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Review

Influence of everyday activities and presence of people in common indoor environments on exposure to airborne fungi

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Abstract: In the indoor environment, occupants are exposed to airborne fungi which may cause adverse health effects. The aim of this study has been to collect and provide an overview of the available knowledge on exposure to fungi in connection with everyday domestic activities to be able to advice sensitized people and to facilitate better measurement of exposure levels. The everyday activities include e.g. bed making, walking, vacuuming, and occupancy. Pre-activity exposure levels to airborne fungi ranged between 10 to 1700 cfu/m^3. In response to activity, exposure to fungi ranged from 15 to ≥31,000 cfu/m^3. The levels of fungal exposure seem to decrease to background levels within app. 30–90 minutes after ceasing an activity. Activities in general cause an increase in exposure levels to fungi, and should be accounted for when correlating exposure levels with health effects. Activities with marked increases in exposure levels were bringing firewood into the house, removing mouldy bread and bed making. Dominant fungal genera found before an activity were often also dominant during an activity, but during an activity other genera were sometimes also found. In most studies fungal species were not identified. The resuspension of fungal spores from floor surfaces as a result of walking depends on the spore load on the floor. The activity induced exposure level is affected by the general exposure in a room, and factors reducing the general exposure may also reduce the activity induced exposure level. Only few studies have investigated the influence of everyday activities on fungal exposure in the home, and, additional research is required to enhance the results of activities already investigated and to describe other everyday and seasonal-related activities in homes.

Keywords: Allergy; mould; fungi; indoor; airborne; environmental monitoring; vacuuming; bed making; walking; exposure

1. Introduction

A growing part of the world population suffers from asthma and allergic rhinitis [1]. The epidemiological evidence of the association between mould exposure, damp indoor environments, and the development and exacerbation of asthma has been strengthened in recent years [2,3]. At the same time, exposure in early life to a highly diverse fungal flora or yeast seems to protect against wheeze and the development of asthma [4,5]. It has been hypothesised that asthma may comprise of different endotypes with different aetiologies and environmental associations [6,7]. This might be one explanation for the often conflicting results when correlating exposure with health effects.

In people sensitised to fungi, allergy symptoms are caused by fungal exposure [2,8-10], and elevated concentrations of a specific species as *Aspergillus niger* has been found in dust in homes of asthmatic children [11] while *A. ochraceus*, *A. unguis*, and *Penicillium variabile* in home dust have been associated with childhood asthma [12]. The advice for allergy patients is to avoid allergens to minimize exposure [10,13,14]. The advocated guidelines on how to avoid exposure have changed little over the last 30 years [14]. These guidelines are partly based on the experience clinicians have gained regarding the effect cessation of exposure has on symptoms [13] combined with a "common sense" approach [10] where for example having indoor plants is discouraged [15].

The clinical effect of avoidance measures in homes is inconclusive, and doesn't take into account when and where people are exposed to allergens during the entirety of a day, and how activities contribute to the level of exposure [13,14]. Exposure to fungi can occur through inhalation, ingestion, or skin contact. For respiratory symptoms, inhalation represents the main exposure route [16]. Transportation of fungal spores from infested or contaminated surfaces into the air is crucial for exposure of the airways to occur. Aerosolisation of fungal spores can be driven by an active mechanism, where energy is provided by the fungus itself [17], or by passive mechanisms such as air currents and vibration [18-22]. In occupational settings, bioaerosol exposure can increase to high levels during activities such as e.g. grain handling on farms [23], sweeping at a bee overwintering site [24], walking in a greenhouse [25], high pressure cleaning at a sewage treatment plant [26], and vacuum cleaning at a biofuel plant [27]. The home is a place where different activities, including work activities occur; during these activities settled fungal spores are expected to be re-aerosolised.

Exposure to fungi may cause allergy and asthma symptoms in people sensitised to fungi and is implicated in the aetiology of asthma and atopy [2,3,28]. In studies measuring fungal background levels in complaint vs. non-complaint homes, the activities of residents during measurement are rarely mentioned. In this study, we have collected and listed the available knowledge on exposure to fungi in connection with everyday domestic activities. To the best of our knowledge, no comprehensive overview exists that has investigated the effect of performing e.g. household chores on the exposure level of airborne fungi. Such an overview can aid when advising allergic people. Furthermore, it may be useful when studying associations between exposure and related health effects.

2. Methods

Literature searches were performed with the databases PubMed and Google Scholar from December 2013 to October 2015. The following search terms were used: air microbiology, air

sampling, indoor analysis, indoor air, environmental monitoring, fungi or mould, spores, activity, domestic activity, sweeping, vacuuming, dusting, cleaning, walking, bed making, residence and humans. In addition, references found in the papers were followed.

3. Results and discussion

3.1. Vacuuming and levels of airborne fungi

Most of the studies looking into the effect of vacuuming found an increase in fungal levels (Table 1). The spike in airborne fungi decreased again within 60 to 90 minutes, although the level was still slightly elevated compared to before vacuuming in four out of five trials (Table 1). A trial that did not find a change in spore level used a vacuum cleaner with exhaust filter [31]. The exhaust of some vacuum cleaners emits mould [35]. Hence the increase in fungal levels can be due to vacuuming activity and/or the exhaust from the vacuum cleaner itself. Similar some vacuum cleaners and bags generate airborne dust mite allergen during vacuuming while some with HEPA-filters do not [36]. Thus, the use of a vacuum cleaner with exhaust filter might explain why the level did not change markedly in the study of Lehtonen et al. 1993 [31]. The other studies did not state the details of the vacuum cleaner used.

3.2. Bed making, sweeping and wet mopping

Only two studies have investigated the effect of handling bedclothes on the levels of airborne fungi, and both studies showed an increase during the activity (Table 2). In homes where fungal levels were monitored at different points of time after an activity, the exposure did not reach normal levels within 30 to 60 minutes after the activity.

In a study investigating sweeping an increase in fungal levels in one of two homes was seen (Table 3). After termination of sweeping the fungal level decreased over time, but did not reach normal level within 30–60 minutes. In an experimental room the fungal levels increased 179-fold during wet mopping, which caused the Andersen sampler to overload (Table 3).

