AMERICAN INDUSTRIAL HYGIENE ASSOCIATION JOURNAL 57:279–284 (1996)

Exposure to Airborne Microbes During the Repair of Moldy Buildings

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Concentrations of airborne microbes, studied during the repair of seven moldy buildings, showed that concentrations of airborne fungi increased during the repair work. This was especially true during the demolition of moldy building materials, even though the total dust levels remained low. Concentrations of viable fungi sampled with a six-stage cascade impactor were 10^3 — $>1.9 \times 10^5$ cfu/m^3, and the total concentrations of fungal propagules, as determined by the Camnea method (i.e., air filtration method with epifluorescence microscopic counting of acridine-stained organisms) showed 10^5 — 10^6 counts/m^3 during the demolition. *Penicillium* was the main genus throughout. Concentrations of viable total bacteria also increased, but this change proved less noticeable than that of the fungi. However, rather high concentrations of viable actinomycetes up to 10^4 cfu/m^3 were detected during the demolition. Results show that construction workers are exposed to high concentrations of microbes, perhaps causing health problems. Thus, personal protection of both the respiratory system and eyes is strongly recommended for workers as they repair moldy buildings. In addition, the repair room should be isolated from other areas to protect occupants or any other people present.

Keywords: airborne fungi, building repair, personal protective equipment

Exposure to high concentrations of bioaerosols, especially airborne microbes in some working environments (see Table I), has been known to cause a wide range of respiratory diseases, such as allergic rhinitis and asthma, chronic bronchitis, extrinsic allergic alveolitis, and organic dust toxic syndrome.[6] However, even though fungal concentrations in moldy houses are usually much lower,[7] people living in those houses also suffer from health problems such as irritation of respiratory mucosa, skin, and eyes and allergic diseases.[8–12]

Concentrations of microbes have been shown to increase during the handling of both moldy and nonmoldy materials.[13–16] Apparently, fungal propagules accumulate on building materials and surfaces. Airflows[17] and the handling of materials[15] release the microbes into the air. Therefore, the demolition of moldy materials could result in a potentially massive exposure to microbes.

No systematic studies have been done of the amount of bioaerosol exposure construction workers receive during demolitions. The aim of this study was to measure microbial concentrations in several working areas during the demolition and repair of moldy structures. The authors investigated exposure to mold spores and bacteria, especially actinomycetes. For mold spores, concentrations of both viable and total (viable and nonviable) propagules were monitored. In addition, total dust concentrations were measured. Simultaneously, a questionnaire study on health effects of the workers was performed. The results of this study will be reported separately.

MATERIAL AND METHODS

Buildings Studied

This study was carried out in seven buildings as they were demolished (Table II). The occurrence of microbial growth on the surfaces of the building materials was confirmed during site visits before the repair started. In each building, samples were taken in the rooms where the demolition and reconstruction work was done and in another room that had no detectable mold and

This study was supported by the Finnish Work Environmental Fund.

TABLE I. Concentrations of Viable Airborne Spores (cfu/m³) in Various Working Environments and in Finnish Houses

Environment	Concentration of Viable Spores	Reference
Wood chip handling	10^3–10^6	1
Saw mills	10^2–10^7	2
Agriculture	10^4–10^7	3
Finnish houses		
in winter	10^0–10^2	4
in summer	10^2–10^3	4
Mold problem houses	10^0–10^5	5

did not need repair. Throughout the study the ventilation of the buildings was operating normally. No attempts to enhance the ventilation were made by either the researchers or the workers.

Air Sampling

Samples for total concentrations of fungal propagules and total dust concentrations were collected onto polycarbonate membrane filters (Nucleopore) with a pore size of 0.4 µm and diameter of 37 mm in closed-face plastic filter holders (Nucleopore, Costar Corp., Cambridge, Mass.) with a flow rate of 2 L/min. Samples were obtained, their times ranging between 30 and 360 minutes, before, during, and after the demolition, and during the reconstruction. Both personal and stationary samples were included.

Total dust concentration was determined gravimetrically by weighing the filters before and after collection. Before weighing, filters were stabilized at a relative air humidity of 60% for one day. After gravimetric analysis the total concentrations of fungal propagules in the filters could be measured, using the Camnea method.[18] These filters were stained with acridine-orange, and the total numbers of fungal propagules were counted at a magnification of 1250× using an epifluorescence microscope. The concentrations are expressed as counts/m³.

