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Primary pollutants in schoolchildren's homes in Wuhan, China

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ABSTRACT

In 2013, field campaigns were performed in the naturally ventilated homes of ten schoolchildren living in Wuhan's urban area, with purpose to ascertain the primary indoor pollutants that have been associated with respiratory and allergic health in children. According to the 2-week monitoring, mean temperature and relative humidity were 19.5 °C and 60% in autumn and 12.7 °C and 55% in winter, respectively; mean level of carbon dioxide (CO_2) was 525 ppm in autumn and 748 ppm in winter. Particulate matter (PM) led to the most severe indoor air pollution with 94% of gravimetric concentrations of $PM_{2.5}$ far beyond 75 μg/m^3. Indoor/outdoor (I/O) ratio of $PM_{2.5}$ level varied between 0.72 and 1.04; furthermore, statistical analysis proved that indoor PM level was significantly associated with outdoor level ($R^2 \geq 0.93$, $p < 0.001$, n = 16). Formaldehyde and acetaldehyde in air samples were always at the levels far below the recommended limits, 100 μg/m^3 and 48 μg/m^3, respectively; but total volatile organic compounds (TVOCs) were higher than the national standard of 600 μg/m^3 in some homes. Furthermore, high levels of di(2-ethylexyl) phthalate (DEHP) and dibutyl phthalate (DBP) were frequently detected in house dust. The results showed that airborne *Aspergillus* and *Penicillium* caused some concerns of fungal pollution in autumn. In conclusion, in the homes of the schoolchildren in Wuhan's urban area, airborne PM, and DEHP and DBP in house dust are primary pollutants; sometimes TVOCs also lead to indoor air pollution; in addition, airborne fungal components indicate to be a contributing factor to indoor pollution of concern in warm environment.

1. Introduction

As modern people spend around 90% of their time indoors [1], indoor air pollution is the second biggest environmental contributor to ill health worldwide [2]. Furthermore, children have greater susceptibility to air pollutants than adults, because they breathe higher volumes of air relative to their body weights and their tissues and organs are actively growing [3,4].

The ISAAC (International Study on Asthma and Allergies in Children) studies have demonstrated the increase in allergic diseases, such as asthma, rhinitis, and eczema (whether atopic or not) among children [5,6]. Today, asthma and allergies have been the issues of great importance in children health, as up to 1/3 of children in some regions have been diagnosed with asthma [7]. Exposures to indoor chemical and microbial pollutants, such as particulate matter (PM), formaldehyde (HCHO), volatile organic compounds (VOCs), semi VOCs (SVOCs), and fungi, have been evidenced to have associations with the children's health. The facts prompted great concerns in people about indoor pollution in their homes.

Based on health impact criteria, the INDEX project in Europe identified high priority VOCs to be regulated in indoor environments, including benzene, HCHO, naphthalene, toluene, xylenes, styrene, d-limonene and α-pinene [8]. VOCs emission from building materials was related to asthma, wheezing and allergies in children [9]; and a few evidences clearly demonstrated elevated risk of

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asthma [10], allergy [11] and airway inflammation [12] in children due to exposure to HCHO. Associations between exposure to SVOCs in dust and childhood asthma or allergies have been a concern in recent years, as children indicated more vulnerable to phthalate exposure via floor dust than adults [13]. The nested case-control studies showed conceivable associations between di(2-ethylexyl) phthalate (DEHP) in floor dust with allergic conjunctivitis [13], asthma [14] and wheezing [15] in children. Moreover, higher level of dibutyl phthalate (DBP) in settled dust could account for diagnosed eczema and eye symptoms [16].

$PM_{2.5}$ is particulate matter (PM) with an aerodynamic diameter of less than or equal to 2.5 μm. It accounts for the prevalence of haze, which is the environmental disaster with uppermost concern in Chinese people. Its long-term exposure could lead to chronic obstructive pulmonary dysfunction for juvenile [17], and its short-term exposure was related to allergic inflammation in children with allergic asthma [18]. Indoor exposure to $PM_{2.5}$ could result in the increase of cumulative incidence of lower respiratory symptoms [19], and might be related to persistent asthma in children [20].

Fungi, as well as PM, are ubiquitous in children's indoor environments. Exposure to fungal fragments, including spores, is a recognized triggering factor for respiratory diseases [21–23] and atopic dermatitis [24]. In addition, fungi can produce specific microbial volatile organic compounds (MVOCs) [25–27], which might be risk factors for asthmatic symptoms. As an evidence, TMPD-DIB (2,2,4-trimethyl-1, 3-pentanediol diisobutyrate, TXIB) from fungi was reported to positively associate with wheeze, daytime breathlessness, doctor-diagnosed asthma and current asthma [27].

In China, with a rapid increase of asthma in children [7], a growing interest is aroused in the associations between indoor pollution and respiratory and allergic symptoms in children. However, the relevant researches mostly focused on preschool children [7,28,29], rarely involved schoolchildren. Recently, Mi et al. measured carbon dioxide (CO_2), nitrogen dioxide (NO_2), ozone and HCHO in naturally ventilated classrooms for children of 13–14 years old in Shanghai [30]. Zhao et al. monitored CO_2, NO_2, sulfur dioxide (SO_2), and chemical markers of microbial exposure in 10 junior high schools in Taiyuan [31,32]. Neither of these two studies considered indoor pollution in the homes where children usually spent over half of their time; moreover, neither included the pollutants such as VOCs, SVOCs, PM and fungi. Therefore, it is lack of data to do complete assessment of indoor pollution for Chinese schoolchildren.

Schoolchildren of around 11 years old are experiencing a shift into pre-adolescence. Their exposure to environmental pollution may lead to a life-span health effects. Hence, a systematical study including survey and field investigation has been performed in Beijing, Changsha, Dalian, Harbin, Shanghai, and Wuhan to quantitatively assess the levels of the pollutants, which have been associated with children's respiratory and allergic health before, in the schoolchildren's residential environments, and investigate the pollutants' adverse health effects in children. This paper will introduce the field investigation of indoor climate and pollution in the homes of the schoolchildren from Wuhan's general urban area, which was part of the aforementioned systematical study. The main purpose is to quantify and identify the primary indoor pollutants with regard to the influences of thermal climate and outdoor (ambient) air pollution. Furthermore, we will examine the differences of indoor pollution at home between the children with one or more respiratory and allergic symptoms and those healthy ones.

2. Methods

The field investigation was carried out in the autumn and winter of 2013, respectively, in order to examine the changes in indoor climate and pollution caused by the seasonal climate variation. The investigation covered the following tasks: (1) monitoring of air temperature, relative humidity (RH) and CO_2 level; (2) measurement of PM mass concentration; (3) test of HCHO, acetaldehyde, and VOCs in air, (4) detection of SVOCs in house dust, (5) identification of fungi suspended in air, contained in house dust and adhering on floor surface. Task (1) lasted for two weeks to characterize the indoor climate, occupation, and operation of heating at home in the seasons. Task (2)–(5) were carried out when we visited the participants' homes one by one to set up the instruments for Task (1). The visits were made between October 26–28 in autumn and between December 19–23 in winter.

2.1. Participants in field campaigns

In spring 2013, we performed a questionnaire survey in the children of 10–12 years old in a primary school in Hongshan District, Wuhan. The interview sheet was developed from the American Thoracic Society – Division of Lung Disease (ATS-DLD) questionnaires, with additional questions on indoor dampness, including the general information of the child, living environment, residential equipment and life style, and children's health status [33]. There were totally 170 effective surveys, among which a few showed interests in the field investigation of climate and pollution in their living room and child's bedroom. We chose ten participants from the volunteers with consideration on gender and health conditions. As shown in Table 1, five children with one or more respiratory and allergic symptoms, such as wheezing, breathlessness, eczema, urticarial, seasonal or allergic rhinitis, diagnosed asthma, were in Group A, while five healthy children without the symptoms in Group B. In winter, there were only three participants in each group. The differences in indoor climate and pollution between two groups will be examined.

The locations of the school and the children's homes are shown in Fig. 1; the information of the children and their residencies are presented in Table 1. All of the children had been living in their current homes with concrete structure for at least 3 years before autumn campaign. The homes had no fresh air supply system. When vising the homes in autumn, they were naturally ventilated through opened windows, as outdoor air temperature was around 21 °C; in winter, as outdoor air temperature decreased to around 9 °C, they were naturally ventilated by air infiltration with windows closed. Moreover, we avoided the visits to the homes during cooking time because indoor pollution by PM, HCHO, TVOCs etc., could be exacerbated while cooking [34,35].

2.2. Monitoring of air temperature, RH and CO_2 concentrations

The data loggers with temperature and humidity sensors (T&D TR-71Ui&TR-72Ui; ESPEC Thermal Recorder RS-11) were used to monitor air temperature and RH at an interval of 10 min for 2 weeks. In each home, the data loggers were placed at three positions: 0.1 m (H0.1 L) and 1.1 m (H1.1 L) above the floor in living room, and 1.1 m above the floor (H1.1B) in child's bedroom. As mentioned thereinafter, measurement of PM concentration and air sampling for HCHO, TVOCs and airborne fungi were performed at the height around 1.1 m, and monitoring of CO_2 concentration and sampling of house dust were performed at the floor level, respectively. Therefore, air temperature and RH at these two heights can helpful in the investigation of indoor air pollution. On the other hand, in living room, air temperatures at the heights of a seated occupant's ankle (0.1 m) and head (1.1 m) can contribute to assess thermal discomfort due to vertical temperature difference. Moreover, attention was paid to avoid the direct influences of solar radiation and indoor heat sources on the sensors.