Even though cleaning is a common task in the home only few studies have focused on fungal exposure during cleaning activities in the home. Domestic and professional cleaning has been associated with work related asthma. The main cause is thought to be exposure to cleaning agents [37]. In a study with asthmatic female homemakers symptoms from the lower respiratory tract were associated with cleaning work. However, the symptoms correlated neither with time spent on cleaning, nor a chemical severity exposure index [38]. Furthermore, an investigation of women with occupational asthma working with professional cleaning showed that asthma was caused by chemicals in 45% of the cases. However, in 55% of the cases the development was caused by fungi with *A. fumigatus* being the primary fungus responsible [39]. Thus indeed it is relevant to reduce the fungal exposure caused by cleaning work; to be able to do this, it is important to identify sub-tasks responsible for the exposure to fungi. Furthermore, asthmatics and persons with allergy to fungi should be aware of the relatively long time fungal levels are increased post cleaning.

Table 1. Effect of vacuuming on levels of airborne fungi.

Environment	Number of trials	Bioaerosol investigated	Sampling method	Sampling height	Before cfu/m^3	During cfu/m^3	After cfu/m^3		Study
Living room, carpets, two dwellings, Great Britain	NM	Fungi	STA	37 cm	600	6830	90 min.: 35		[29]
					88	1520	65 min.: 265		
Bedroom carpets in dwelling A,B, Great Britain	NM	Fungi	STA	37 cm	A) 129	694	90 min.: 224		[29]
					B) 88	388	65 min.: 141		
Living room, Finland	1	Fungi	STA	1 m			10–15 min.	30–60 min.	[30]
					190	160	190	260	
Vacuum, exhaust air filter, living room, Finland	1	Fungi	STA	1 m	No marked change in spore concentration				[31]
Experimental room loaded with aerosolized spores (10^5 spores/m^3) nylon pile carpet	5	*Penicillium chrysogenum* Size 1.8–3.5 µm	STA, Burkard, Surface Air sampler	0.3 m and 1 m	Significant increase in spore concentration				[32]
Experimental room (10^7cfu/m^2), loop pile carpet	1	*P. chrysogenum* Size 1.8–3.5 µm	Andersen, BS	Floor level and 1.5 m	1 NM	17-fold increase	-		[33]
Experimental room (10^7 cfu/m^2), cut pile carpet	1	*P. chrysogenum* Size 1.8–3.5 µm	Andersen, BS	Floor level and 1.5 m	1 NM	2-fold increase	-		[33]
Hall way in an old country house, UK	1	*Aspergillus* and *Penicillium*	24	1.39 m	App. 20 spores/m^3	App. 120 spores/m^3	App. 1 hour App. 80 spores/m^3		[34]

App. = approximately, cfu = colony forming unit, NM = not mentioned, min. = minutes, STA = Six stage Andersen sampler, 24 = 24 hour continuous recording volumetric sampler, BS = Burkard personal sampler.

Table 2. Effect of bed making i.e. puffing up, fitting, or changing sheets and linen on levels of airborne fungi.

Environment	Number of trials	Sampling method	Sampling height	Before cfu/m^3	During cfu/m^3	After cfu/m^3		Study
Homes: A,B,C, Finland	1	STA	1 m			10–15 min.	30–60 min.	[30,31]
				A) 320	520	860	1100	
				B) 1100	1400	1100	-	
				C) 1700	5500	2600	2100	
4-room flat, Singapore	Three in duplicates	STA	1 m	Total fungi 265	Total fungi 1897	-		[40]

Cfu = colony forming unit, min. = minutes, STA = Six stage Andersen sampler.

Table 3. Effect of sweeping and wet mopping on levels of airborne fungi.

Environment	Number of trials	Bioaerosol investigated	Sampling method	Sampling height	Before cfu/m^3	During cfu/m^3	After cfu/m^3		Study
Sweeping, homes: A and B, Finland	1	Fungi	STA	1 m			10–15 min.	30–60 min.	[30,31]
					A) 40	290	150	110	
					B) 20	15	25	25	
Wet mopping, vinyl floor, loaded with 10^7 cfu/m^2 *P. chrysogenum*	1	*P. chrysogenum*	OSA, BS	Floor level, 1 and 1.5 m	-	OAS: ≥179-fold increase; BS: 40-fold increase			[33]

BS = Burkard personal sampler, cfu = colony forming unit, min. = minutes, OSA = one stage Andersen sampler, STA = six stage Andersen sampler.

3.3. Various activities

Several activities, such as baking, handling plants, removing mouldy food, preparing potatoes, and bringing firewood into the home were investigated in two Finnish studies [30,31] (Table 4). They found marked increases in the levels of airborne fungi with the handling of firewood resulting in up to 26,000 cfu/m^3 and removing mouldy bread resulting in over 31,000 cfu/m^3. Preparing potatoes and removing mouldy jam caused increase in fungal levels too, though less than the other activities. Baking or handling house plants did not result in marked increases.

Another study investigating the handling of house plants in several homes, found a significant, but marginal increase in fungal levels [15] (Table 4). Different fungal species have been found on soil surfaces of ornamental plants in hospitals [41,42], however these fungal species had very little resemblance at genus and species level to fungi found in the air [42]; thus soil-borne fungi seem not to contribute to the indoor airborne fungi. For preparing potatoes and removing mouldy jam, the fungal levels decreased to normal level within 30–60 minutes, while the levels were still highly elevated for bringing in firewood and removing mouldy bread 30–60 minutes after the activity.

3.4. Walking

The effect of walking on concentrations of airborne fungi seems not to have been investigated in residential buildings, but we have found studies that investigated the effect of walking in two public buildings and in experimental rooms (Table 5). In the public buildings, a hospital and a library, peak traffic was associated with a significant increase in the genus *Aspergillus*. During ordinary foot traffic *Aspergillus* levels were only significantly increased in the hospital [43]. However, in a controlled experiment, with normal walking in a library, a significant increase in *Aspergillus* level was also found [43].

It is difficult to standardize an activity as walking, and an instrument has been developed for resuspension of dust from carpets as affected by a falling weight [44]. Resuspension of fungal spores as a result of walking has been studied in an experimental room fitted with nylon carpet and fungal spores. The fungal spore concentration influenced the increase in aerosolisation. When the room was loaded with 10^5 spores/m^3 of *P. chrysogenum*, which were allowed to settle before measuring, the concentration of aerosolised fungal spores was significantly affected by walking. However, when loaded with 10^4 spores/m^3 only two (Surface Air sampler and Burkard sampler) of four samplers found significant increases in airborne spore concentration during walking [32] (Table 5).

