm) situations of CO_2 concentration revealed poor ventilation in houses of Group A, which could increase the risk of children's asthma and respiratory infections. Indoor carbonyls and VOCs levels in almost all the homes did not exceed the guideline. However, the integrated influence of these compounds should be noted for possible adverse health effects, especially in child's bedroom where children spent more time. Dibutyl phthalate (DBP) and Di (2-ethylhexyl) phthalate (DEHP) were most frequently detected SVOCs in house dust. In summer, the average child's daily intake of phthalates from house dust in homes of Group A was significantly higher ($p < 0.01$) than that of Group B. *Cladosporium* spp., *Penicillium* spp. and *Aspergillus* spp. accounted for about 90% of indoor airborne fungi. Airborne fungal levels in about 70% of measured rooms exceeded 1000 cfu/m^3 in summer. The high correlation between airborne fungi and PM was found, consequently, children's health could be affected by the combined action of airborne fungi and PM. These results were helpful to evaluate and design healthy housing environment for schoolchildren.
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1. Introduction

People in modern society spend approximately 90% of their time indoors [1], including homes, schools and workplaces. It is estimated that approximately more than half of the time is spent at home [2,3]. Therefore, indoor environmental condition at home is of great importance for human health. Compared with adults, children's breathing capacity is higher relative to their weights and they are more susceptible to indoor pollutants [4]. Also, because of children's exploratory behavior, e.g. frequent mouthing of hands and other objects, they are particularly vulnerable to indoor environmental exposure.

Asthma and allergies are two of the most prevalent diseases in children [5]. The prevalence of asthma and allergies among children in developing countries appears to be lower than that in developed countries [6,7]. However, in recent years, some epidemiological studies have demonstrated there is a rapid increase in the prevalence of asthma and allergies among children in the past decades in developing countries, especially in China [8,9]. An ongoing project studying on the association between home environmental factors and asthma and allergies among preschool children in 10 Chinese cities, CCHH (China, Child, Homes, Health), has indicated that the prevalence of asthma varied from 1.7% to 9.8% (mean 6.8%) in different cities during 2010–2012, a considerable increase from 0.91% in 1999 and 1.50% in 2000, and more than half of the preschool children have had at least one manifestation of wheeze, rhinitis or eczema [10].

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The rapid increase in the prevalence of asthma and allergies among children also has stimulated researchers' interests in potential causes of childhood asthma and allergies in the indoor environment [11]. A considerable number of studies in different countries have demonstrated that living in a damp home can significantly enhance the prevalence of childhood allergic symptoms [12–17]. Also, low humidity is equally dangerous, can result in respiratory and allergic symptoms, such as dry skin, irritated sinuses and throat [18–20]. Nitrogen dioxide (NO_2) is an important constituent of both indoor and outdoor air pollution and exposure to NO_2 in the indoor environment has been linked to increased respiratory symptoms in children [21,22]. A few evidences have clearly indicated exposure to formaldehyde (HCHO) can elevate the risk of allergy, asthma and airway inflammation in children [23–25]. In the literature, associations between exposure to VOCs and poor respiratory health have been found in infants [26–28], preschool and school children [29,30]. As an essential category of volatile organic compounds (VOCs), benzene has been proven to have an association with childhood asthma, even at low concentrations of the pollutant [31]. $PM_{2.5}$ is particulate matter (PM) with an aerodynamic diameter of less than or equal to 2.5 μm. Indoor exposure to $PM_{2.5}$ is related to allergic inflammation and persistent asthma in children [32,33]. Also, a cross-sectional survey in schools conducted by Madureira et al. [34] has showed that high levels of total VOC, acetaldehyde, $PM_{2.5}$ and PM_{10} are associated with higher odds of wheezing in children. Semi-volatile organic compounds (SVOCs) are ubiquitous in indoor environments, redistributing from their original sources to all indoor surfaces [35]. As two common SVOCs, Di (2-ethylhexyl) phthalate (DEHP) and Dibutyl phthalate (DBP) may have associations with asthma, eye symptoms and eczema in children [36–38]. Fungi, as indoor biological pollutants, pose a serious threat to public health in indoor environments [39]. A study has showed exposure to airborne fungal spores is related to persistent cough in infants whose mothers had asthma [40]. In addition, fungi can lead to respiratory and allergic diseases, such as allergic asthma, allergic rhinitis and hypersensitivity pneumonitis [16,41]. All of these reviewed literature demonstrate that indoor environmental pollution have an important effect on childhood health problems.