Samples for viable microbes were taken with six-stage cascade impactors (Model 10–800, Andersen Samplers, Inc., Atlanta, Ga.) calibrated at a flow rate of 28.3 L/min. One sample was taken in each house before demolition and two to four samples during the demolition work. One to two samples were also taken during and soon after the completion of the reconstruction. One control sample was taken one to six months after the repair work was finished.

Malt-extract agar[19] was used with streptomycin for viable fungi, and tryptone-yeast-glucose (TYG)[20] agar with cycloheximide for viable bacteria and actinomycetes. Before and after demolition, sampling time varied between 5 and 15 minutes, and during demolition work, 0.5 to 3 minutes. The fungal culture plates were incubated at 25°C for seven days, and the plates for bacteria and actinomycetes for five days. The concentrations were calculated using positive hole correction method[21] and expressed as colony-forming units/m³ (cfu/m³). Fungal colonies were identified to genus with an optical microscope. Particle size distributions of fungal spores were also analyzed from the six-stage impactor samples. The size classes retained by the different stages of the sampler are 0.65–1.1, 1.1–2.1, 2.1–3.3, 3.3–4.7, 4.7–7.0, and >7.0 µm, as given by the manufacturer (Andersen Samplers, Inc.).

The data were lognormally distributed with geometric means and standard deviations used for the calculations both for the total concentration of fungi and fungal genus. The Wilcoxon test helped to identify the differences between the concentrations before and during demolition.

Material Samples

Material samples were also collected during the demolitions. Using the cultivation method[22] with malt-extract agar, the fungal genera of both moldy and nonmoldy building materials were analyzed. The fungal cultures were incubated at 25°C for seven days and the colonies identified to genus via an optical microscope.

RESULTS AND DISCUSSION

Total Concentrations of Fungal Propagules

Before the repair began, the mean total concentration of fungal propagules in the repair rooms stood at 5.9×10^4 counts/m³ (Figure 1A). The mean concentration increased to 1.3×10^6 counts/m³ during demolition and on average was 20-fold as compared with the level before demolition. The increase proved statistically significant ($p<0.05$). The levels of fungal propagules observed were of the same order of magnitude as those measured in saw mills with the Camnea method.[23] The mean total concentration of fungal propagules decreased to 2.3×10^5 counts/m³ during the reconstruction phase. In the reference rooms no significant changes in the total concentrations of fungal propagules were observed (Figure 1A).

Concentrations of Viable Fungi

During the demolition the mean concentration of viable fungi increased from 3.7×10^2 cfu/m³ to 2.3×10^4, (range $10^3 - >1.9 \times 10^5$ cfu/m³) (Figure 1B), a statistically significant increase ($p<0.05$). These concentrations were of the same order of magnitude as those previously reported during the handling of wood chips[1] and also came close to those concentrations reported in saw mills[2] and agricultural environments.[3] Concentrations of viable fungi increased by almost two orders of magnitude during the demolition, an increase higher than that of the total fungal propagules. This may indicate that viable spores were released from the fungal mycelia at the time of demolition, whereas a great number of fungal propagules were released earlier and only resuspended during the demolition. This result also shows that the method by which viable fungi can be detected may be more sensitive to environmental monitoring in this type of working situation than that for the total numbers of fungal propagules.

TABLE II. The Buildings Studied

Building	Construction Year	Ventilation	Reason for Mold Growth
Terraced house	1984	natural	moisture condensation
Terraced house	1984	natural	structural engineering error
House	1988	mechanical exhaust	structural engineering error
House	1974	natural	water leak
House	1892	mechanical supply and exhaust	condensation
Day-care center	1977	mechanical exhaust	water leak
Industrial hall	1942	mechanical supply and exhaust	condensation