Another investigation looking at walking in an experimental room compared the effect of different flooring materials on the levels of aerosolised *P. chrysogenum* [33] (Table 5). The flooring material affected the re-aerosolisation of settled fungi for both levels of spore contaminations (10^6 and 10^7 spores/m^2). For cut pile carpeting, the resuspension was significantly higher than for both vinyl floor and loop pile carpeting. With a spore load of 10^7 spores/m^2, the concentration of airborne spores was significantly higher for the loop pile carpet than for the vinyl floor as measured with the Burkard sampler [33]. For all floor types and both spore loads the measurements of the Burkard sampler were significantly higher than the Andersen sampler's [33]. Both studies investigating walking in experimental rooms found a significantly higher resuspension of spores with higher spore load [32,33].

Table 4. Effect of various activities on level of airborne fungi as measured using Six Stage Andersen sampler.

Environment	Activity	Number of trials	Sampling height	Before cfu/m^3	During cfu/m^3	After cfu/m^3		Study
						10–15 min.	30–60 min.	
11 homes, USA	Watering house plants or airflow on plants	Each home at least once	NM	Significant, but marginal increase for fungi				[15]
One home, Finland	Handling plants	1	1 m	80	120	100	150	[30]
Two homes A,B, Finland	Baking	Once per home	1 m	A) 380	410	510	700	[30]
				B) 120	110	110	-	
Two homes, Finland	Baking	Once per home	1 m	No notable increase				[31]
Two homes A,B, Finland	Washing and peeling potatoes	Once per home	1 m	A) 160	570	160	140	[30,31]
				B) 50	160	110	60	
One home, Finland	Handling plants	1	1 m	Fungal spores ranged between 70 and 150; there were no marked changes				[31]
One home, Finland	Removing moldy bread	1	1 m	60	>31,000	-	>12,000	[30,31]
One home, Finland	Removing moldy jam	1	1 m	190	310	220	150	[30,31]
One home, Finland	Bringing firewood into the house	1	1 m	310	26,000	13,000	11,000	[31]

App. = approximately, cfu = colony forming unit, NM = not mentioned, min. = minute

Table 5. Effect of walking and foot traffic on levels of airborne fungi.

Environment	Number of trials	Bioaerosol investigated	Sampling method	Sampling height	Before	During	Study
Room loaded with aerosolized spores (10^4 /m^3)	5	*P. chrysogenum*	STA	-	-	No significant increase	[32]
			SAS, BS			Significant increase	
Floor: nylon pile carpet			Depositional	0.3, 1.0, 1.5 m	11 cfu/m^2	79 cfu/m^2, not significant	
Room loaded with aerosolized spores (10^5 /m^3)	5	*P. chrysogenum*	STA, SAS, BS	-	-	Significant increase with all samplers	[32]
Floor: nylon pile carpet			Depositional	0.3, 1.0, 1.5 m	22 cfu/m^2	111 cfu/m^2, significant	
Room loaded with aerosolized spores	Triplicates	10^6 *P. chrysogenum* cfu/m^2 floor	OSA, BS	Floor level, 1 and 1.5 m	-		[33]
Floor: loop pile carpet						0.00015%–0.00009% of spores aerosolized	
Floor: cut pile carpet						0.39%–0.076% of spores aerosolized	
Floor: vinyl flooring						0.004%–<0.0008% of spores aerosolized	
Room loaded with aerosolized spores	Triplicate	10^7 *P. chrysogenum* cfu/m^2 floor	OSA, BS	Floor level, 1 and 1.5 m			[33]
Floor: loop pile carpet					0.0043%–0.0011% of spores aerosolized		
Floor: cut pile carpet					≥0.37%–0.22% of spores aerosolized		
Floor: vinyl flooring					0.0043%–0.0007% of spores aerosolized		
Hospital and library hallway + controlled walking experiment, USA	2 at hospital and 3 at a library	*Aspergillus* qPCR	Cyclone	0.7 m	Significant effect at the hospital and library for peak foot traffic, but not for all foot traffic in the library. Significant resuspension in the controlled experiment		[43]

App. = approximately, BS = Burkard sampler, cfu = colony forming unit, min. = minutes, qPCR = quantitative polymerase chain reaction, SAS = Surface air sampler, STA = Six stage Andersen sampler, OSA = One stage Andersen sampler.

Table 6. Effect of people and transformed activity measure on levels of airborne fungi and (1→3)-β-D-glucan in homes.

Environment	Activity	Number of trials	Bioaerosol investigated	Sampling method	Sampling height	Exposure: activity level and emission			Study
						Before cfu/m^3	During cfu/m^3	After cfu/m^3	
2 flats, 3 rooms, Japan	Family dinner	3	Fungi	Reuter centrifugal air sampler	1 m	App. 100	App. 200	6 hours App. 100	[47]
Nine family groups of four, Australia	Low activity e.g. reading. Moderate activity: e.g. cleaning	36 subjects, 4 days	*Alternaria, Cladosporium*	Nasal air sampler, Personal air sampler	Different	Higher number of spores measured during moderate activity than during low activity			[48]
Two person household flat, Italy	Presence and absence of people and furnishing in rooms	5	Fungi	Surface Air system	1.2–1.5 m	102–132	147–297*	-	[49]
Dining room, suburban house, UK	Person entering the room	1	*Aspergillus, Penicillium*	24	1.29 m	App. 15 spores/m^3	App. 100 spores/m^3	App. 1 hour App. 8 spores/m^3	[34]
Hall way, country house, UK	Household getting ready for bed	1	*Aspergillus, Penicillium*	24	1.39 m	App. 60 spores/m^3	App. 940 spores/m^3	-	[34]
Hall way, country house, UK	Postman and dog entering hall	1	*Aspergillus, Penicillium*	24	1.39 m	App. 10 spores/m^3	App. 120 spores/m^3	App. 1 hour 70 spores/m^3	[34]
10 homes, California, USA	Number of people, type and length of activity transformed to activity strength	1	(1→3)-β-D-glucan	Cyclone	1.20 m	Significant correlation between activity strength and $PM_{10–2.5}$ and (1→3)-β-D- glucan during the daytime.			[45]
10 homes, Denmark	Presence versus absence of people	1during 12-15 days	Fungi	EDC	1.60 m	BD-1495 cfu/m^2/day	299–10696 cfu/m^2/ day	-	[50]

App. = approximately, BD = below detection limit, cfu = colony forming unit, PM = particulate matter size fraction in µm, 24 = 24-hour continuous recording volumetric sampler, EDC= Electrostatic Dust Fall Collectors * = difference significant in the bedroom and living room, but not the kitchen and bathroom.

