Building and Environment 122 (2017) 161–170

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Airborne fungal species associated with mouldy and non-mouldy buildings – effects of air change rates, humidity, and air velocity

Sofie M. Knudsen [a, b, *], Lars Gunnarsen [b], Anne Mette Madsen [a]

[a] National Research Centre for the Working Environment, Lersø Parkallé 105, 2100 Copenhagen Ø, Denmark
[b] National Danish Building Research Institute, Aalborg University, A. C. Meyers Vænge 15, 2450 Copenhagen SV, Denmark

ARTICLE INFO

Article history:
Received 23 March 2017
Received in revised form
6 June 2017
Accepted 7 June 2017
Available online 9 June 2017

Keywords:
Airborne fungal exposure
ERMI
Release rate
Air change rate
Species composition
Water damage

ABSTRACT

Several studies have shown an association between dampness and health issues like headache and asthma. To better understand the exposure risk of fungal growth in buildings this study investigates the release of fungi from gypsum boards infested with fungi from a moisture-damaged house. Further, the composition and concentration of fungal species in indoor air of five non-moisture-damaged homes are analysed, and the ratio between species associated- and not associated with moisture-damaged buildings are related to air change rate (ACR) and relative humidity (RH). The air velocity near the surface of the gypsum boards in combination with the changes in sampling time influenced the particle release rate. After 8 h particles were still released, and more species were released during 8 h with low air velocity than during 15 min with high air velocity. More fungal species and a higher release rate were found from damp surfaces with substantial growth than from gypsum boards dried out before they were totally colonized. In the five homes ACR and RH had a significant influence on the fungal species composition. Thus, a low ACR and a high RH were associated with increased ratio of species associated with moisture-damage relative to species not associated with moisture-damage. In conclusion, increasing the ventilation and reducing the RH of the indoor air will have a beneficial effect on the airborne species composition. Further, fast action by drying out a fungal infestation has a positive impact on the exposure risk in terms of exposure level and species composition.

1. Introduction

Several studies have shown association between dampness or visible fungal growth in buildings and health issues such as colds, fatigue, headache, concentration difficulties, and on a more severe level, asthmas and allergies [1–4]. To better understand the exposure risk of fungal growth in buildings, a fungal index, ERMI (Environmental Relative Mouldiness Index), has been developed based on fungi in homes in the US. The ERMI value is a ratio between common species associated with (Group1) and common species not associated with (Group 2) moisture-damaged buildings in the US [5]. Higher ERMI values have been found in homes of asthmatic children [6,7] and adults [8]. Likewise, a French study found a significant positive correlation between higher ERMI values and measures of fungal growth in buildings [9]. Air or surface dust samples are often used to identify the potential presence of fungal growth in a building, especially if it cannot be revealed by a visual inspection, e.g. if the fungal growth is located on a non-visible surfaces within the building structure [10]. Also the ERMI index is based on dust samples, and ERMI values are shown to correlate with measures of airborne fungi [11]. Recently, it has been shown that fungal species in the ERMI index are also common in airborne settled dust sampled by the electrostatic dust collector (EDC) in Danish homes [12], and concentrations of fungi sampled by the EDC correlates with fungal concentrations in airborne inhalable dust [13]. In some homes, indoor concentrations of fungi follow the outdoor concentration [14–16], which are affected by season and ventilation rate [14,16]. Several studies have found poor association between observed dampness and total fungal DNA on door frames [17] as well as between concentration of airborne fungi and visible fungal growth [10,14,18,19]. A reason for this might be the entrance of outdoor fungi contributing to what is released from the indoor infested surfaces. Identification of fungal species may help the understanding of factors affecting the occupants' exposure risk to airborne fungi.

* Corresponding author. National Research Centre for the Working Environment, Lersø Parkallé 105, 2100 Copenhagen Ø, Denmark.
E-mail address: smk@sbi.aau.dk (S.M. Knudsen).

http://dx.doi.org/10.1016/j.buildenv.2017.06.017
0360-1323/

Fungi need damp conditions and organic material to initiate growth and proliferate in buildings. Elevated moisture levels in building materials can occur for several reasons. One could be a water-damage from e.g. a leaking installation; another could be condensation of the room air on cold surfaces within the building. When elevated moisture levels in building materials are caused by condensation, the moisture level varies depending on the temperature and relative humidity (RH) [20], thus resulting in periods with varying conditions of dampness or dryness in the same area. This may have an influence on the fungal growth process [21] in the area, and thereby on the occupants' exposure risk. Many building materials contain organic substances, e.g. the cardboard sandwiching the gypsum in a gypsum board. Gypsum boards are commonly used in buildings for wall or ceiling constructions. Gypsum boards are sensitive to damp conditions in the indoor environment since they easily absorb water. Further, they contain cellulose which support fungal growth [22]. These might be the reasons that gypsum boards often have been used in investigations of fungal growth on building materials and spore release [23–27].

