On-Site Measurement of Airborne Fungi in Shanghai Residences

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Abstract

With on-site measurements, this paper analyzed the current status of airborne fungi in the child’s bedroom of the residences in Shanghai and its associations with the characteristics of residences. The average concentration of airborne fungi in the 446 children’s bedrooms was 310 CFU/m\textsuperscript{3} (range: 6 to 3184 CFU/m\textsuperscript{3}). Only one bedroom had higher concentration of airborne fungi than the standard concentration of 2500 CFU/m\textsuperscript{3} with 3180 CFU/m\textsuperscript{3}. Compared to the residences with building areas \(\leq 75\) m\textsuperscript{2}, those residences > 100 m\textsuperscript{2} had significant higher average concentrations (mean \(\pm\) standard deviation: 270 \(\pm\) 183 vs. 354 \(\pm\) 409). The children’s bedrooms at the ground floor or the attic floor of the residential building had higher average concentration of airborne fungi than others. The results indicate that building characteristics of residences may be associated with the concentrations of airborne fungi in the child’s bedroom.

1. Introduction

Indoor air quality is one of the most important factors that influence our general life quality, physical health and the efficiency of work or study [1]. Dacarro et al. found that people nearly breathe 10 m\textsuperscript{-3} airs every day, and 80\%-95\% of these airs are breathed directly from indoor [2]. The microbes, such as bacteria, mold, and microzyme, are live particles which often adhered to the surface of the tiny aerosol particles in air, which were called airborne fungi [3]. Airborne fungi are very common in indoor air and are inimitable indoor contaminants which can stay in the air for
long time and can widely spread with the air flowing [4]. Numerous studies had shown that small fungal fragments could cause allergic diseases, such as respiratory infections, acute toxic effects, allergies, and asthma which will make great impact on people’s physical and even mental health [5,6]. Shanghai locates in the Yangtze River estuary and belongs to the subtropical monsoon climate with profusion of rain and moist and warm climate [7]. Especially in the “plum rains period” of spring, the indoor relative humidity would stay higher than 80% for long time in Shanghai residences, which provides favorable conditions for the growth of bacteria [8]. Therefore, it is necessary to figure out the current status of indoor airborne fungi in Shanghai. However, some related studies were still limited in Shanghai. In this study, we analyzed current status of airborne fungi in the child’s bedroom in Shanghai residences and its associations with characteristics of the dwelling building.

2. Methods

From March 2013 to December 2014, the concentrations of airborne fungi in 454 residences were measured in a case-control study (China, Children, Health, Homes (CCHH) phase two) in Shanghai, China [9,10]. Those inspected residences did not alter, redecorate in large area, or purchase large furniture, from last questionnaires study (April 2011 to April 2012) to home inspection. The point for air sample was set at a height of about one meter upper the floor (child’s breathing zone) closed the center of child’s sleeping room. Family members maintained their normal status of life during the whole inspection. Microflow (AQUARIA Inc., Italy) were used to sample 1000 Liters (100 L min⁻¹ for 10 minutes) air with using nutrient agar as the sampling medium. After the samples were cultivated in 35±1°C thermostat for 48 hours, the colony forming unit (CFU) of airborne fungi was counted by microscopic observation or magnifier. Characteristics of the residence were provided by the residents’ questionnaire. Independent-samplers t-test was used to compare concentration of airborne fungi in the child’s bedroom with different building characteristics. Significance in statistical analysis was set at $p$-value $< 0.05$.

3. Results

A total of 445 children’s bedrooms had valid data. Figure 1 shows the concentration of airborne fungi in different inspection dates. The numbers of inspected residences had no notable difference in different seasons. Concentrations of airborne fungi mainly distributed in 0-1000 CFU/m³; concentrations in six bedrooms were higher than 1500 CFU/m³; only one bedroom had higher concentration than the national standard concentration of 2500 CFU/m³, which was stipulated in Indoor Air Quality Standard (GB/T 18883-2002) [11].

![Fig. 1. The concentrations distribution of airborne fungi in 445 children’s bedroom with different inspection time](image-url)
The average concentration in 445 children’s bedrooms was 310 CFU/m³ (range: 6 to 3184 CFU/m³). Average concentration among children’s bedrooms which were inspected in spring was higher than in other seasons and the highest concentration was measured in spring; average concentration in autumn was significantly lower than in spring; spring, summer, winter didn’t have significantly differences about average concentration of airborne fungi. But concentrations in different seasons had similar percentiles. Compared to urban bedrooms, the suburban bedrooms had significant lower average concentration and had more compact percentiles (Table 1). The highest average concentration was in Jingan district and the lowest in Fengxian district; but average concentrations in different districts didn’t have notable difference.

