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The Effects of Local Factors on the Concentrations and Flora of Viable Fungi in School Buildings

H. Salonen, E. Castagnoli, C. Vornanen-Winqvist, R. Mikkola, C. Duchaine, L. Morawska, J. Kurnitski

Abstract—A wide range of health effects among occupants are associated with the exposure to bioaerosols from fungal sources. Although the accurate role of these aerosols in causing the symptoms and diseases is poorly understood, the important effect of bioaerosol exposure on human health is well recognized. Thus, there is a need to determine all of the contributing factors related to the concentration of fungi in indoor air. In this study, we reviewed and summarized the different factors affecting the concentrations of viable fungi in school buildings. The literature research was conducted using Pubmed and Google Scholar. In addition, we searched the lists of references of selected articles. According to the literature, the main factors influencing the concentration of viable fungi in the school buildings are moisture damage in building structures, the season (temperature and humidity conditions), the type and rate of ventilation, the number and activities of occupants and diurnal variations. This study offers valuable information that can be used in the interpretation of the fungal analysis and to decrease microbial exposure by reducing known sources and/or contributing factors. However, more studies of different local factors contributing to the human microbial exposure in school buildings—as well as other type of buildings and different indoor environments—are needed.

Keywords—Fungi, concentration, indoor, school, contributing factor.

I. Introduction

MICROBIAL growth in buildings is common all over the world and has adverse health effects [1]-[6]; the association between elevated levels of fungi and symptoms related to microbial exposure is supported by the observation that the symptoms decrease after the exposure has been eliminated [7], [8]. However, the causal links between the exposing agents and disease are poorly understood [9], and there are no established health-based guidelines or standards related to fungal concentrations in indoor air [10].

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Despite the lack of knowledge about the causal links and dose–response relationship in microbial exposure and disease, air samples from indoor settings are commonly collected to assess human exposure to fungi and find hits of abnormal sources of microbes [11], [12]. Air samples are also collected for the detection and quantification of fungi if there are concerns about the abnormal presence of fungi in the absence of any visible mold growth (e.g., musty odor), to identify fungi release from sources, and to monitor the effectiveness of control measures [13]-[15].

Based on residential studies, statistical associations suggest that factors governing indoor bioaerosols include excess moisture, the presence of pets, occupancy patterns, geography, building ventilation, and building materials [16]. However, there are no studies available summarizing the factors that contribute significantly to fungal levels in the school environment. Thus, our goal was to summarize different local factors affecting viable fungi concentrations on those environments.

II. Materials and Methods

A PubMed and Google Scholar search of the literature published between 1995 and 2016 was performed. Altogether 20 search terms, such as “indoor”, “school”, “fungi”, “concentration”, and “contributing factor”, as well as different combinations of these terms were used. Original peer-reviewed journal articles, books, reports and conference papers were included in the search. We also searched the reference lists of the publications first identified in the literature search. The search for relevant literature was performed from August 2016 to October 2016. Altogether 103 abstracts were selected (based on the eligibility of their title), and 80 full publications were then read based on the eligibility of their abstracts. A search limitation was set for publications which were electronically available through Aalto University library subscriptions or as free downloads from the Internet. Following the reading of the articles, 59 publications were selected for the redaction of this review paper.

III. Results and Discussion

Table I summarizes the relationship between local environmental factors and the concentration of viable fungi in indoor air. The table illustrates that there is extremely strong scientific evidence to show that mold/moisture damage, the season (temperature, humidity), and the type and rate of ventilation affect the concentration of viable fungi in school buildings. Moreover, there is strong scientific evidence suggesting that activities of occupants, the presence of carpet, number (or density) of occupants, and diurnal variations affect the concentration of viable fungi in school buildings. In addition, there is scientific evidence that the age of the building, the building frame material, moisture-damage repairs, outdoor fungal concentration, sampling at different times of the day, and study location influence the measured viable fungi concentrations in the school buildings.

TABLE I
RELATIONSHIP BETWEEN LOCAL ENVIRONMENTAL FACTORS AND CONCENTRATIONS OF AIRBORNE FUNGI IN SCHOOL BUILDINGS

Environmental factors	Association with concentrations of viable fungi in indoor air	Reference
Activities of occupants	**	[17]-[22]
Age of the building	*	[23]
Building frame material	*	[24]
Existence of carpet/presence of carpeting	**	[19], [25]-[27]
Moisture-damage repairs	*	[28], [29]
Mold/Moisture damage; Visualized mildew/visible mold	***	[24], [28], [30]-[35]
Number of students/Density of occupants/existence of occupants	**	[17],[18],[36]-[38]
Outdoor fungal concentration	*	[23], [39]
Sampling at the different time of the day/diurnal variations	**	[21], [40], [41]
Season/Temperature/Humidity/Month of study	***	[17], [20], [23], [35], [38], [42]-[45]
Study location/study site	*	[17]
Type of ventilation/Indoor CO_2 concentration/Ventilation rate/air exchange rate	***	[18], [19], [23], [34], [38], [43], [45]-[48]

***Extremely strong scientific evidence was found (over six empirical studies from peer-reviewed journals and/or at least three systematic reviews, as reviewed herein) ** Strong scientific evidence was found (three to six empirical studies from peer-reviewed journals and/or at least three systematic reviews, as reviewed herein);* Scientific evidence was found (one or two empirical studies from peer-reviewed journals)

A. Mold and Moisture Damage

The effects of the mold/moisture damage on concentrations and on the flora of viable fungi in school buildings were discussed in seven journal papers [24], [28], [30]-[35]. In these articles, 87 school buildings were studied.

