International Journal of Occupational Medicine and Environmental Health, Vol. 15, No. 3, 303—307, 2002

FIREFIGHTING EFFORTS MAY LEAD TO MASSIVE FUNGAL GROWTH AND EXPOSURE WITHIN ONE WEEK. A CASE REPORT

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Abstract. A case study on extensive fungal growth that occurred in an apartment building after firefighting efforts is described in this paper. Exposure to airborne microorganisms (both viable and total) was investigated by filter sampling in three periods before and during remedial actions after the fire. Material samples were also analyzed. Extensive mold growth was observed on the building materials as soon as eight days after the fire. High concentrations of fungal spores, 10^7 cfu/g, were found when material samples were analyzed. Concentrations of airborne fungal spores (10^4 spores/m^3) were also high and increased by two orders of magnitude during the demolition of moldy building materials and during the clean-up after the demolition. The proportions of airborne viable fungi in comparison with the total spore concentrations were 28–83% immediately after the fire, but they had decreased to <1% two months after the fire during the reconstruction phase. *Paecilomyces* was the main fungal genus in the indoor air before and during the demolition, while *Penicillium* dominated during the reconstruction. *Paecilomyces* was not detected in the outdoor air. *Paecilomyces* and *Penicillium* were also found in the material samples. The results show that fast and extensive mold growth in a building may take place also in subarctic climates, at least during summer. High concentrations of fungal spores are released to the air during the demolition of moldy building materials and the following clean-up. Therefore, personal protection is necessary during such work.

Key words:
Microbial growth, Fungi, Occupational exposure, Construction work, Fire

INTRODUCTION

The increased prevalence of respiratory symptoms and alterations in the pulmonary functions of construction workers have been connected with the demolition of moldy building materials moistened by water leakage and other flaws in their construction, such as condensation and inadequate ventilation [1]. It has been suggested that these health effects are caused primarily by exposure to the microorganisms present on the building materials. Firefighting is an acute event resembling a major failure in plumbing. It involves masses of water and leads to thorough wetting of large areas of buildings. In this case study, firefighting efforts caused massive fungal exposure during remedial actions eight days after a fire.

CASE DESCRIPTION

In a summer night, a severe thunderstorm caused a fire in a six-floor apartment building in eastern Finland. There were no earlier damages in the building and no visible mold was found on its structures. The firemen had used 50 tons of water before they brought the fire under control.

This study was supported by a grant from the Finnish Work Environment Fund.
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The attic and the roof were totally destroyed, and all the apartments on the sixth floor and part of those on the fifth floor suffered from water damage. The repair of the water damage started the next day. However, due to the large number of apartments damaged, not all of them could be immediately restored.

MATERIALS AND METHODS

Samples for microbial analyses were taken in three periods from one of the water-damaged sixth-floor apartments. The first air samples were collected eight days after the fire before any repair work had started. The second set was taken the next day, as the wet building materials were demolished and clean-up was in progress. The third set of samples was collected during the reconstruction work about two months after the fire. Outdoor air samples were also taken, one for each sampling day.

The samples for the microbial analyses were collected onto polycarbonate membrane filters (diameter 37 mm, pore size 0.4 µm; Nuclepore Corp., Cambridge, Mass.) with a flow rate of 2 l/min. Before the repair work, only stationary samples were taken, 1.5 m above the ground in the middle of the room, whereas during the demolition, clean-up and reconstruction work, both personal and stationary samples were collected. All the outdoor air samples were taken as stationary samples at a height of 1.5 m. The sampling time varied from 3 min to 3 h.

The concentrations of viable fungi and actinobacteria were determined by the cultivation [2] of indoor and outdoor air samples. For culturing, dichloran glycerol agar (DG18) [3] was used for xerophilic fungi and 2% malt-extract agar (2% MEA) [4] for hydrophilic fungi. Tryptone-yeast-glucose (TYG) [5] with cycloheximide was used for actinobacteria. The plates were incubated in the dark at 25°C for 7 and 14 days for fungi and actinobacteria, respectively. The concentrations of viable fungi are expressed as colony-forming units per cubic meter (cfu/m^3). Fungal colonies were identified morphologically to genus under an optical microscope. The total concentrations of spores in indoor air were determined with acridine orange staining and counting under an epifluorescence microscope without any separation of the fungal and actinobacteria spores [2]. The total concentrations of spores are expressed as spores per cubic meter.