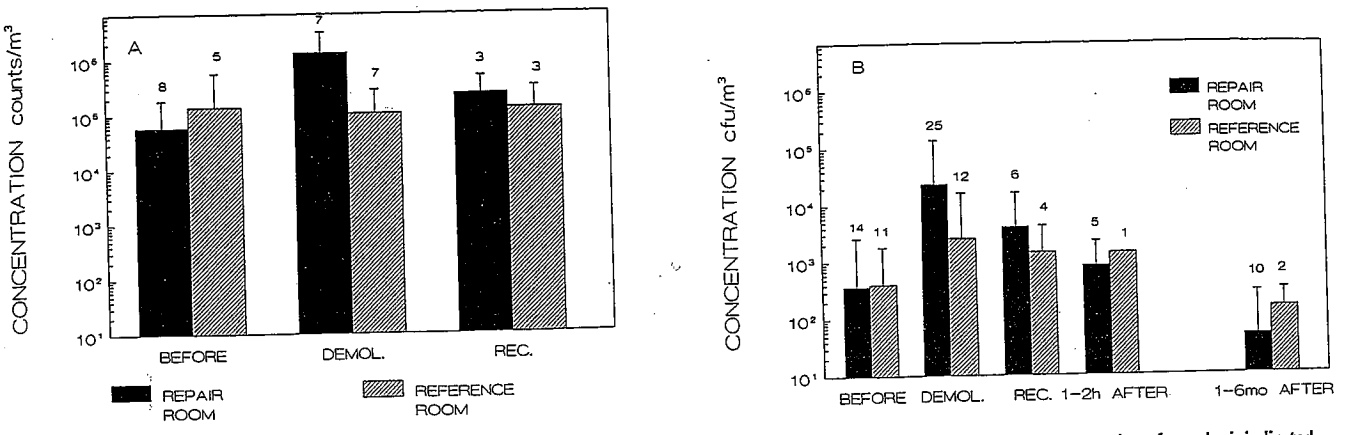

FIGURE 1. The geometric means and geometric standard deviations of total concentrations of fungal propagules (1A) and viable fungi (1B). The number of samples is indicated above the column (before = before repair work, demol. = during demolition, rec. = during reconstruction).

Concentrations of viable fungi increased even in the reference rooms during the demolition ($p<0.05$) (Figure 1B). Those concentrations were about one order of magnitude higher during demolition than before it. The demolition thus caused fungal contamination of major parts of the buildings. Similar findings have also been obtained during repair work at a hospital.[16]

During the reconstruction the concentrations of viable fungi decreased from those observed during demolition, but the concentrations remained still higher than the level observed before work started. The construction occurred immediately following demolition or the next day. The mean concentration of viable fungi initially stood at 3.9×10^3 cfu/m³ in the repair rooms, whereas 1–2 hours later the mean concentration measured 8.1×10^2 cfu/m³. The concentrations decreased to half of the maximum concentrations within the hour. Control sampling one to six months after repair showed that the mean concentration of viable fungi had decreased to the level $10–10^2$ cfu/m³, a level common to mold-free houses.[4]

Particle Size Distributions

Concentrations of viable fungi increased for each size class in both the repair and reference rooms during demolition (Figure 2).