Table 7. Effect of people and transformed activity measure on levels of airborne fungi in public buildings.

Environment	Activity	Number of trials	Sampling method	Sampling height	Exposure as activity level and emission			Study
					Before cfu/m^3	During cfu/m^3	After cfu/m^3	
Several rooms and spaces in a middle school, USA	Activity and number of people monitored every 5 min. and transformed to emission factors	3 days	STA	1.1 m	Calculated emission factors in cfu/hr/person-min: total fungi 167, thermophilic fungi 36, mesophilic fungi 119, *Penicillium* 161			[51]
Public building office, Italy	Empty or up to 4 people present	5	Surface Air system	1.2–1.5 m	224	858▲	-	[49]
University auditorium, Italy	Empty or app. 180 people present	5	Surface Air system	1.2–1.5 m	301–431	1256–1769▲	-	[49]
University hallway, Switzerland	Opening doors and students present. Before and after lectures	3 days with 1 and or 3 samples	Mas-100-eco impaction sampler	1.2 m	Amount of fungi is associated with activity			[52]
University classroom, USA	Empty versus on average 4.7 people present	1	8-stage non-viable impactor	NM	Calculated emission rate per person-hour of 7.3×10^6 genome copies for total particle mass for fungi			[53]
Schools China, USA, Germany, Denmark	Empty or people present	1	STA, qPCR	NM	Calculated average emission rate of 14×10^6 spore equivalent/person/h for fungi			[54]
Schools China, USA, Germany, Denmark	Empty or people present	1	Andersen sampler, qPCR	NM	Higher spore equivalents/m^3 for occupied versus vacant rooms. Occupancy enriched airborne allergenic fungi concentration			[55]

App. = approximately, BD = below detection limit, cfu = colony forming unit, NM = not mentioned, ▲ = difference significant, qPCR = quantitative polymerase chain reaction, STA=Six stage Andersen.

As opposed to walking, the aerosolisation of *P. chrysogenum* during vacuuming was higher for loop pile carpet than for cut pile carpet (Table 1 and 5). Hence the apparently same surfaces seem to affect resuspension of *P. chrysogenum* spores differently with different activities.

3.5. Occupancy and transformed activity measure

The effect of people present or of the number of people present and their activity transformed to e.g. person-hour or activity strength has been investigated both in homes (Table 6) and public buildings (Table 7). Except for one study in ten Californian homes [45], studies have found positive association between the observed measure and levels of airborne fungi. The Californian study did not find the number of people present to have an effect on (1→3)-β-D-glucan in any of the size ranges investigated. However, a correlation was found between (1→3)-β-D-glucan in the size range of $PM_{2.5–10}$ and self-estimated occupancy.

The studies presented in Tables 6 and 7 together show that the presence of people affects the concentration of airborne fungi considerably, but how much people themselves, their activities, or the materials they handled were sources of exposure were not parts of these studies. It is known that common indoor fungi as *Cladsoporium* spp. and *Penicillium* spp. are often present on human skin [46].

3.6. Fungal flora and activity

In Finnish homes the predominant genus before activities was *Penicillium*. Other prevalent genera and fungal groups were *Cladosporium*, sterile mycelia, other fungi, and *Aspergillus* [31]. For the activities removing mouldy bread and jam, washing and peeling potatoes, bed making, sweeping and bringing in birch firewood, an increase was seen for *Penicillium* [31]. When sweeping or preparing potatoes, an increase was seen for sterile mycelia. Bed making caused an increase for *Aspergillus*, while preparing potatoes caused an increase in *Cladosporium* [31]. *Aspergillus* appeared when a person entered the house; the group 'other fungi' appeared during preparation of potatoes [31].

Airborne *Cladosporium* and or *Penicillium* also increased as an effect of vacuum cleaning [29] and from disturbances of house plants [15]. These fungal genera were also predominant without these activities. However, using fungal spore morphology for identification, the fungal genera found to be predominant were *Alternaria*, *Periconia*, and *Epicoccum* with an increase in *Alternaria* during disturbance of plants [15].

The effect of people and their different activities on the airborne fungal flora has been investigated in indoor environments in Italy [49] and in Japan [47]. In Italy, in the absence of people, the predominant airborne fungal genera were *Penicillium* and *Aspergillus*. With people present in an auditorium: *Penicillium*, *Aspergillus*, *Curvularia*, and *Cladosporium* were found; in an office with people: *Penicillium*, *Cladosporium*, *Mucor* and *Absidia* were found; and in a flat with people: *Penicillium*, *Cladosporium*, *Alternaria* and *Absidia* were found [49].

In the early morning in a Japanese flat, the predominant genera of airborne fungi were in descending order *Cladosporium*, the *Aspergillus restrictus* Group, *Penicillium* and sterile mycelia [47]. During activities related to a family dinner, the greatest increases in levels of airborne

fungi were seen for the *Aspergillus restrictus* Group, *Wallemia sebi*, *Penicillium*, and *Cladosporium* [47].

In general, the genus of airborne fungi most frequently identified before and during an activity was *Penicillium*. Other prevalent genera were *Cladosporium*, *Aspergillus* and *Alternaria*, though also less common genera as *Periconia* and *Epicoccum*, as well as sterile mycelia, and other fungi could be found before an activity. It is noteworthy that fungi, which were not found or were less prevalent before an activity, increased or appeared during the activity. This included *W. sebi* [47], *Aspergillus* and sterile mycelia [31], and *Cladosporium*, *Curvularia*, *Alternaria*, *Mucor* and *Absidia* [49].