Compared to residences with building areas ≤ 75 m², those residences with > 100 m² had significant higher concentrations, including average concentration and percentiles. The concentrations in bedrooms which were constructed before 1990 and after 2006 were lower than those bedrooms which were constructed from 1990 to 2006, whereas the differences didn’t reach significant level. Residences which were constructed from 1990 to 2000 had the highest average concentrations. Bedrooms at the ground floor or the attic floor of the residential building had higher average concentration of airborne fungi than others, but the difference didn’t up to be significant in statistical analysis. Bedrooms at the residential building higher than 7 floors had significantly higher average concentration than those residential buildings lower than 7 floors. Bedrooms from multi-storey apartment dwelling (MSAD) had significant higher average concentration than those from dwellings in other types. Bedrooms with wood window frame or with double layers window glass had higher average concentrations than with other types of window frame or with window glass of single layer, respectively.

### Table 1. The concentrations distribution of culturable fungi in children’s bedrooms with different seasons and districts

| Items                      | Sample size N (%) | Mean ± SD (CFU/m³) | p-value | Min (CFU/m³) | 25% | 50% | 75% | Max (CFU/m³) |
|----------------------------|-------------------|---------------------|---------|--------------|-----|-----|-----|-------------|
| **Total**                  | 445 (100.0)       | 310±313             |         | 6            | 152 | 234 | 343 | 3184        |
| **Inspection season**      |                   |                     |         |              |     |     |     |             |
| Spring                     | 128(28.8)         | 368±478             | 0.076   | 6            | 140 | 233 | 352 | 3184        |
| Summer                     | 123(27.6)         | 285±208             | 0.025   | 76           | 167 | 239 | 323 | 921         |
| Autumn                     | 104(23.4)         | 267±140             | 0.288   | 27           | 144 | 228 | 353 | 1218        |
| Winter                     | 90(20.2)          | 314±266             |         |              |     |     |     |             |
| **Urban or suburban**      |                   |                     |         |              |     |     |     |             |
| Urban                      | 257(57.8)         | 335±363             | 0.037   | 6            | 154 | 249 | 399 | 3184        |
| Suburban                   | 188(42.2)         | 278±222             |         | 44           | 150 | 215 | 320 | 1522        |
| **District**               |                   |                     |         |              |     |     |     |             |
| Zhabei                    | 74(16.6)          | 310±164             |         | 63           | 176 | 278 | 420 | 780         |
| Yangpu                     | 34(7.6)           | 310±228             | 0.116   | 34           | 164 | 245 | 400 | 2283        |
| Jingan                     | 87(19.6)          | 390±431             | 0.881   | 6            | 101 | 201 | 321 | 3184        |
| Hongkou                    | 62(13.9)          | 301±474             |         |              |     |     |     |             |
| Fengxian                   | 93(20.9)          | 269±227             | 0.194   | 48           | 148 | 213 | 304 | 1522        |
| Baoshan                    | 95(21.4)          | 284±219             | 0.388   | 44           | 152 | 215 | 325 | 1218        |

a) SD, standard deviation.

### 4. Discussion

Although the cultivation-based methods have several limitations including lack of reproducibility, selection effect, limitation of sampling time, and underestimation of total number of fungal propagules, they were still widely used in inspections of airborne fungi [12,13,14]. Therefore, we considered that concentrations of airborne fungi in the children’s bedroom which we tested by culture-based method could represent the current status of the exposure level of indoor airborne fungi in the Shanghai residences. It is found that most families had rather low concentrations of airborne fungi, which was consistent with similar study in Xi’an, China [15]. Concentrations of airborne fungi in 445 children’s bedroom met the standard concentration, and 98.7% of the concentrations were attained to the “cleaning state” [16]. Concentrations of airborne fungi in spring were significantly higher than in autumn, which could be caused by the “plum rains period” of spring. Higher indoor relative humidity for long time during the “plum rain period” provided favorable conditions for the growth of airborne fungi [17]. Whereas, indoor air is a little drier with suitable
temperature in Shanghai during autumn [18], and the frequencies of ventilation in residences were also higher so that indoor air could be effectively maintain clean during autumn [19]. According to the concentrations distribution of airborne fungi in children’s bedrooms with different building characteristics (Table 2), we found that residences with better constructions conditions (larger residence areas, the total floors of the building > 7 floors, double layers of window glass) had higher concentrations of airborne fungi, which out of our expectation. Families in the residences with larger building area (101-150m² or more than 150m²) perhaps had more members and had more frequent human activities than in the residences with smaller building area. So it gave rise into the result that concentrations of airborne fungi in families with larger building area (101-150m² or more than 150m²) was higher than in families with smaller building area. In theory, residences which were constructed before 1990 would easier find damp stains or moldy odor, inferior conditions in those residences which probably also exist dampness and mold. Significant differences may explained by wooden windows frame and single layer glass windows indicated that residences with smaller building area. So it gave rise into the result that concentrations of airborne fungi should be higher than other residences. However, it is found that concentrations in the residences which were constructed before 1990 were lower than other residences. Those probably were related with that these residences were redecorated [20]. Elevated airborne fungi concentrations measured in dwellings on ground or attic floor was consistent with results of Roussel et al.’s study [21]. This result may be caused by that residences in ground or attic floor of the buildings commonly were more humid because of more moisture exchange between indoor air and wet ground than residences in intermediate floor (2-5 floor or >6 floor). Meanwhile, residences in ground floor couldn’t obtain enough sunshine and didn’t have excellent ventilation. A majority of families chose to live in multi-storey apartment dwellings. Although the sample size of families who chose other residential type was smaller than those chose multi-storey apartment dwellings but still had 77 homes. It is believed that the result of bedrooms from multi-storey apartment dwelling (MSAD) had significantly higher average concentration than those from dwellings in other types could be closed to the actual conditions. In our study, we also found notable difference of airborne fungi at different type s of windows frame and glass layers of windows but not significant. This differences may explained by wooden windows frame and single layer glass windows indicated inferior conditions in those residences which probably also exist dampness and mold.

Table 2. Concentrations distribution of airborne fungi in children’s bedrooms with different factors of building characteristics

| Items                                      | Sample size | Mean ± SD (CFU/m³) | p-value | Min (CFU/m³) | 25% | 50% | 75% | Max (CFU/m³) |
|--------------------------------------------|-------------|---------------------|---------|--------------|-----|-----|-----|-------------|
| **The area of residences**                 |             |                     |         |              |     |     |     |             |
| ≤75 m²                                     | 140(32.2)   | 270±183             |         | 17           | 147 | 218 | 331 | 1047        |
| 76-100 m²                                  | 128(29.4)   | 286±268             | 0.572   | 15           | 147 | 226 | 323 | 2177        |
| 101-150 m²                                 | 167(38.4)   | 354±409             | 0.018   | 6            | 162 | 247 | 381 | 3184        |
| **The construction period of residences**  |             |                     |         |              |     |     |     |             |
| Before 1990                                | 67(15.3)    | 281±192             |         | 27           | 147 | 228 | 346 | 887         |
| 1991-2000                                  | 125(28.5)   | 340±371             | 0.222   | 17           | 152 | 236 | 368 | 2283        |
| 2001-2005                                  | 160(36.4)   | 315±354             | 0.355   | 6            | 151 | 234 | 323 | 3184        |
| After 2006                                 | 87(19.8)    | 283±206             | 0.954   | 44           | 152 | 226 | 343 | 1109        |
| **The floor of the children’s bedrooms**   |             |                     |         |              |     |     |     |             |
| Ground floor                               | 67(15.3)    | 360±306             |         | 51           | 167 | 268 | 424 | 1522        |
| 2-5 floor                                  | 184(42.4)   | 309±301             | 0.210   | 6            | 162 | 238 | 343 | 3184        |
| >6 floor                                   | 132(30.4)   | 293±344             | 0.430   | 15           | 136 | 200 | 321 | 2283        |
| Attic floor                                | 62(14.3)    | 318±314             | 0.439   | 44           | 151 | 247 | 363 | 2232        |
| **The total floors of the residential building** |             |                     |         |              |     |     |     |             |
| ≤7 floors                                  | 235(53.9)   | 280±347             |         | 6            | 148 | 213 | 323 | 3184        |
| >7 floors                                  | 201(46.1)   | 347±340             | 0.029   | 13           | 159 | 244 | 412 | 2283        |
| **The type of residences**                 |             |                     |         |              |     |     |     |             |
| MSAD                                       | 359(82.3)   | 320±336             |         | 6            | 152 | 234 | 344 | 3184        |
| Other                                      | 77(17.7)    | 266±164             | 0.040   | 27           | 148 | 228 | 344 | 887         |
| **The type of window frames**              |             |                     |         |              |     |     |     |             |
| Wooden                                     | 28(6.8)     | 342±271             | 0.523   | 13           | 160 | 250 | 484 | 1029        |
| Other                                      | 310(91.7)   | 301±325             |         | 6            | 148 | 228 | 335 | 3184        |
| **The glass layers of windows**            |             |                     |         |              |     |     |     |             |
| Single layer                               | 284(65.7)   | 295±294             | 0.194   | 6            | 151 | 221 | 325 | 3184        |
| Double layers                              | 148(34.3)   | 337±355             |         | 13           | 148 | 239 | 400 | 2260        |

a) Because of data missing, the sum of category-sample sizes was not equal to the total sample sizes.
b) The sample sizes of the Ground floor, 2-5 floor, >6 floor, and attic floor didn’t contain the quantity of attic floor.
c) SD, standard deviation; MSAD, multi-storey apartment dwelling.

However, some limitations in this study must be identified and addressed. The time of inspections could be modest fortuitous, different residents activities at different time may cause different influence to the results of inspection. The location of instrument may have great impact on inspection results. If the instrument was put in a location with less-than-average fungi concentration, the inspection results would not be able to represent the actual exposure level of airborne fungi. Furthermore, randomness does exist due to the inspection time and parents or guardian of children. So far, we have measured 454 homes, large sample sizes also could remediate this problem in some degree. As for the location of instrument, the middle part of children’s bedroom was usually chosen to be representative.

5. Conclusions

Concentrations of airborne fungi in most residences were lower than national standard concentration (2500 CFU/m³) in Shanghai. Concentrations of airborne fungi had significant differences in different seasons and in different districts. Building characteristics of residences (such as area of residences, construction period of residences, and floor of the children’s bedrooms) may be associated with indoor concentrations of airborne fungi.

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