In China, there is also an increasing interest in the investigation of indoor environmental pollution in locations where children spend their time, especially at home and in school. Liu et al. [42] examined cultivable fungi, particle concentration and size distribution in 24 homes with preschool children in Xi'an and analyzed their relationships with children's respiratory illness. Zhang et al. [43] investigated the levels and possible origins of phthalates in settled house dust from 215 urban dwellings with young children in Nanjing and found that the levels of phthalate esters were associated with indoor dampness. Zhang et al. [44,45] monitored indoor carbon dioxide (CO_2), NO_2, sulfur dioxide and microbial components in dust in 10 junior high schools in Taiyuan. However, these investigations only involved one or several indoor pollutants, and rarely focused on schoolchildren. Schoolchildren aged 8–12 years old are experiencing a shift into pre-adolescence. At this stage, children's exposure to environmental pollution may affect their life-long health. Thus, during 2012–2013, a large-scale systematic study on environmental conditions in homes with 8–12 years old schoolchildren was carried out in typical cities in China including Beijing, Shanghai [46], Changsha, Harbin, Dalian and Wuhan [47]. The research project was developed in two phases, a cross-sectional questionnaire survey in the first phase and a detailed field measurements on housing environmental conditions in the second phase. In all cities, similar measured methods and measured instruments were used. From the published literature on the systematic study, indoor dampness in winter, poor ventilation in homes and fungi were important risk factors for schoolchildren's health in Shanghai [46], and in Wuhan airborne PM, and DEHP and DBP in house dust are primary pollutants in schoolchildren's homes [47]. Although both Shanghai and Wuhan were located in the hot-summer and cold-winter region [48], the results still showed great differences. Moreover, Beijing situates in the cold region [48], different from Wuhan and Shanghai. In different climatic regions, outdoor climate conditions, building equipment types and personal lifestyles had a great difference. These factors could affect housing environmental conditions.

This paper summarizes the results of field measurement in Beijing. The main objective of this paper is to inspect environmental conditions in schoolchildren's homes in Beijing. Also, possible environmental factors for schoolchildren's health were analyzed by comparing the difference of environmental parameters and personal exposures to some pollutants in homes with healthy and unhealthy children. These results were helpful to evaluate environmental conditions in schoolchildren's homes and design healthy housing environment for schoolchildren.

2. Methods

2.1. Homes involved in field measurements

As part of the aforementioned systematic study, in winter 2012, the questionnaire survey was firstly conducted on 150 schoolchildren aged 8–12 years old in Chaoyang District, Beijing. The interview sheet referred to the American Thoracic Society-Division of Lung Disease (ATS-DLD) questionnaires and its contents mainly included general information of the child, living environment, residential equipment, life style and children's health status [49,50]. The questionnaire survey indicated that 43.3% of the children were diagnosed with at least one respiratory or allergic symptom [51]. Afterwards, we selected separately ten children from the respondents, considering on gender and health conditions, to perform detailed field measurements in their homes in winter and in summer in 2013. As shown in Table 1, the ten children's houses were split into two groups (i.e. Group A and Group B). Children in Group A displayed one or more respiratory and allergic symptoms, that is unhealthy ones, while those in Group B showed no symptoms, that is healthy ones.

All of measured homes are residential apartments with ferro-concrete structure, and they are surrounded by populated buildings and roads. Because Beijing situates in the cold climate region and the outdoor temperature is low in winter, indoor heating equipment is popularly used in every household in winter. Central hot water heating system (CH) is prevalent. Also, wall-mounted gas heater (GH) and electric heater (EH) are used in some homes. In summer, cooling equipment in all homes is the split-type air conditioner (AC). There is no mechanical ventilation system in measured homes involved in this study. The field measurement was carried out in living rooms and children's bedrooms in each family in the winter and summer of 2013, respectively.

2.2. Field measurement and analysis

The field measurement covered the following tasks: (1) monitoring of air temperature, relative humidity (RH) and CO_2 levels; (2) measurement of PM mass concentration; (3) test of VOCs and carbonyl compounds in air; (4) detection of SVOCs in house dust; and (5) identification of fungi suspended in air, contained in house dust and adhering on floor surface. Each household was visited twice. The initial visits to each family were made between 22 and 24 February in winter and 13–14 September in summer. A second visit took place two weeks after the initial one. During the initial

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