It is interesting that increases in response to activity were seen particularly for *Penicillium*, *Cladosporium*, *Alternaria*, *W. sebi*, and *Aspergillus*. These genera contain known allergenic species that can exacerbate allergy and asthma symptoms in sensitised individuals [28,56,57]. A meta-analysis of longitudinal studies looked at the association of mainly airborne exposure to the genera *Penicillium*, *Cladosporium*, *Alternaria*, and *Aspergillus* and asthma symptoms [58]. They found that increased exposure to these genera was associated with exacerbation of current asthma in both adults and children. Association with specific species could not be assessed, since fungi were only identified to genera level [58]. The status of fungal allergy in the tested subjects in the meta-analysis was not stated [58]. At species level it has been shown that exposure to floor dust with *A. ochraceus*, *A. unguis*, or *P. variabile* increase the risk of asthma at age 7 [59]. Exposure to floor dust with *C. herbarum*, *A. alternata* and *P. chrysogenum* in infancy did not predict the risk of asthma [59]. However, the fungal species *C. herbarum*, *A. alternata* and *P. chrysogenum* are those routinely tested for in clinical diagnosis of fungal allergy [28]. For indoor surface dust the rank order and genera composition differs from indoor air [60-62]. Thus, older children and adults may be exposed to different fungal genera and species due to height differences.

Every choice of sampling and identification methods is a compromise, and different methods have different limitations [60,63,64]. Identification of sampled indoor airborne fungi has mainly earlier been performed with methods only detecting cultivable fungi [64], and these methods exclude identification of non-cultivable fungi as obligate parasites [28;60;64]. In most studies in this paper Malt Extract [31,33,49,51] and DG18 [47,50] agar have been used for quantification of fungi by cultivation. These agars may be good choices as they allow growth of different species; however xerophilic species may be underestimated. The present study shows that studies on effects of indoor activities on fungal exposure generally haven't identified fungi to species level. Studies from 1979 to 1999, mainly using microscopy for identification, show that *Cladosporium*, *Alternaria*, *Aspergillus*, and *Penicillium* are genera commonly predominant in indoor air in homes [29,60,61,65,66]. Also studies using newer identification methods as PCR (quantitative polymerase chain reaction)-based methods find the same genera in indoor air in homes [46,55]. However, indoor fungal composition and rank order differ between geographical regions [55,67] and seasons, and other fungi as *Ulocladium*, yeasts, *Sistotrema brinkmanii*, and non-sporulating moulds can also be predominant [29,60,61,66].

3.7. Comparisons with common fungal levels

The majority of the studies reviewed in this paper were conducted in buildings not described to have problems with mould damage. However, one study was performed in a home with mould growth in a cellar and opening of the cellar door resulted in a marked increase in the concentration of

Penicillium spores in the entrance hall [31]. Generally, the fungal background exposure level before activity ranged between app. 10 to 1700 cfu/m^3 (Table 1 to 7) with an average of 265 cfu/m^3 in residential buildings. This is in the lower end of the range of 17–9100 cfu/m^3 (average 1252 cfu/m^3) found in a review by Gots et al. 2003 [68] for non-complaint residential buildings in different seasons and climates.

Residential and outdoor fungal levels vary widely depending, amongst other things, on season, time of day, climate, and geographic location [2,61,68-70]. Furthermore, differences between samplers also affect the measured level and genera found [2,15,32,33,71]. Indeed, there is no agreement for standardised methods to study exposure levels [2]. Thus, background exposure levels from different studies are not directly comparable, making it difficult to correlate adverse health effects with an exposure level. However, measurements before and during activities may reveal the contribution of an activity to the exposure level. The increase in exposure during some activities as e.g. bed making is expected not only to depend on the activity but also on the amount of spores present on the affected material. The exposure levels during and or directly after an activity range from 15 to over 31,000 cfu/m^3 (Table 1 to 7) with an average of 3800 cfu/m^3. If the exposures from mouldy bread and bringing in firewood were excluded (Table 4), the exposure level averaged only 1046 cfu/m^3. In some occupational settings higher exposure levels are often found; thus exposures of 2200–13,931 cfu/m^3 have been found for sweeping in an overwintering beekeeping facility (average 6142 cfu/m^3) [24], 9000 cfu/m^3 for walking in a greenhouse [25], and 1.3×10^6 cfu/m^3 *Aspergillus fumigatus* for cleaning a wood chip pit [72]. Even though exposure levels during indoor activities are lower there is a clear increase in exposure level in response to most indoor activities compared to backgrounds levels. During the measurement or in the following evaluation of measured indoor concentrations of airborne fungi activities in the home should be considered.

Increased levels of *Cladosporium*, *Alternaria*, *Aspergillus*, and *Penicillium* species have been associated with exacerbation of asthma [58], but the size of the increased exposure level was not mentioned. The concentration of fungal propagules that cause symptoms varies between patients sensitized to fungi [73,74]. For *Alternaria* and *Cladosporium* outdoor spore level thresholds of 100 spores/m^3 and 3000 spores/m^3, respectively, have been cited in literature [16,64,74,75]. At these levels every patient with allergy to those fungi is supposed to develop allergy symptoms [74]. For *Penicillium*, 10^4–5×10^7 inhaled spores have elicited asthma in sensitized patients with mild asthma [73]. Individual genus levels were found for *Penicillium* with app. 24,000 cfu/m^3 for bringing in fire wood, 31,000 cfu/m^3 for removing mouldy bread, 782–4800 cfu/m^3 for changing sheets, 124 cfu/m^3 for preparing potatoes, 160 cfu/m^3 for sweeping [31], and 46–77 cfu/m^3 for dinner activities [47]. Levels for bringing in fire wood and removing mouldy bread reached levels that elicited symptoms in some asthma patients. For *Cladosporium* levels of approximately 285 cfu/m^3 for preparing potatoes [31] and 77–131 cfu/m^3 for dinner activity were seen [47]. These levels did not reach the threshold level reported for *Cladosporium*.