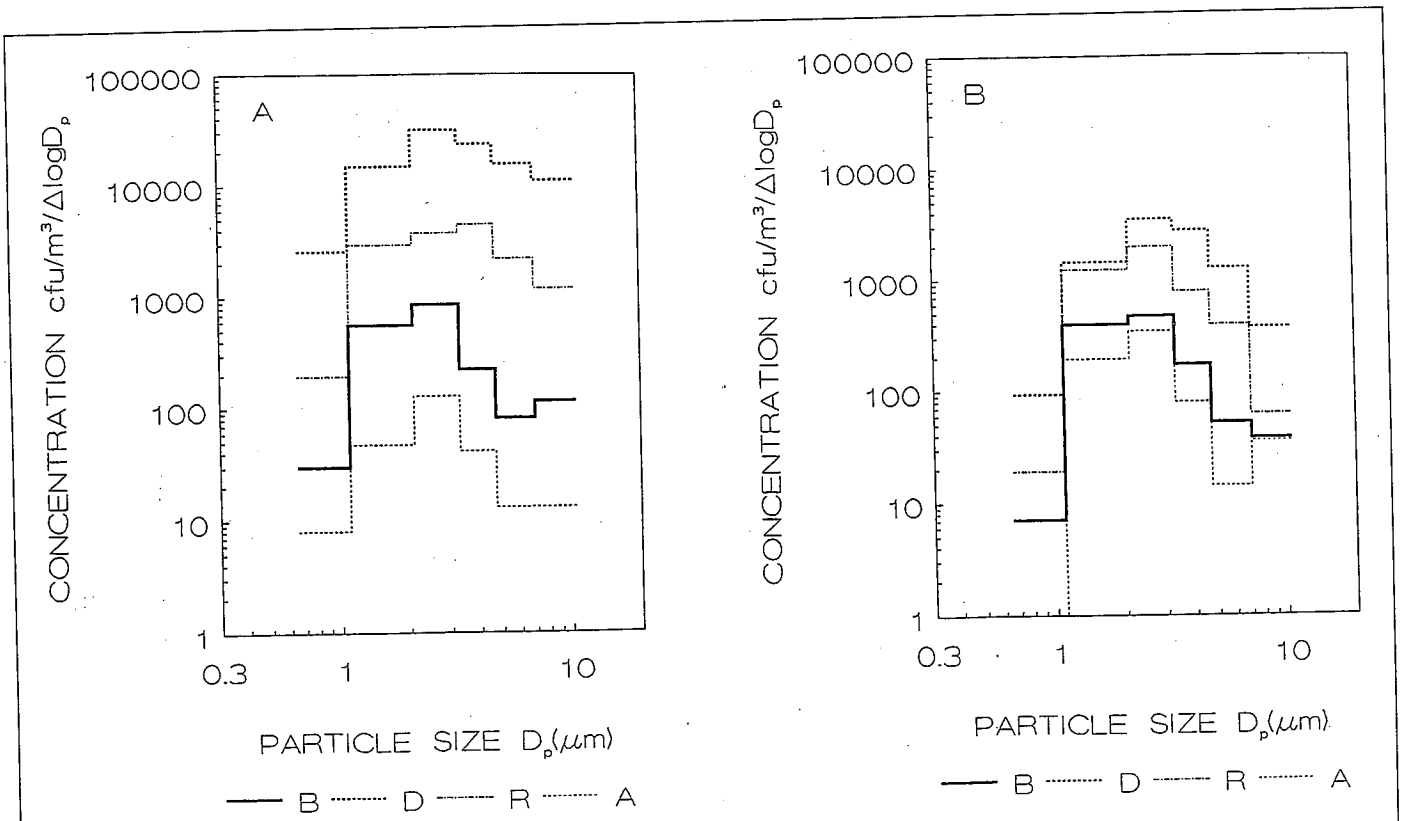

FIGURE 2. Particle size distributions of fungal spores in the repair rooms (2A) and in the reference rooms (2B). B = before repair work, D = during demolition, R = reconstruction work, A = one to six months after repair work.

The concentrations increased most in the size class 2–3 µm, except during reconstruction work in the repair room, where the maximum level showed in the size class 3–4 µm. Concentrations of small (D_p <1 µm) and large particles (D_p >3 µm) increased by approximately two orders of magnitude in the repair rooms; conversely the intermediate particles (1 µm <D_p <3 µm) increased approximately one order. In the reference rooms the increase showed at one order of magnitude in each class. Thus, the maximum increase observed was in the size ranges of the large or small particles. The relatively large increase of viable particles >3 µm may partly explain the rapid decrease (see Figure 1B) of the concentrations after the completion of the work. Larger particles settle more rapidly than smaller ones due to gravity (e.g., 5-µm particles need over 30 minutes to settle 1.5 m, while a 1-µm particle needs over 700 minutes to settle the same distance).[24]

Fungal Genera

Penicillium and *Aspergillus*, common fungi in indoor air,[25–27] represented the most common fungal genera in the study (Figure 3). Concentrations of several fungal genera increased during the demolition (Figure 3). *Penicillium* and *Mucor* in particular showed a statistically significant increase ($p<0.05$). Some of the fungal genera, such as *Botrytis* and *Fusarium*, had low concentrations that appeared in the repair rooms during the demolition. These fungal genera were also found in the material samples. Fungal genera *Humicola*, *Polyscytalum*, *Ulocladium*, and *Umbelopsis* were detected only before the demolition work.

Penicillium and *Aspergillus* also constituted the main genera found in the reference rooms (Figure 3). Concentration of *Penicillia* rose significantly higher ($p<0.05$) during the demolition than prior to it. By contrast, other fungal genera—in particular *Absidia*, *Botrytis*, *Exophiala*, *Fusarium*, *Graphium*, *Mucor*, and *Staphylotrichum*— were detected only during the demolition and coincidentally in the material samples. These fungal genera, not common in normal indoor air in Finland,[7] were released from the building materials on which they may have grown due to water damage.

Concentrations of Viable Bacteria and Actinomycetes

Before the repair work started, the mean concentration of viable bacteria in the repair rooms registred at 9.1×10^2 cfu/m^3 (Figure 4A) and that of actinomycetes 4 cfu/m^3 (Figure 4B).

During the demolition the mean concentration of the total viable bacteria increased to 1.4×10^4 cfu/m^3 (range 10^2–10^5 cfu/m^3) and that of viable actinomycetes to 5.6×10^2 cfu/m^3 (range 10–10^4 cfu/m^3). The concentrations of viable bacteria increased by about one order of magnitude and those of viable actinomycetes about two orders of magnitude. The increase proved statistically significant ($p<0.05$) for both.

During the reconstruction the mean concentration of viable bacteria decreased to 6.9×10^3 cfu/m^3, while the mean concentration of viable actinomycetes remained at 3.6×10^2 cfu/m^3. Bacteria and actinomycete readings, taken within 1 or 2 hours after the reconstruction, decreased to levels that matched those observed before the repair began. Even after one to six months, the bacterial concentrations remained at this level. The actinomycete concentrations in the control samples decreased to a lower level than that observed before the repair began. All concentrations for bacteria and actinomycetes registered within the range of normal background levels expected in Finnish homes.[4,28]

Before the repair, concentrations of viable bacteria and actinomycetes in the reference rooms appeared at the same level as that in the repair rooms. During the demolition, concentrations of viable bacteria and actinomycetes increased, but were still less than those in the repair rooms (Figure 4). Increases proved statistically significant ($p<0.05$).

Total Dust Concentration

Total dust concentrations increased 100- to 1000-fold during the demolition, varying from 0.1 to 2.9 mg/m^3. The fact that

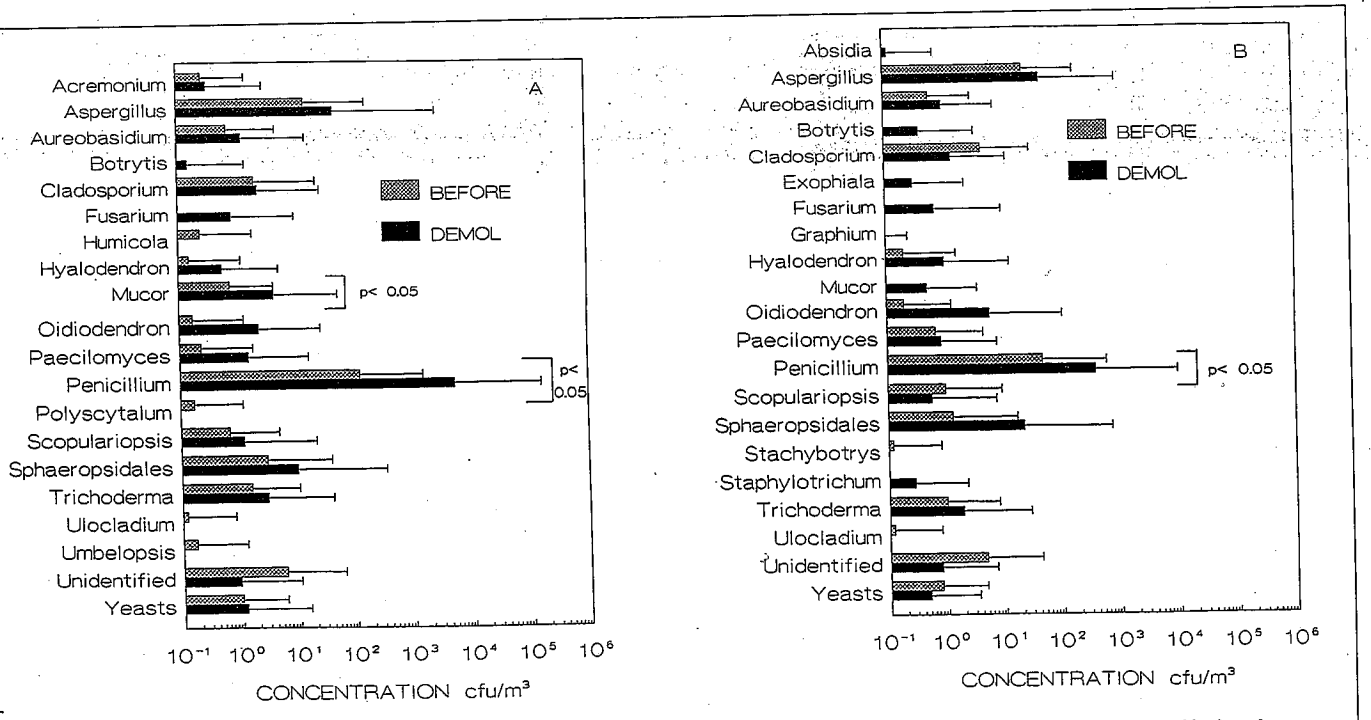

FIGURE 3. The geometric means and geometric standard deviations of fungal genera before repair and during demolition work in the repair rooms (3A) and in the reference rooms (3B). The differences between the concentrations of each genera before and during demolition work were studied using the Wilcoxon test.

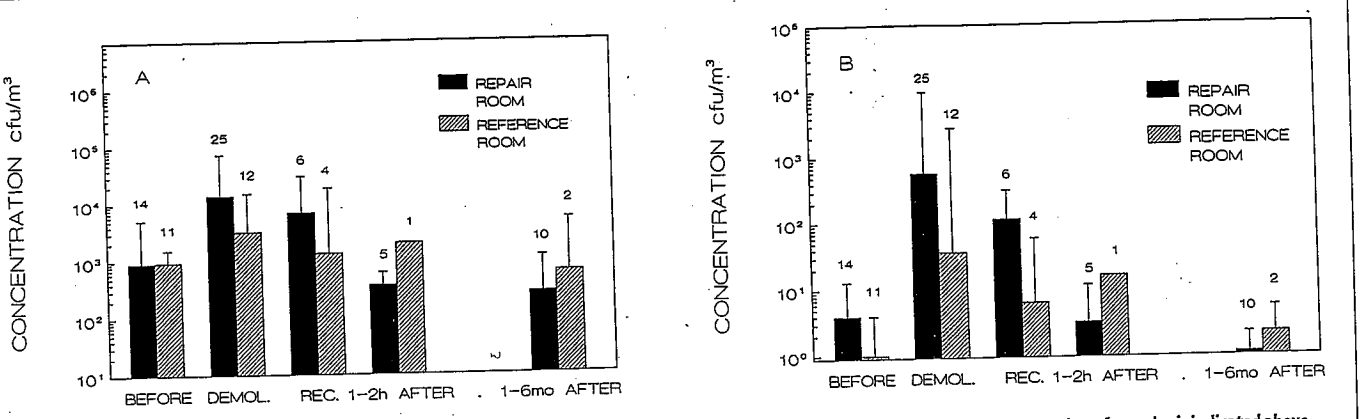

FIGURE 4. The geometric means and geometric standard deviations of viable bacteria (4A) and actinomycetes (4B) during repair work. The number of samples is indicated above the column (before = before repair work, demol. = during demolition work, rec. = during reconstruction).

these concentrations showed up as low compared with total dust concentrations measured at the time of construction[29] indicates that high bioaerosol levels seen at demolition were not caused by dusty working practices. Therefore, it is the exposure to bioaerosols rather than to larger amounts of total dust during the work on moldy buildings that seems to pose a greater health risk.

CONCLUSIONS

Concentrations of fungi, especially viable fungi, increased considerably during the repair of moldy buildings; this was especially noted during the demolition work. The maximum concentrations exceeded 1.9×10^5 cfu/m³ (close to the levels observed during the handling of wood chips).[1] In addition, the concentrations of viable actinomycetes, which do not occur in mold-free indoor air, increased up to 10^4 cfu/m³ during the demolition. Thus, this work on moldy structures can be considered as a situation in which there is significant exposure to bioaerosols.

Despite high microbial levels the total dust concentration remained low during the demolition. Therefore, the absence of visible dust does not guarantee safe working conditions.

Fungal levels also increased in the reference rooms. To remedy this the repair rooms could be isolated from others to protect the occupants and any others present. It is highly recommended that the occupants not stay in the rooms that are connected to the repair work.

ACKNOWLEDGMENTS

The authors wish to thank Ms. Ritva Karhunen and Ms. Tuula Wallenius for excellent technical assistance.

REFERENCES

1. Kotimaa, M.: Occupational exposure to fungal and actinomycete spores during the handling of wood chips. *Grana 29*:153–156 (1990).
2. Alexandersson, R., G. Hedenstierna, L. Belin, G. Rosen, et al.: Decreased pulmonary function in wood trimmers. A cross-sectional and longitudinal study. *Arbete och Hälsa 18*:1–21 (1986). [In Swedish with English summary]
3. Kotimaa, M.: Spore exposure arising from stored hay, grain and straw. *J. Agric. Sci. Finland 62*:285–291 (1990).
4. