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Home dampness-related exposures increase the risk of common colds among preschool children in Shanghai, China: Modified by household ventilation

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Few studies have estimated the effects of dampness-related exposures and its interaction effects with poor household ventilation on common colds of preschool children. During April 2011–April 2012, we conducted a cross-sectional survey on home environment and childhood health and collected 13,335 parents-reported questionnaires of 4–6-year-old children in Shanghai, China. In this paper, we investigated associations between the incidence and duration of common colds among these children during the past 12 months before the survey and frequency of opening windows, as well as household dampness-related exposures (indicated by six dampness indicators). Significantly higher incidence (>3 times) and longer duration (>2 weeks) of common cold were found among children with than without these dampness exposures (p-value < 0.01 for mold spots and p-value < 0.001 for all other indicators). The number of dampness-related indicators had a positive and strong dose-response relationship with common colds (p-trend < 0.01). Low frequency of ventilation was also a risk factor for children common colds. After adjusted for the potential confounders in the multiple logistic regression analyses, all dampness-related indicators were significantly associated with the increased odds of common colds and the highest odds ratio was 1.21 (95% CI: 1.16–1.27). We also found that dampness-related exposures and household ventilation habits (p-value for interaction < 0.001) had a strong interaction effect on the incidence and duration of common cold. The stratified analysis of ventilation condition displays that the influence of dampness-related exposures has been modified by ventilation. Therefore, good household ventilation habits may have an effect of modification for dampness-related exposures.

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1. Introduction

The indoor air quality has been deteriorating along with the rapid development of economy, the outdoor pollution and the modernization and artificialization of furnishing. Its effects on residents’ health, especially on respiratory health, can’t be overlooked. Children, as the susceptible populations, the respiratory disease incidence of them are considerably higher than that of adults. According to the statistics, as usual, the frequency of common cold for adults were 2–5 times per year, and 4–8 times for children [1]. Research results from America [2,3], Finland [4], Italy [5] and so on also demonstrated that children are the high-risk group of respiratory disease. The researchers observed that there is a periodic surge increase of fever and acute respiratory infection on Pediatric Clinic in Shanghai, China [6], Therefore, the pathological mechanism and influence factors of respiratory infection for childhood are becoming the research hotspot gradually.

There are two types of cold. Firstly, it is familiar as influenza. Influenza is a highly contagious airborne disease caused by influenza virus. It is one of the most common infectious diseases [7]. Secondly, it refers to common cold, which is a mild viral infection of upper respiratory and it is less infectious than influenza. The incidence of cold for children, who have weak immunity, is higher than that of adults [8], and it further may lead to some complication, such as asthma, rhinitis and pneumonia [9].

Indoor environment factors, including the indoor temperature and humidity, bacteria, virus and microorganism and so on, have
been indicated as the risk factors for respiratory diseases for children [10–12]. In consequence, plenty of researches have been conducted to explore the association between indoor environment factors and childhood respiratory disease. Dong, G., et al. [13] assessed the effects of housing characteristics and home environmental factors on respiratory symptoms of Chinese children by cross-sectional survey. It has been drawn that home environmental factors including visible mold on walls are particularly important for the development of respiratory morbidity among children. Wang, J. [6,14] conducted the research on domestic environmental factors and its associations with health in Chongqing during 2008–2011. Lowen, A.C., et al. [11], stated that influenza virus transmission is dependent on relative humidity and temperature. Lin, Z., et al. [15] found the associations of home dampness signs with childhood asthma and allergic diseases in Urumqi. Hu, Y. [16] performed the research on the association between home dampness and asthma related symptoms among pre-school children of Shanghai during 2011–2013. Norback D., et al. [17] studied associations between fraction of exhaled nitric oxide (FeNO), respiratory symptoms and airway infections among students and dampness and fungal DNA in schools in Malaysia. They found that building dampness and the mould aspergillus versicolor in schools in Malaysia can be risk factors for impaired respiratory health among the students. Zhao, Z. [18], Wang, T. [19], Zhang, M. [20], Zheng, X. [21], Wang, H. [22] et al. conducted cross-sectional survey in Taiyuan, Urumqi, Wuhan, Nanjing, Chongqing and other cities in China during 2011–2012. All these results demonstrated that among these environmental factors, the indoor dampness increase the incidence of childhood asthma, rhinitis and other respiratory disease. Heating and ventilation mode affect the indoor air quality, meanwhile they determine the propagation and development of bacteria and virus [23]. They further might be the direct or indirect initiation factors for common cold. It has been stated that household ventilation (opening window in bedroom) were found to be strongly associated with childhood rhinitis [19,24], asthma [25] and other allergic symptoms [26]. Low home ventilation rate in combination with moldy odor from the building structure increase the risk for allergic symptoms in children [27]. For college students, who live in the crowded dormitories with low ventilation rate were demonstrated to have more common colds [28]. Therefore, to investigate the effects of household ventilation and indoor environmental dampness exposures on childhood respiratory disease is urgent and important.

There are already abundant research on respiratory diseases, especially common cold. Most of them were in medically, including the mechanism of influenza virus propagation [29,30], the prevalence of cough [31] or common cold, the vaccines for common cold [32], the duration of common cold [33] and also the impact factors [34,35]. However, few studies focused on the effects of dampness exposures on children's common cold, meanwhile considering the modified impact from ventilation. These two factors play a considerable role in the indoor environment and the research on them are becoming the hot topics. This study is a part of phase one in the China, Child, Homes, Health (CCHH) study which was a national multicenter cross-sectional study of the home environments and childhood asthma, allergies, and airway diseases [36]. Based on the results from a cross-sectional survey in phase one and the data from environment measurements of residential buildings in phase two, the prevalence of children's allergic diseases, such as asthma, rhinitis, eczema and so on, and the associations between them and building environment have been illustrated. However, neither the prevalence of children's respiratory tract infection (RTI), namely common cold, in Shanghai, nor the risk factors of indoor environment for residential buildings were revealed. This study aims to discover how the low ventilation rate effects home dampness in residential buildings and further becomes the risk factor for common cold of children. The interaction effects of these two factors on children's common cold were also investigated.

2. Methods

Two phases were included in CCHH study. Phase I, is cross-sectional questionnaire survey of children 1–8 years old during 2010–2012. The questionnaire included the International Study of Asthma and Allergies in Childhood (ISAAC) [37] core health questions and additional questions regarding housing, life habits and outdoor environment. The related diseases or symptoms of children covered asthma, pneumonia, rhinitis, eczema, common cold and so on. For the dampness related exposure, the Dampness in Buildings and Health (DBH) study [38] in Sweden was for the reference. The questions were discussed and repeatedly improved by the research group and the uniform questionnaire was used in China [36]. The questionnaire could also be seen in supplemental materials Table S1. Similarly, the analysis method was uniform in CCHH group all over the country.

After Phase I, the main risk factors and the sequence of risk factors were obtained. Then the Phase II was a case-control study with measurements of pollutants in sampled air, dust and urine (2013–2014). The objectives of the CCHH research project are to investigate and compare indoor environmental aspects of sick and healthy children’s homes; to study associations between children’s health and indoor environmental factors [36,39]. During this phase, the parameters of indoor environment, such as the concentration of dust mite, fungi, temperature and relative humidity (refer to dampness exposures), were recorded or tested. However, the methodology adopted in this part was totally different from that in Phase I. Moreover, the associations between indoor environmental parameters, such as temperature and relative humidity, and the pollutants, like the dust mite, fungi and VOCs and so on, would be evaluated further, as well as the interaction effects between them on children’s health. This paper focused on the results from Phase I-Across sectional survey. The field tests in Phase II were not included.

Shanghai, located in the Yangtze River estuary, had a population of more than 23 million in 2011 [40] and 24 million in 2015, including 1.07 million preschool children (<6 years old) [41]. Shanghai is a subtropical humid monsoon climate, four distinct seasons, full sunshine and abundant rainfall. The average temperature is around 16 °C. In Shanghai, a total of 17,898 parents or guardians of children from 72 kindergartens were surveyed in one time for each child by on-site (in urban districts) or by post (in suburban districts). The samples of preschool children were reported by their parents during April 2011–April 2012. The survey reported from Yangpu district in Downtown were taken as the pre-research results and were excluded. Details of the recruitment and survey process have been previously described. The distribution of these kindergartens is displayed as Fig. 1 [42]. The CCHH study was approved by the ethical committee of the School of Public Health, Fudan University in Shanghai, China.

2.1. Questionnaire

In brief, the questionnaire of International Study of Asthma and Allergies in Childhood (ISAAC) [37] was referenced to propose the children’s health questions. Childhood asthma and allergy symptoms, such as diagnosed rhinitis, eczema and current wheeze, dry cough, croup, and other health problems, as pneumonia, common cold and so on were all taken as questions to request the report.
These allergic and respiratory diseases were common and uniform in epidemiology and public health, so they were available for children’s health study. In addition, the questions about home environment and lifestyle behaviors from the Dampness in Building and Health (DBH) study in Sweden [38] were adopted in this study by translation. Questions on home environment covered from residential building characteristics, renovation status, air conditioning equipment to dampness exposures and window opening frequency. All of these questions were in accordance with current conditions of China, like the construction year (before 1980, 1980–1990, 1991–2000, 2001–2005 and 2006 until the survey day), the materials of bedroom floor and wall (categories of materials were based on the report of building materials usage in China), the exposure of quilts in the sunshine (totally chinese characteristics) and so on. In this study, the questions in relation to common cold, home dampness and frequencies of window opening were included.

1. The questions on common cold infections were “How many times has your child had a cold in the last 12 months (options: <3 times; 3–5 times; 6–10 times; >10 times)” and “How long does a common cold usually last (options: <2 weeks; 2–4 weeks; >4 weeks)”.
2. Questions on home dampness features were: “Any visible mold spots (VMS) in your child’s room (no/yes)”, “Any visible damp stains (VDS) of child’s room (no/yes)”, “Any damp on clothing/beddings (DCB) (no/yes)”, “Any water damages (WD) in the apartment (no/yes)”, “Condensation on window panes (WPC) (no/yes)” and “Any mildewy odor (MO) (no/yes)”.
3. Questions on frequency of window opening were categorized by seasonally: “How about the frequency of the window opening in your child’s room: a) in spring, b) in summer, c) in autumn, d) in winter (options: Never; Sometimes; frequently)”.

2.2. Statistical methods

Pearson’s Chi-square ($\chi^2$) test was used to determine the differences between groups. Gamma correlation analysis was used to investigate correlations between window opening mode and environmental dampness because the variables are dichotomous (Yes vs. No). Logistic regression analysis was applied to investigate crude associations between indoor environmental dampness, frequency of window opening and children’s cold symptoms. Multiple logistic regression analysis was used to address the potential founders, which included age (4 vs. 5 vs. 6-years-old), gender (male vs. female), family history of atopy, residence location (urban area vs. suburb), ownership of residents (Tenancy vs. Owned) and current environmental tobacco exposure (Yes vs. No). Associations would be indicated by crude odds ratio (OR) and adjusted odds ratio (AOR) with 95% confidence interval (CI). The significance in statistical analyses would be indicated by p value < 0.05. The multiplicative interaction between household ventilation and dampness-related indicators on cold symptoms of children was addressed by multiple logistic regress model and Cox model, meanwhile the spreadsheet proposed by Knol MJ [43,44] and Andersson [45] was adopted to analyze the additive interaction and 95% confidence interval between them. The relative excess risk due to interaction ($RR_{11} - RR_{10} - RR_{01} + 1$), the attributable proportion due to interaction (AP = $RR_{11}$), the synergy index ($S = (RR_{11}-1)/[(RR_{01}-1)(RR_{10}-1)]$) were three indexes to estimate the interaction effect of household ventilation and dampness-related indicators. There are strong indications that the estimated effect on the additive scale of two investigated factors if the $RR_{11}$ is above 0, $S$ above 1 and $P$-value < 0.05. To evaluate the effects of missing data of dampness related exposure options on questionnaires, the sensitivity analyses were conducted. All of the missing data were set as 1 and 0 respectively to inspect the difference of results. The abnormal error of tested relative humidity was eliminated firstly. The range between 25th–1.5IQR and 75th + 1.5IQR
3. Results

15,266 valid questionnaires (85.3%) were collected from cross-sectional survey. In this research, 13,335 questionnaires of 4–6 years old children were analyzed. Demographic information and living habits of dormitory occupants have been reported in details by a previous paper [47]. Relating to this research, forty-nine point two percent (49.2%) of surveyed children were girls. 5561 (about 41.7%) children were less than or equal to four years. Reports from the kindergartens in five different districts were 3071 (23%) in Zhabei district, 2598 (19.5%) in Jing’an district, 1907 (14.3%) in Hongkou district, 3306 (24.8%) in Fengxian District and 2453 (18.4%) in Baoshan district respectively. In these families, 36.8% of them rented their existing home and 63.2% of them owned it. For the surveyed children, 56.5% of their patriarch (including their parents and grandparents living with them) smoked.

3.1. Prevalence of common colds among children, status of current ventilation and dampness of residential environment

Results from primary analysis indicated that in last 12 months, the incidence of children’s common cold is 56.4% for <3 times, 35.1% for 3–5 times, 7.3% for 6–10 times and 1.2% for >10 times. Because the incidence of colds above 6 times was relevant low, in this research, the cold times were classified to <3 times and ≥3 times. This method was also applied to cold duration (<2 weeks and ≥2 weeks). Therefore, the incidence of children common colds no less than three times (≥3 times) in the previous 12 months was 43.6% and that of a cold duration time no less than two weeks (≥2 weeks) was 14.8%.

Ventilation conditions in this questionnaire were presented as window opening situation. Fig. 2 displays the frequency of window opening in four seasons of these residential buildings. Residents are used to opening windows for ventilation in summer more often than that in winter. About sixty-two percent (61.9%) families “Always” open the windows in summer. Corresponding to this, 36.1% families “Never” open their windows in winter. Even though in spring and in autumn, there are also more than 10% families who “Never” open the windows in their child’s room. Based on this distribution information, window opening index (WOI), which is a principle from the perspective of a year, is further proposed to reveal the situation of residents’ natural ventilation habits. It could be defined as “Rarely” (assigned as 0), when this family “Never” open their windows in no less than two seasons; “Often” (2), when this family “Always” open their window in no less than three seasons; “Sometime” (1), when the window opening mode of this family belongs to those excluding situations described above. Based on this new index, the window opening information of all these families was reorganized. 14.9% families “Rarely” open their window in children room, while 31.1% others “Often” have window opening. About half of them (54%) open their windows “Sometimes”. This index could also be considered as the natural ventilation condition in qualitatively. Three levels are related to ventilation rate as “Low”, “Medium” and “High” respectively.

Dampness-related exposure of every residence were surveyed and counted. The frequency of six dampness problems existing in all these families were separately 7.8% for VMS, 15.3% for VDS, 42.1% for DCB, 18.2% for WD, 55.7% for WPC and 11.9% for MO. For a single family, there might be several dampness-related indicators reported, so the total number of dampness-related indicators was proposed here to describe the dampness level, and it could be expressed as n, where it might be equal to 0, 1, 2, 3, 4, 5 and 6. The frequency of the total dampness-related indicators is displayed in Fig. 3. The valid samples for this statistics were 8068 by abandoning the sample missing any value of these six dampness-related indicators. It demonstrates that the residential buildings with one or two kinds of dampness exposures accounted for 49.3%. In other words, half of the residence in Shanghai have more than one dampness problem. Less than 1% residence was exposure to all six dampness problem. The analysis on the validity of subjective questionnaire in evaluating dwelling home dampness and indoor odors based on Cross-sectional survey and on-site inspection in Shanghai have been already conducted before [48]. In the paper, the consistency of the dampness
exposures from children's parents-reported questionnaires in Phase I and on-site tester inspection in Phase II were analyzed. According to the observed, positive, and negative proportional agreement ($P_o$, $P_{pos}$, and $P_{neg}$), parents and inspectors had substantial prefect consistencies in dampness exposure indicators ($P_o = 0.51–0.96$). Therefore, the validity of the dampness-related exposure from questionnaires has been confirmed.

3.2. Associations between children common colds and residential environment

Window opening mode in seasonally and further window opening index were significantly associated with children common cold incidence and a cold duration, as seen in Table 1. The incidence of common cold ($\geq 3$ times) in children living in the residence with lower window opening frequency was higher than that living in the residence with higher window opening frequency, whatever in which season. Especially in spring, the highest incidence of common cold ($\geq 3$ times) happened in residence with never window opening, was 6.6% higher than the lowest one existed in those with frequently window opening. Similarly, the lower the window opening rate was, the longer was the children common cold duration. It could be displayed as WOI (or ventilation rate). Lower WOI was significantly associated with higher common cold incidence and longer cold duration in children.

Besides, the dampness-related exposures were also found to be positively associated with common cold among children. Table 2 demonstrates that the incidence of common cold ($\geq 3$ times) among children increased and significantly increased when anyone of six dampness-related factors appeared. The highest increment could up to be 9.3% when there was condensation on window panes. The common cold duration of them also lengthened with these dampness-related factors and the largest increment of frequency for duration no less than weeks was 5.7% when the

| Table 1 | Frequency distribution of window opening condition and children common cold. |
|---------|--------------------------------------------------------------------------------|
| Season  | Window opening mode               | Common cold incidence | Common cold duration          |
|         |                                  | $\geq 3$ times | n (%) | $\chi^2$/ | P value | $\geq 2$ weeks | n (%) | $\chi^2$/ | P value |
| Spring  | Never                            | 699(48.6)    | 21.4/ | <0.001   |          | 234(16.5)    | 5.4/  |          |          |
|         | Sometime                         | 2475(44.1)   | <0.001 |          |          | 835(15.1)   | 0.066 |          |          |
|         | Frequently                       | 2315(42.0)   |          |          |          | 772(14.2)   |      |          |          |
| Summer  | Never                            | 467(44.4)    | 3.4/  |          |          | 187(18.2)   | 12.7/ |          |          |
|         | Sometime                         | 1583(42.5)   | 0.18   |          |          | 504(13.7)   | 0.002 |          |          |
|         | Frequently                       | 3423(44.3)   | 12.4/  |          |          | 1341(15.0)  |      |          |          |
| Autumn  | Never                            | 586(47.5)    | 203(16.6)|          |          | 771(14.3)   | 4.7/  |          |          |
|         | Sometime                         | 2399(44.5)   | 0.002  |          |          | 802(15.1)   | 0.096 |          |          |
|         | Frequently                       | 2319(42.4)   |          |          |          | 771(14.3)   |      |          |          |
| Winter  | Never                            | 2159(49.1)   | 79.8/  |          |          | 719(16.3)   | 15.3/ |          |          |
|         | Sometime                         | 2304(41.4)   | <0.001 |          |          | 762(13.9)   | <0.001 |          |          |
|         | Frequently                       | 5283(43.9)   |          |          |          | 283(13.9)   |      |          |          |
| WOIb    | Often                            | 1680(42.4)   | 23.99/ |          |          | 558(14.3)   | 14.6/ |          |          |
|         | Sometime                         | 2937(42.8)   | <0.001 |          |          | 960(14.2)   | 0.001 |          |          |
|         | Rarely                           | 932(48.7)    |          |          |          | 333(17.6)   |      |          |          |

Bold value represents $p < 0.05$.

* Pearson Chi-square test.

b Window opening index.
residence had water damage during past year. To further indicate the relationship between dampness-related factors and children common cold. The relationship between the total numbers of dampness indicators (DI) and the incidence and duration of common cold were established. The larger was the number of home dampness-related indicators in the current residence, the higher was the incidence of common cold (>=3 times), and the longer was the common cold duration.

In Table 3, the associations between the window opening condition, dampness indexes of residential buildings and children's common cold are presented. The window opening condition was negatively and the dampness-related exposure was positively associated with higher common cold incidence (>=3 times) and longer common cold duration (>=2 weeks). In addition, most of the relationships were significant, for the significance testing P-value was less than 0.001. For window opening index, "Rarely" or "Sometime" opening the windows became the risk factors for increasing the chance of common cold (the highest AOR = 1.29, 1.15–1.44) and prolonging the cold duration (the highest AOR = 1.29, 1.12–1.48) by compared to "Often" opening the windows. Furthermore, compared with the risk assessment for all these six dampness-related indicators, where the AOR values were above 1.2, the dampness index was significantly and positively related with children's common cold incidence and duration, where all the adjusted odds ratios for children were above 1.30 and the highest one (2.18, 1.14–4.14) were found in homes with all six dampness-related exposures.

Besides, since both the window opening mode (related to natural ventilation rate) and the dampness-related exposures were related to children common cold symptoms, and the association between them were significant, therefore the interaction effects of these two factors on children common cold were further investigated. The binary regression results indicate that dampness indexes and window opening index have a multiplicative and additive effect on children health. The adjusted odds ratio for these two factors by multiplicative effect on common cold incidence and duration were 1.10 (95% CI: 1.07–1.13) and 1.14 (95% CI: 1.10–1.18) with P-value <0.01 of significance testing. The relative excess risk due to interaction (REI), attributable proportion due to interaction (AP), and synergy index (S) for additive effect of household ventilation and dampness-related indicators on common cold were 0.142 (95% CI: 0.100–0.186), 0.075 (95% CI: 0.075–0.126) and 1.509 (95% CI: 1.363–1.671). Three indexes for one cold duration were 0.041 (95% CI: –0.009–0.091), 0.030 (95% CI: –0.004–0.065) and 1.127 (95% CI: 0.993–1.278). There are strong indications that the estimated effect on the additive scale of these two factors presented (REI >0, S > 1, p < 0.05) [44,49].

4. Discussion

The dampness exposures and window opening index were separately associated with common cold of 4–6 years old children in Shanghai, China, and a significant dose-response relationship for adjusted proportions was found between low WOI, high DI and children's common cold symptoms. This has been stated by other researchers before [27,50]. The dampness exposures in this paper covered from odor to spots. It is more comprehensive. Window opening mode was directly related to the natural ventilation condition, as discussed before. Therefore, there is a hypothesis proposed by current results that poor household natural ventilation could be in somehow associated with severe dampness exposures and further increase the risk for common cold symptoms in children. It was consistent with the statement by previous research [51]. In other words, good household natural ventilation (HNV) could weaken the dampness exposures. Then the association between HNR and DI was discovered in this paper, as seen in Table 4 and Fig. 4.

Table 4 indicates that the frequency of all these six dampness indicators increased with the natural ventilation improving. Good natural ventilation was positively associated with less dampness

| Table 2 |
| Frequency of indoor dampness exposures (features and indexes) and common cold times, a cold duration of 4–6 years old children in Shanghai. |
| Factors | Sub-category | Total n = 13,335 (%) | Cold incidence n = 12,729 | Cold duration n = 12,535 |
| | | | >=3 times (%) | >-2 weeks (%) |
| | | | | |
| VMS | No | 42.1 | 41.8 | 38.1 | 9.2/0.002 |
| | Yes | 84.3 | 43.1 | 14.5 | 9.2/0.002 |
| VDS | No | 57.9 | 41.8 | 38.3 | 82.2/0.001 |
| | Yes | 44.3 | 47.6 | 11.7 | 82.2/0.001 |
| DCB | No | 57.9 | 41.8 | 38.3 | 82.2/0.001 |
| | Yes | 44.3 | 47.6 | 11.7 | 82.2/0.001 |
| WD | No | 57.9 | 41.8 | 38.3 | 82.2/0.001 |
| | Yes | 44.3 | 47.6 | 11.7 | 82.2/0.001 |
| WPC | No | 57.9 | 41.8 | 38.3 | 82.2/0.001 |
| | Yes | 44.3 | 47.6 | 11.7 | 82.2/0.001 |
| MO | No | 57.9 | 41.8 | 38.3 | 82.2/0.001 |
| | Yes | 44.3 | 47.6 | 11.7 | 82.2/0.001 |
| n | | | | |
| 0 | 36.7 | 43.2 | 14.5 | 9.2/0.002 |
| 1 | 32.5 | 43.1 | 14.5 | 9.2/0.002 |
| 2 | 17.1 | 42.4 | 13.8 | 44.3/0.001 |
| 3 | 17.1 | 42.4 | 13.8 | 44.3/0.001 |
| 4 | 3.9 | 50.3 | 19.5 | 52.8/0.001 |
| 5 | 1.6 | 54.8 | 22.6 | 78.2/0.001 |
| 6 | 0.5 | 59.0 | 23.1 | 78.2/0.001 |

Bold value represents p < 0.05.

a Visible mold spots.
b Visible damp stains.
c Damp on clothing/beddings.
d Water damage.
e Condensation on window panes.
f Mildewy odor.
g n represents the total number of dampness-related indicators.
exposures, which could also be illustrated by the adjusted odds ratio for dampness index in Fig. 4. With the “frequent” natural ventilation as reference, the risk of household ventilation on each dampness level was significant. Poor natural ventilation resulted in severe dampness level for AOR value above 1 and poor ventilation had a stronger association with high dampness level for the AOR value grew up with dampness index increased (the highest one presented at DI equal to 5, AOR, 95% CI: 1.60, 1.24–2.08). It provides a strong evidence that poor home ventilation could encourage dampness problems generation. This has been stated by previous research. Hagerhed-Engman et al. has also presented that a moldy odor along the skirting board and severe moldy odor in indoor air were significantly associated with a low ventilation rate [27,52].

The primary results from phase II in our group have also provided the general evidence on this statement. The concentration of CO₂ for 24 h in children’s bedroom was recorded and it was then taken as the trace gas to calculate the natural ventilation rate. The average values were 1.51 h⁻¹ and 2.28 h⁻¹ for day and night time respectively. High risk of moldy odor, visible mold in the wall covering and window pane condensation was associated with low ventilation rate. Moreover, ventilation rate in winter was lower than that in summer and with the increasing of it, the frequency of children cough and eczema decreased. Therefore, the significance of home ventilation is noticeable. To eliminate indoor dampness problems, providing favourable home ventilation is efficient.

The risk of high frequency and long duration of common cold due to dampness exposures stratified by the frequency of opening window in different seasons. The results (in autumn, for example) were listed in Table 5, the results from other three seasons were listed in supplementary materials Tables S2–4. It displays that with the modification effect of natural ventilation, the risk of dampness exposures on both the incidence and duration of children’s common colds decreased. It also confirms that the natural ventilation not only weaken the household dampness exposures, but also reduce the risk of dampness exposure on children health.

From the architecture point of view, the dampness exposure was effected by home ventilation and both of these two factors might be further associated with common colds of children, however what the mechanism of this effect is. From the perspective of common cold mechanism, there are numerous virus inducing upper respiratory infection (common cold) [7,53]. The rhinoviruses, coronaviruses, staphylococcus aureus, one of gram-negative bacteria, were
most familiar. Most of them are transmitted by air. According to the statistics, among all the viruses which cause common cold of children, rhinovirus accounts for 15–40%, coronavirus for 10–20%, and staphylococcus aureus are also one of the main viruses causing child’s respiratory infection. There are variety of reproduction methods and propagation paths for different viruses. Researches indicate that indoor environmental humidity has an obvious effect on reproduction and propagation of respiratory infection viruses [54]. Taking the rhinovirus for example, high humidity condition improves the performance of the cell development. It on the one hand affects the stability of virus cell, on the other hand affects the droplet size and water capacity evaporation. Results from aerosol experiments demonstrate that rhinovirus is more stable under the high humidity condition [55]. It also illustrated that the natural decline rate is lower when indoor relative humidity is 50–60% than that under 35% of RH [56].

Dry environment may cause the bacteria/virus cell death because of protein denaturation and brine concentration. It testifies that humidity condition not only affects the propagation of bacteria, but also determines its survival time [57]. When RH was 15%, 35% and 80%, the staphylococcus aureus could survive for 9 ± 2 days, 21 ± 4 days and 67 ± 7 days respectively. The relationship between relative humidity and survival time of bacteria could be established by regression, as seen in Fig. 5. It could be deduced that with the increasing of the measured RH, the survival time of relevant bacteria increased. The researchers also conducted experiments to investigate the association between the transmission of flu virus and indoor relative humidity. The results showed that in the 28 °C environment, the transmission speed of flu virus accelerated with the relative humidity increasing [11].

Several kinds of bacteria/virus with high morbidity were analyzed. Although these were limited, it aims to explore the environmental inducement of child’s respiratory infection (common cold). The results from regression analysis of virus survival

| Table 5 |
|---------|
| Effect of household ventilation in different seasons on common colds among preschool children (Autumn). |
|        | Cold incidence, AOR, 95% CI (P-value) | A cold duration, AOR, 95% CI (P-value) |
|         | Window opening mode (ventilation) | Window opening mode (ventilation) |
| Dampness indicators levels | n = 0 | n = 839 | n = 5392 | n = 5473 | n = 5301 | n = 5399 |
| n = 0 | Never, n = 839 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1 | 1.46, 1.02–2.10 | 1.24, 0.04–1.47 | 1.28, 1.08–1.52 | 2.00, 1.16–3.44 | 1.50, 1.17–1.93 | 1.30, 1.02–1.67 |
| 2 | 1.97, 1.30–3.00 | 1.31, 1.07–1.61 | 1.40, 1.14–1.72 | 3.03, 1.69–5.42 | 1.49, 1.11–1.99 | 1.54, 1.15–2.06 |
| 3 | 1.40, 0.79–2.47 | 1.84, 1.39–2.43 | 2.10, 1.59–2.78 | 2.82, 1.34–5.93 | 2.46, 1.74–3.48 | 2.27, 1.60–3.22 |
| 4 | 1.89, 0.90–3.94 | 1.48, 1.02–2.16 | 1.68, 1.16–2.41 | 4.17, 1.76–9.87 | 1.69, 1.02–2.80 | 1.74, 1.07–2.83 |
| 5 | 0.55, 0.17–1.85 | 1.95, 1.12–3.39 | 3.40, 1.75–6.58 | 3.16, 0.91–11.04 | 2.55, 1.32–4.92 | 2.15, 0.96–4.81 |
| 6 | 1.68, 0.67–4.19 | 1.97, 0.72–5.40 | 1.07, 0.01–8.78 | 18.11, 1.35–242.9 | 0.95, 0.21–4.26 | 2.68, 0.85–8.43 |

![Fig. 4. Association between home ventilation and dampness index.](image)
time and relative humidity were identical to that drawn from survey. They reflected that indoor environmental dampness was the risk factor of common cold for children.

Furthermore, the sample sizes largely decrease from 13,335 to 8086 when we conducted the analysis dampness index, as seen in Table 4. It is due to the missing data of dampness-related questions. The statistical principle for creation of dampness index is abandoning any questionnaire with no less than one missing data. After elimination of six items, the left questionnaires are 8086. To explore the effect of missing data on the identification of common cold risk, the sensitivity analysis was conducted. There were three cases for this analysis: 1) assigning all the missing data as 1 (existing related dampness feature); 2) assigning all the missing data as 0 (non-existing related dampness feature); 3) removing the missing data (used in this paper). The association between dampness index and common cold of children was analyzed by using these three methods. Table 6 displays the results obtained from three cases. It could be found that when the missing data were assigned with 0 or 1, the adjusted odds ratio for common cold incidence and duration accordingly decreased in comparison with being assignments before. However, the AORs of case 1 and case 2 were all still above 1.00 and they were consistent with case 3, which represented that the testing results of AOR for common cold of children were insensitive to missing data of dampness index. Therefore, the analysis conclusion drawn from case 3 was convicitive.

Although the window opening mode and dampness related exposures have been surveyed and the associations between them and children’s common cold were analyzed, there are still some problems and limits that have not been discussed in this paper. (1) All these results and conclusion were obtained from CCHH phase I – Questionnaires, so the dampness feature and home ventilation situation were obtained by reporting and they were subjective. It needs more data from phase II – Measurements to verify and improve these outcomes. (2) In the same way, household natural ventilation should be determined by density of indoor CO₂ from field measurements, then the correlation between it and window opening mode could be built [27,50]. The related work has been conducted by other member in our group. (3) Besides, indoor temperature and relative humidity are connected [58], so different combinations of temperature and relative humidity may have different effects on the incidence of common cold. It was not analyzed in this paper. Although these were limited, it aims to explore the environmental inducement of child’s respiratory infection (common cold). They reflected that indoor environmental dampness was the risk factor of common cold for children. Therefore, improving the insulation and humidity control performance and adopting the appropriate home ventilation mode to avoid environmental dampness, which provides the necessary condition for propagation of bacteria, could effectively eliminate the incidence of common cold among children.

5. Conclusion

Indoor dampness exposures play a negative role on children health and they were significantly associated with high incidence of common cold among children. However, good household natural ventilation could modify these effects. In this paper, these findings could be drawn.

(1) More than 40% of children in Shanghai were reported that the frequency of catching a common cold in one year was above 3 times and about a common cold duration for 15% of children was no less than two weeks.

(2) Both natural ventilation mode and dampness exposures in residential buildings are important to and significantly

![Fig. 5. Relationship of relative humidity and virus duration.](image-url)
Sensitivity analysis on the risk of dampness-related exposures on common colds of preschool children.

Factors/Cold incidence, AORa (95% CI) Cold duration, AORa (95% CI)

| Levels | n   | P-value | Case 2 N | P-value | Case 1 N | P-value |
|--------|-----|---------|----------|---------|----------|---------|
| 1      | 12,729 | <0.001 | 1.25 (1.13,1.38) | <0.001 | 1.20 (1.10,1.30) | <0.001 |
| 2      | 8086   | <0.001 | 1.36 (1.18,1.52) | <0.001 | 1.35 (1.27,1.44) | <0.001 |
| 3      | 12,729 | <0.001 | 1.50 (1.32,1.70) | <0.001 | 1.57 (1.36,1.81) | <0.001 |
| 4      | 8086   | <0.001 | 1.35 (1.16,1.58) | <0.001 | 1.60 (1.31,1.94) | <0.001 |

a Adjusted odds ratio: adjustments made for age, gender, location of the kindergarten, ownership of residents and current parental smoking.

Therefore, the natural ventilation by window opening could weaken the effect of household dampness exposures on children’s common cold.

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Appendix A. Supplementary data

Supplementary data related to this chapter can be found at http://dx.doi.org/10.1016/j.buildenv.2017.07.033.

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