Most studies of fungal growth on building materials have used a monoculture known to grow in moisture-damaged buildings [23,25,27]. However, in buildings, both with and without moisture-damage, several fungal species are present in indoor air [5,28], thus both occupants and damp surfaces are exposed to several fungal species. This may be of importance for the fungal growth on building materials and the following release from infected surfaces. The release rate of fungal particles from fungal colonised gypsum boards depends on the species [27], the dampness of the surface [24], and the air velocity near the surface [12,25,27]. In buildings, the air velocity near surfaces varies. For example, visible surfaces in occupied rooms are often exposed to a larger air velocity than surfaces in non-ventilated and sealed construction cavities. Likewise, the air velocity near surfaces behind furniture or in corners will usually be lower than near free and open surfaces in the room. Most studies on the effect of air velocity on the fungal release from fungal infested surfaces are conducted over a short time spand of 1–5 min [12,24–26]. However, most occupants spend up to 60–90% of their time indoors [29], resulting in a considerable longer exposure time. To better understand the occupant's exposure risk to airborne fungi it is therefore important to gain knowledge on the effect on long-term release of airborne fungi in buildings.

The aim of this study was to gain knowledge on the exposure risk of airborne fungal species associated- and not associated with water-damage. We have investigated the exposure risk from a fungal infested surface, by laboratory simulation of a water-damage leading to fungal growth on gypsum boards. To make it as representative as possible, the gypsum boards were inoculated with a mixture of fungal species sampled in a moisture-damaged house. The effect of reducing the moisture level in the infested gypsum boards was studied as well as the effect of varying sampling time and the air velocity near the surfaces. Further, the species composition of airborne fungi in five non-moisture-damaged homes were analysed against the ERMI index, and the effect of air change rate (ACR) and RH was studied.

2. Method

2.1. Design of the fungal release study

Investigation of the aerosols from the infested gypsum boards included four scenarios of both measurements of particles and sampling of fungal spores (Table 1). Three repetitions for each scenario were prepared. Further, surface scrapings and contact plates were each conducted on a total of 6 damp and 6 dry surfaces.

Table 1
Release scenarios with fungal release from damp and dry gypsum boards. Three repetitions for each scenario were prepared, and both sampling time and air velocity was varied to insure that the infested gypsum boards were affected by the same air volume across the four scenarios.

Scenarios	Description of scenarios
1	APS measurements and GSP sampling at 2.5 m/s for 15 min over damp surfaces
2	APS measurements and GSP sampling at 9.0 m/s for 8 h over damp surfaces
3	APS measurements and GSP sampling at 2.5 m/s for 15 min over dry surfaces
4	APS measurements and GSP sampling at 9.0 m/s for 8 h over dry surfaces

APS = Aerodynamic Particle Sizer, GSP = GesamtStaubProbenahme.

Air velocity and sampling time is varied simultaneously to ensure that the infested gypsum boards were affected by an equal air volume across the scenarios (Table 1, scenario 1–4).

The scenarios were conducted in series, leaving a rather significant time gap in between them, where growth was allowed to continue on the boards referred to as boards with damp surfaces (Figure 1). The damp and dry surfaces did therefore not have equivalent growth. The GSP (GesamtStaubProbenahme) sampling was conducted firstly, the APS (Aerodynamic Particle Sizer) measurements secondly, the surface scrapings thirdly, and lastly the contact plates (Figure 1). The sampling by GSP and measurements with the APS were conducted to on different surfaces. Likewise, the scrapings and contact plate samplings were conducted on different surfaces. Particle concentrations were used as measure of the release of fungal aerosols, as it was assumed that fungal particle was the primary aerosols released from the infested gypsum boards.

2.2. Sampling of fungi from moisture-damaged house

The EDC was used for sampling of wild flora fungi in a moisture-damaged house. The sampling was conducted over a two-week period in October 2014 and two EDCs were placed in different rooms of the house. The EDC consisted of four electrostatic cloths (Zeeman Alphen, Netherlands) with an exposure area of 0.0209 m^2 each (11 × 19 cm). In the laboratory, the dust on the EDC cloths was extracted in 20 ml extraction liquid (0.05% Tween20 solution) (SIGMA-ALDRICH, USA) by shaking at 300 rpm for 1 h.

2.3. Sampling of fungi in non-moisture-damaged homes

The species composition of dust sampled by EDCs from five non-water-damaged homes for each season: summer, autumn, winter, and spring, was analysed. The homes were labelled A-E, and out of the five homes there were three detached houses (A, B and D), one town house (C), and one apartment (E). All samples were taken in the living room of the homes. Home E was the only home with mechanical ventilation. The ACR of all five homes were measured using the constant concentration method. The results and a detailed description of the ACR measurements can be found in Frankel et al. [16]. Likewise, the RH was measured in all five homes using a TinyTag Plus Data Loggers (Gemini Data Loggers, UK) [16].

2.4. Inoculation on gypsum boards

Sterilised gypsum boards were moisturised in a sealed and sterilised environment before inoculation with fungi from the EDC sampling of the moisture-damaged house (Figure 2).

To simulate the situation of a water-damage in a building,