3.8. Factors influencing exposure levels of airborne fungi

In the studies conducted in the experimental rooms, the resuspension of *P. chrysogenum* was dependent on the concentration of spores on the floors [32,33]. Similarly, genera found in the air before an activity often increased during an activity. Hence, it is important to know what affects fungal exposure levels in homes. Fungi enter the home from outdoors through openings and

ventilation, and the indoor levels follow the natural variation of fungi outdoors [56,68,70,76]. Thus, indoor fungal levels are associated with air exchange rates [68,70], unless there is e.g. indoor fungal growth [31,76,77]. Indeed, the fungal levels were generally higher in a leaky country house than in a better insulated suburban house [34]. Depending on the climate, the usual indoor/outdoor ratio is below 1 [34,43,51,56,68,70,76]. In temperate climates, fungal levels are highest in the summer and fall, and lowest in winter, when indoor concentration can become higher than outdoors [29,64,70]. Thus, in the wintertime it seems to be possible to decrease fungal levels indoor by ventilation [2,31,78].

Fungi need oxygen, source of nutrition, suitable temperature, and water for growth [2,57,64]. Indoor temperature, oxygen and nutrition are usually not critically limiting factors, making water the most critical requirement [2,57]. A WHO report found that exposure to damp indoor environments is associated with adverse health effects and asthma [2].Thus, review studies that propose methods to reduce fungal levels indoors emphasise the importance of keeping moisture levels down [2,56,79]. On the other hand fungi adapted to growth in environments with low water activity can also be found in the indoor environment [80]. To avoid excess moisture and keep fungal levels down the following has been proposed: adequate ventilation, avoiding cold surfaces for condensation, heating all rooms in the winter, insulating the residence, proper maintenance of filter units, intelligent building design, changing the residents habits, and remediation and prevention of water damage [2,56,79]. Other factors that may affect fungal levels are, poverty, age of home, and presence of pets [2,56,79]. Dust control, frequent vacuuming, remediation of areas with fungal growth, air conditioning, and replacing carpeting with firm flooring materials may directly reduce exposure to fungi [2,56,66], but may also reduce it indirectly by reducing the re-aerosolisation of spores.

4. Conclusions

Outdoor fungal concentration and composition influence the levels and composition of airborne fungi indoors. During occupancy and activities in the indoor environment, levels of airborne fungi increase. People allergic to fungi should be aware of activities such as e.g. bed making, handling fire wood, and mouldy items that cause increased fungal exposure. Furthermore, they should be aware of the relatively long time fungal levels remain increased post activity. Due to sedimentation of fungal spores on indoor surfaces followed by re-suspension during activities, the increase in exposure caused by specific activities is expected to be affected by the general exposure level in a room. This has been shown for resuspension of *Penicillium* spores from floor surfaces. Furthermore, genera predominant (*Penicillium*, *Cladosporium*, and *Aspergillus*) before an activity often increase during an activity. Therefor attempts to reduce the indoor exposure level are also expected to reduce the increased exposure caused by activities. In addition to the species found before an activity other species could be found during human activities and occupancy. Hence, activities and occupancy must be taken into account when studying associations between exposures and health effects. In most studies of influence of everyday activities on exposure, fungal species have not been identified. Exposure research should focus on species, and not genus, since health effects are expected to be related to fungal species. The knowledge on influence of everyday and seasonal specific activities on levels of aerosolised fungi is limited. Additional research is required to both describe more activities and strengthen the results of those already investigated to help to identify those activities that can cause and those that cannot cause concern for sensitised patients. The number of fungal spores

aerosolised from a material seems not only to be dependent on the spore load, but also on material properties, this should be explored further and used in the selection of materials in a home.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

Reference

1. Cruz AA, Mantzouranis E, Matricardi PM, et al. Global surveillance, prevention and control of Chronic Respiratory Diseases—A comprehensive approach. World Health Organization; 2007.
2. Afshari A, Anderson HR, Cohen A, et al. Dampness and Mould. WHO Regional Office for Europe; 2009.
3. Reponen T, Vesper S, Levin L, et al. (2011) High environmental relative moldiness index during infancy as a predictor of asthma at 7 years of age. *Ann Allerg Asthma Im* 107: 120-126.
4. Dannemiller KC, Mendell MJ, Macher JM, et al. (2014) Next generation DNA sequencing reveals that low fungal diversity in house dust is associated with childhood asthma development. *Indoor Air* 24: 236-247.
5. Behbod B, Sordillo JE, Hoffman EB, et al. (2013) Wheeze in infancy: protection associated with yeasts in house dust contrasts with increased risk associated with yeasts in indoor air and other fungal taxa. *Allergy* 68: 1410-1418.
6. Lötvall J, Akdis CA, Bacharier LB, et al. (2011) Asthma endotypes: a new approach to classification of disease entities within the asthma syndrome. *J Allergy Clin Immunol* 127: 355-360.
7. Radon K (2006) The two sides of the "endotoxin coin". *Occup Environ Med* 63: 73-78.
8. Hamilos DL (2010) Allergic fungal rhinitis and rhinosinusitis. *Proc Am Thora Soc* 7: 245-252.
9. Pringle A (2013) Asthma and the diversity of fungal spores in air. *Plos Pathogens* 9: e1003371.
10. Denning DW, Pashley C, Hartl D, et al. (2014) Fungal allergy in asthma-state of the art and research needs. *Clinical and Translational Allergy* 4: 14.
11. Vesper S, Barnes C, Ciaccio CE, et al. (2013) Higher environmental relative moldiness index (ERMI) values measured in homes of asthmatic children in Boston, Kansas City, and San Diego. *J Asthma* 50: 155-161.
12. Reponen T, Lockey J, Bernstein DI, et al. (2012) Infant origins of childhood asthma associated with specific molds. *J Allergy Clin Immunol* 130: 639-644.
13. O'Connor GT (2005) Allergen avoidance in asthma: What do we do now? *J Allergy Clin Immunol* 116: 26-30.
14. Tovey E, Ferro A (2012) Time for new methods for avoidance of house dust mite and other allergens. *Curr allergy asthma rep* 12: 465-477.
15. Burge HA, Solomon WR, Muilenberg ML (1982) Evaluation of indoor plantings as allergen exposure sources. *J Allergy Clin Immunol* 70: 101-108.