Studies from the continental climatic area (Finland) reported that during winter (while there was snow cover), the mean concentration of fungi in mold-damaged school buildings was significantly higher than the concentration of fungi in non-damaged buildings. In the continental climatic region, these differences between damaged and non-damaged buildings were more obvious in winter than during seasons with higher outdoor fungal concentrations [30].

It should be noted that differences between airborne indoor and outdoor fungal concentrations were not always observed, even in buildings with clearly visible fungal (mold) growth. Moreover, the effect of moisture damage on concentrations of fungi was clearly seen in buildings of concrete/brick construction but not wooden school buildings [30].

B. Season, Temperature, Humidity, and Month of Study

We found several studies [17], [20], [23], [35], [38], [42]-[45] reporting the effects of season, temperature, humidity, and/or month of the study on the measured concentration of viable fungi in indoor air. For example, [23] reported that the season affects significantly the fungal concentrations and the proportional representation of the fungal genera from the statistical point of view. In our previous study [44], we found that increasing both temperature and humidity resulted in higher levels of fungal concentration.

C. Type of Ventilation, Ventilation Rate, and Indoor CO_2-Concentration

We found several studies reporting the significant effect of the type of ventilation [23], [46]-[48] and ventilation rate [19], [34], as well as indoor CO_2-concentration [18], [38], [43], [45] on the concentration of indoor viable fungi. Lower concentrations of viable fungi were found in mechanically ventilated classrooms with lower CO_2 levels and humidity [18], [38], [43], [45].

In naturally ventilated school buildings, the measured mean concentrations of total viable fungi and the concentration of common species, such as *Penicillium* spp., were generally higher than the mean concentrations reported from those with mechanical ventilation in similar climatic areas [23], [46]-[47]. In the buildings with mechanical ventilation, the concentrations of microbial aerosols are lower than they are in buildings with natural ventilation due to the filtration of incoming air and the removal of particles derived from intramural sources via the exhaust air [48]. It has been reported that the effect of the ventilation system varied depending on the construction type. For example, [24] found that in wooden schools, concentrations were the highest in fully mechanically ventilated rooms, whereas in concrete schools, lower concentrations were associated with mechanical exhaust and the air supply. The ventilation rate has been also reported to affect the concentration of viable fungi [19], [34].

D. The Presence of Occupants, Density of Occupants, Number of Students, and Occupants' Activities

The indoor fungal concentrations have been reported to be significantly higher in schools with occupants than in those without occupants due to contamination by the occupants [37]. Madureira et al. [38] reported that the *Geotrichum sp.* prevalence indoors was positively correlated with the number of students (r_s = .259). Occupants' activities have been reported to increase bioaerosol concentrations directly, through the presence of students [17]-[18], as well as indirectly, through the resuspension of deposited bioparticles [18], [19].

E. The Presence of Carpet

The airborne concentration of culturable fungi has been reported to be significantly higher in carpeted classrooms/schools than in classrooms/schools with tile flooring [25]-[26]. Carpeting has been reported to be a significant factor affecting *Alternaria* [27] and *Aspergillus* concentrations [19]. However, there are also contrary findings suggesting no association between the presence of carpet and fungal concentrations [23]. The effect of carpet may depend on the carpet type; cut pile counterpart-carpet was found to retain less dust in its structure than loop-pile-type carpet [49].

F. Sampling at the Different Times of the Day and Diurnal Variations

Sampling at different times of the day affected the concentration and flora of viable fungi [40]-[41]. For example, the indoor concentration of *Cladosporium* spp. was reported to be consistently higher in the afternoon than in the morning.

G.Age of the Building

Bartlett et al. [23] reported that the age of the building is one of the variables that may explain the variation in the measured fungal concentration between buildings. However, in contrast,. [35] found mold in both new and older schools, and correlation between the school age and total mold was not found.

H.Building Frame Material

One study [24] reported on the effect of the building frame material on the concentrations of airborne viable fungi. In their study, the mean concentrations of viable fungi were significantly higher in wooden schools than in concrete ones. A concentration of viable fungi >100 cfu/m^3 was three times more frequent in wooden than in concrete schools, and the concentration >500 cfu/m^3 was found in 0.3% and 3% of samples in concrete and wooden schools, respectively.

I. Outdoor Fungal Concentration and Study Location/Study Site

It has been reported that outdoor fungal concentration [23], [39] and study location or study site affect the concentrations of airborne viable fungi in indoor air [17].

J. Moisture-Damage Repairs

Studies have shown that remedial actions to the school buildings resulted in the removal of interior fungal growth and a decreased fungal concentration compared with the situation before remedial actions [28], [29]. However, [28] reported that in partly renovated schools, the fungal diversity remained as high as before repairs.

The air tightness of the building, air conditioning systems, resuspension of dust, vacuuming frequency, frequency of floor and fan cleaning, and the age of carpets and building materials, as well as the presence of kitchens and bathrooms, may also influence the composition and concentration of indoor bioaerosols [4], [10], [50]-[59]. However, these factors were not studied in the published school studies reviewed in this study.

In addition to the local factors mentioned above, the measured concentration of fungi largely depends on the sampling and analytical methods used (e.g., selection of sampling device, total counts or cultivation, DNA analysis or culture media and incubation temperature) [4], [10].

A potential limitation of the present study is that the literature search was based on specific search terms and on the lists of references of the selected articles. Therefore, its content could be limited.

IV. Conclusion

This study found strong scientific evidence that some local factors, such as mold/moisture damage, the season, the type and rate of ventilation, and the presence of carpet, affect the concentration of viable fungi in school buildings. However, concerning the effects of some environmental factors the literature, findings are lacking or inconsistent; thus, additional studies on school buildings, as well as other building types, are needed. Although this review may be limited in content, it offers important information on the factors contributing to fungal levels in the indoor environment in school buildings and forms the basis for a wider literature search.

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