Material samples were also collected from visibly damaged building materials (gypsum board and wood). The samples were weighed (1–5 g), homogenized, and extracted with dilution water (distilled water with 42.5 mg/l $KH_2PO_4 \times 7H_2O$, 250 ml/l $MgSO_4$, 8 mg/l NaOH and 0.02% Tween 80 detergent). Suspensions were held in an ultrasonic bath for 30 min and in a shaker for 60 min. Dilution series were made and plated on DG18, 2% MEA, and TYG agars. The fungal plates were incubated in the dark at 25°C for 7 days, and actinobacteria plates were kept at 25°C for 14 days. The concentrations are expressed as colony-forming units per gram (cfu/g). Fungal genera were also identified for genus under an optical microscope.

RESULTS

During the first sampling, there was massive visible growth of mold on the walls and the ceilings of the apartment studied. High concentrations of fungal spores, $2.6–4.1 \cdot 10^7$ cfu/g, were found when samples of moldy gypsum board and wooden materials were analyzed (Table 1). Species of *Aspergillus*, *Paecilomyces* and *Penicillium,* and also yeasts were found in material samples. No actinobacteria were detected.

The results of the air measurements are presented in Tables 2 and 3. Before the demolition began, the concentrations of viable fungal spores and the total spore concentrations were at the level of 10^4 spores/m^3. The concentrations increased during the demolition and clean-up, aver-

Table 1. Microbial content of the material samples

Material	Viable fungi cfu/g	Fungal genera, rank order
Gypsum board	$2.7–3.5 \cdot 10^7$	Aspergillus Paecilomyces Penicillium
Wood	$2.6–4.1 \cdot 10^7$	Aspergillus Penicillium Paecilomyces Yeasts

Table 2. Microbial content of the indoor air samples taken after the firefighting

Measurement period	Days from the fire	Indoor air			Fungal genera, rank order
		Total spore spores/m^3	Viable actinobacteria cfu/m^3	Viable fungi cfu/m^3	
Before the demolition	8	Stationary $2.7 \cdot 10^4$	Stationary b.d.	Stationary $1.4–1.8 \cdot 10^4$	*Paecilomyces* *Penicillium* *Aspergillus* *Cladosporium*
During the demolition of wet and moldy gypsum board and wood	9	Stationary $7.8 \cdot 10^6$ Personal $2.9 \cdot 10^6$	Stationary b.d. Personal b.d.	Stationary $4.8–6.5 \cdot 10^6$ Personal $1.4–1.8 \cdot 10^6$	*Paecilomyces* *Penicillium* *Aureobasidium* *Aspergillus*
During the clean up procedures, when moldy building materials were gathered and removed and the floors were swept	9	Stationary $2.9 \cdot 10^6$ Personal $7.8 \cdot 10^6$	Stationary b.d. Personal b.d.	Stationary $8.1–9.1 \cdot 10^5$ Personal $4.3–6.4 \cdot 10^6$	*Paecilomyces* *Penicillium* *Aspergillus* Yeasts Non-sporing isolates
During the reconstruction	60	Stationary $7.7 \cdot 10^6$ Personal $3.4 \cdot 10^6$	Stationary $2.8 \cdot 10^1$ Personal $1.7 \cdot 10^2$	Stationary $2.4–2.6 \cdot 10^4$ Personal $1.9–3.1 \cdot 10^4$	*Penicillium* *Aspergillus* *Chrysonilia* *Paecilomyces* *Cladosporium*

b.d. – below detection limit.

aging 100 times higher than the level observed before the demolition. The proportion of viable fungi in comparison with the total spore concentration was 52–67% before the demolition and 28–83% during the demolition and clean up. The results of the personal samples showed the levels similar to those of the stationary sampling. During the reconstruction, the concentrations of viable fungi decreased, but the total spore concentrations remained at the level observed during the demolition and clean-up. The concentrations of viable fungi decreased to 0.3–0.9%

Table 3. Microbial content of the outdoor air samples

Measurementperiod	Days from the fire	Outdoor air Viable fungi cfu/m^3	Fungal genera, rank order
Before the demolition	8	Stationary $2.6–2.7 \cdot 10^3$	Penicillium Non-sporing isolates Cladosporium Aspergillus Chrysonilia Absidia
During the demolition and clean-up procedures	9	Stationary $2.9–3.0 \cdot 10^3$	Penicillium Aspergillus Cladosporium Non-sporing isolates
During the reconstruction	60	Stationary $0.4–2.5 \cdot 10^2$	Aspergillus Penicillium Cladosporium Non-sporing isolates Yeasts Acremonium Mucor

of the total concentration of spores. Actinobacteria were also found. The fungal spore measurements in the outdoor air showed concentrations of 10^3 cfu/m^3 during the first sampling days and 10^1–10^2 cfu/m^3 during the last sampling. No actinobacteria were found in outdoor air samples.

DISCUSSION

Massive mold growth is rare on interior surfaces in subarctic conditions at 63° latitude. However, this case demonstrated that fast fungal proliferation can occur if the building structures become very wet. The weather also provided favorable circumstances for fungal growth. The fire occurred during a warm period that was unusually long and continued after the thunderstorm. The daytime temperature was continuously +25–30°C, which is 5–10°C warmer than the average at that time of year.

The material samples confirmed the growth of *Aspergillus*, *Paecilomyces*, *Penicillium*, and yeasts on the room surfaces. The fungal concentrations of these samples (10^7 cfu/g) were higher than those previously reported (10^2–10^6 cfu/g) for moisture-damaged building materials [6,7]. The common occurrence of *Penicillium* and yeasts in wood and gypsum board has been reported earlier in other studies [8,9], but *Paecilomyces* has been rarely found in material samples in subarctic climates [6,7,9,10].

Already before the demolition work began, massive mold growth yielded airborne viable fungal spore levels that were higher than those usually detected in moldy Finnish buildings in the summer [11,12]. The fungal spore levels at that time were also ten times higher indoors than outdoors, although the fungal spores from outdoor sources usually dominate indoor air at that time of the year [13,14]. The results showed that high concentrations of fungal spores were not only produced but also released from the mold growth under these highly favorable conditions. Fungal spore levels are not necessarily higher in buildings with visible mold growth than in buildings without such growth [15], but in this case, the mold growth was unusually massive. During the renovation periods, airborne fungal spore levels increased further and were 100–1000 times higher indoors than outdoors due to the release of spores from the materials being handled.

The results indicated again that high concentrations of fungal spores (10^5–10^6 spores/m^3) were released into the air during the demolition of moldy building materials. In this study, the concentrations of fungal spores were about 10 times higher than those previously measured in demolition work [16,17] and close to those connected with health disorders in agricultural environments [18,19]. High concentrations of fungal spores were also detected when moldy building materials were gathered and removed, and the floors were swept after the demolition. During the reconstruction, the concentrations of fungal spores were lower, but they remained still higher than before the demolition. The fungal spore levels of this study were about 10 times higher than those during reconstruction reported in other studies [16].

The proportion of viable fungi in comparison with the total concentration varied between 28 and 83% before the repair work and during the demolition and clean-up. The corresponding values were only 0.3–0.9% during the reconstruction. In a previous study, the concentration of viable fungi in indoor air was about 1% of the total concentrations of fungal spores [20]. The unusually high viable/total spore levels in this study were obviously due to the freshness of the microbial growth in the favorable growth conditions.

Paecilomyces was the main fungal genus in the indoor air during the first two sampling days, although it was not detected outdoors. It was identified from the material samples, and this identification confirmed that the airborne *Paecilomyces* spores originated from mold growth on the building materials. We have earlier found small amounts of *Paecilomyces* in indoor air [16], but it does not belong to the indoor fungal genera typical of subarctic climates [12,16,21]. However, in warmer climate, *Paecilomyces* has been reported to be a common contaminant in the air, on building materials, and in house dust [22]. This preference for warm climate may explain the abundant occurrence of *Paecilomyces* in this study. The weather was unusually warm during the first two sampling days and resembled

that of warmer climate. In addition, the heat produced during the fire may have affected its growth as well.

This case study indicates that fast and extensive mold growth is possible on building materials even in subarctic climate if a building becomes thoroughly wet. Therefore, wet constructions should be dried quickly and effectively after water damage to prevent the development of mold growth. According to a previous study [23], sensitive materials, such as gypsum board, need to be dried within 2–3 days. If not possible, for example, due to the extensiveness of the damage, as in this case, the wet materials should be replaced or repaired as soon as possible. Since high concentrations of fungal spores may be released into the air during the repair of moldy materials, methods to protect occupants and workers from exposure are always needed.

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Received for publication: May 20, 2002
Approved for publication: July 15, 2002