16. Twaroch TE, Curin M, Valenta R, et al. (2015) Mold allergens in respiratory allergy: from structure to therapy. *Allergy Asthma Immunol Res* 7: 205-220.
17. Trail F (2007) Fungal cannons: explosive spore discharge in the Ascomycota. *FEMS Microbiol Lett* 276: 12-18.
18. Frankel M, Hansen EW, Madsen AM (2014) Effect of relative humidity on the aerosolization and total inflammatory potential of fungal particles from dust-inoculated gypsum boards. *Indoor Air* 24: 16-28.
19. Madsen AM (2012) Effects of air flow and changing humidity on the aerosolisation of respirable fungal fragments and conidia of *Botrytis cinerea*. *Appl Environ Microbiol* 78: 3999-4007.
20. Górny RL, Reponen T, Grinshpun SA, et al. (2001) Source strength of fungal spore aerosolization from moldy building material. *Atm Environ* 35: 4853-4862.
21. Pasanen A-L, Pasanen P, Jantunen MJ, et al. (1991) Significance of air humidity and air velocity for fungal spore release into the air. *Atm Environ* 25a: 459-462.
22. Zoberi MH (1961) Take-off of mould spores in relation to wind speed and humidity. *Annals of Botany* 25: 53-64.
23. Eduard W (2009) Fungal spores: a critical review of the toxicological and epidemiological evidence as a basis for occupational exposure limit setting. *Crit Rev Toxicology* 39: 799-864.
24. Sigler L, Abbott SP, Gauvreau H (1996) Assessment of worker exposure to airborne molds in honeybee overwintering facilities. *Am Ind Hyg Assoc J* 57: 484-490.
25. Madsen AM, Tendal K, Frederiksen MW (2014) Attempts to reduce exposure to fungi, ß-glucan, bacteria, endotoxin and dust in vegetable greenhouses and a packaging unit. *Sci Total Environ* 468: 1112-1121.
26. Visser MJ, Spaan S, Arts HJ, et al. (2006) Influence of different cleaning practices on endotoxin exposure at sewage treatment plants. *Ann Occup Hyg* 50: 731-736.
27. Madsen AM. Identification of Work Tasks Causing High occupational Exposure to Bioaerosols at Biofuel plants Converting Straw or Wood Chips. In: Dr.Marco Aurelio DosSantos Bernardes, editor. Environmental Impact of biofuels.InTech; 2011. 251-270.
28. Simon-Nobbe B, Denk U, Pöll V, et al. (2008) The spectrum of fungal allergy. *Int Arch Allergy Immunol* 145: 58-86.
29. Hunter CA, Grant C, Flannigan B, et al. (1988) Mould in buildings: the air spora of domestic dwellings. *Inte Biodeter* 24: 81-101.
30. Reponen T, Lehtonen M, Raunemaa T, et al. (1992) Effect of indoor sources on fungal spore concentrations and size distributions. *J Aerosol Sci* 23: 663-666.
31. Lehtonen M, Reponen T, Nevalainen A (1993) Everyday activities and variation of fungal spore concentrations in indoor air. *Int Biodeterior Biodegradation* 31: 25-39.
32. Buttner MP, Stetzenbach LD (1993) Monitoring airborne fungal spores in an experimental indoor environment to evaluate sampling methods and the effects of human activity on air sampling. *Appl Environ Microbiol* 59: 219-226.
33. Buttner MP, Cruz-Perez P, Stetzenbach LD, et al. (2002) Measurement of airborne fungal spore dispersal from three types of flooring materials. *Aerobiologia* 18: 1-11.
34. Millington WM, Corden JM (2005) Long term trends in outdoor Aspergillus/Penicillium spore concentrations in Derby, UK from 1970 to 2003 and a comparative study in 1994 and 1996 with the indoor air of two local houses. *Aerobiologia* 21: 105-113.
35. Veillette M, Knibbs LD, Pelletier A, et al. (2013) Microbial Contents of Vacuum Cleaner Bag

Dust and Emitted Bioaerosols and Their Implications for Human Exposure Indoors. *Appl Environ Microbiol* 79: 6331-6336.
36. Hegarty JM, Rouhbakhsh S, Warner JA, et al. (1995) A comparison of the effect of conventional and filter vacuum cleaners on airborne house dust mite allergen. *Respiratory Medicine* 89: 279-284.
37. Siracusa A, De BF, Folletti I, et al. (2013) Asthma and exposure to cleaning products - a European Academy of Allergy and Clinical Immunology task force consensus statement. *Allergy* 68: 1532-1545.
38. Bernstein JA, Brandt D, Rezvani M, et al. (2009) Evaluation of cleaning activities on respiratory symptoms in asthmatic female homemakers. *Ann Allerg Asthma Im* 102: 41-46.
39. Mäkelä R, Kauppi P, Suuronen K, et al. (2011) Occupational asthma in professional cleaning work: a clinical study. *Occup Med* 61: 121-126.
40. Balasubramanian R, Nainar P, Rajasekar A (2012) Airborne bacteria, fungi, and endotoxin levels in residential microenvironments: a case study. *Aerobiologia* 28: 375-390.
41. Summerbell RC, Krajden S, Kane J (1989) Potted plants in hospitals as reservoirs of pathogenic fungi. *Mycopathologia* 106: 13-22.
42. Summerbell RC, Staib F, Dales R, et al. (1992) Ecology of fungi in human dwellings. *J Med Vet Mycol* 30: 279-285.
43. Goebes MD, Boehm AB, Hildemann LM (2011) Contributions of foot traffic and outdoor concentrations to indoor airborne Aspergillus. *Aerosol Sci Tech* 45: 352-363.
44. Kildesø J, Vinzents P, Schneider T, et al. (1999) A simple method for measuring the potential resuspension of dust from carpets in the indoor environment. *Textile Res J* 69: 169-175.
45. Chen Q, Hildemann LM (2009) The effects of human activities on exposure to particulate matter and bioaerosols in residential homes. *Environ Sci Technol* 43: 4641-4646.
46. Adams RI, Miletto M, Taylor JW, et al. (2013) Dispersal in microbes: fungi in indoor air are dominated by outdoor air and show dispersal limitation at short distances. *The ISME journal* 7: 1262-1273.
47. Takahashi T (1997) Airborne fungal colony-forming units in outdoor and indoor environments in Yokohama, Japan. *Mycopathologia* 139: 23-33.
48. Mitakakis TZ, Tovey ER, Xuan W, et al. (2000) Personal exposure to allergenic pollen and mould spores in inland New South Wales, Australia. *Clin Exp Allergy* 30: 1733-1739.
49. Sessa R, Di PM, Schiavoni G, et al. (2002) Microbiological indoor air quality in healthy buildings. *The New Microbiologica* 25: 51-56.
50. Madsen AM, Matthiesen CB, Frederiksen MW, et al. (2012) Sampling, extraction and measurement of bacteria, endotoxin, fungi and inflammatory potential of settling indoor dust. *J EnvironMonitor* 14: 3230-3239.
51. Scheff PA, Paulius VK, Curtis L, et al. (2000) Indoor air quality in a middle school, Part II: Development of emission factors for particulate matter and bioaerosols. *Applied Occupational and Environmental Hygiene* 15: 835-842.
52. Brandl H, von Däniken A, Hitz C, et al. (2008) Short-term dynamic patterns of bioaerosol generation and displacement in an indoor environment. *Aerobiologia* 24: 203-209.
53. Qian J, Hospodsky D, Yamamoto N, et al. (2012) Size-resolved emission rates of airborne bacteria and fungi in an occupied classroom. *Indoor Air* 22: 339-351.
54. Hospodsky D, Yamamoto N, Nazaroff WW, et al. (2014) Characterizing airborne fungal and

bacterial concentrations and emission rates in six occupied children's classrooms. *Indoor Air* doi: 10.1111/ina.12172.
55. Yamamoto N, Hospodsky D, Dannemiller KC, et al. (2015) Indoor emissions as a primary source of airborne allergenic fungal particles in classrooms. *Environ Sci Technol* 49: 5098-5106.
56. Bush RK, Portnoy JM (2001) The role and abatement of fungal allergens in allergic diseases. *J Allergy Clin Immunol* 107: S430-S440.
57. Levetin E. Fungi. In: Burge HA, editor. Bioaerosols.Lewis Publishers; 1995, 87-120.
58. Sharpe RA, Bearman N, Thornton CR, et al. (2015) Indoor fungal diversity and asthma: a meta-analysis and systematic review of risk factors. *J Allergy Clin Immunol* 135: 110-122.
59. Reponen T, Lockey J, Bernstein DI, et al. (2012) Infant origins of childhood asthma associated with specific molds. *J Allergy Clin Immunol* 130: 639-644.
60. Gravesen S (1985) Indoor airborne mould spores. *Allergy* 40: 21-23.
61. Ren P, Jankun TM, Leaderer BP (1999) Comparisons of seasonal fungal prevalence in indoor and outdoor air and in house dusts of dwellings in one Northeast American county. *J Expo Anal Environ Epidemiol* 9: 560-568.
62. Chew GL, Rogers C, Burge HA, et al. (2003) Dustborne and airborne fungal propagules represent a different spectrum of fungi with differing relations to home characteristics. *Allergy* 58: 13-20.
63. Mandal J, Brandl H (2011) Bioaerosols in Indoor Environment-A Review with Special Reference to Residential and Occupational Locations. *Open Environ Biol Monit J* 4: 83-96.
64. D'Amato G, Spieksma FThM (1995) Aerobiologic and clinical aspects of mould allergy in Europe. *Allergy* 50: 870-877.
65. Rosas I, Calderón C, Martínez L, et al. (1997) Indoor and outdoor airborne fungal propagule concentrations in Mexico City. *Aerobiologia* 13: 23-30.
66. Kozak PP, Gallup J, Cummins LH, et al. (1979) Factors of importance in determining the prevalence of indoor molds. *Ann Allergy* 43: 88-94.
67. Amend AS, Seifert KA, Samson R, et al. (2010) Indoor fungal composition is geographically patterned and more diverse in temperate zones than in the tropics. *Proc Natl Acad Sci* 107: 13748-13753.
68. Gots RE, Layton NJ, Pirages SW (2003) Indoor health: background levels of fungi. *AIHA J* 64: 427-438.
69. Larsen L, Gravesen S (1991) Seasonal variation of outdoor airborne viable microfungi in Copenhagen, Denmark. *Grana* 30: 467-471.
70. Frankel M, Beko G, Timm M, et al. (2012) Seasonal variation of indoor microbial exposures and their relations to temperature, relative humidity and air exchange rates. *Appl Environ Microbiol* 78: 8289-8297.
71. Stetzenbach LD, Buttner MP, Cruz P (2004) Detection and enumeration of airborne biocontaminants. *Curr Opin Biotechnol* 15: 170-174.
72. Madsen AM (2006) Exposure to airborne microbial components in autumn and spring during work at Danish biofuel plants. *Ann Occup Hyg* 50: 1-11.
73. Licorish K, Novey HS, Kozak P, et al. (1985) Role of Alternaria and Penicillium Spores in the Pathogenesis of Asthma. *J Allergy Clin Immunol* 76: 819-825.
74. Bagni N, Davies RR, Mallea M, et al. (1977) [Spore concentration in cities of the European Economic Community. II. Spores of Cladosporium and Alternaria]. *Acta Allergologica* 32:

118-138.
75. Gravesen S (1979) Fungi as a Cause of Allergic Disease. *Allergy* 34: 135-154.
76. Garrett MH, Rayment PR, Hooper MA, et al. (1998) Indoor airborne fungal spores, house dampness and associations with environmental factors and respiratory health in children. *Clin Exp Allergy* 28: 459-467.
77. Adhikari A, Lewis JS, Reponen T, et al. (2010) Exposure matrices of endotoxin, (1-->3)-beta-d-glucan, fungi, and dust mite allergens in flood-affected homes of New Orleans. *Sci Total Environ* 408: 5489-5498.
78. Reponen T, Nevalainen A, Jantunen M, et al. (1992) Normal range criteria for indoor air bacteria and fungal spores in a subarctic climate. *Indoor Air* 2: 26-31.
79. Sharpe R, Thornton CR, Osborne NJ (2014) Modifiable factors governing indoor fungal diversity and risk of asthma. *Clin Exp Allergy* 44: 631-641.
80. Micheluz A, Manente S, Tigini V, et al. (2015) The extreme environment of a library: Xerophilic fungi inhabiting indoor niches. *Int Biodeterior Biodegradation* 99: 1-7.

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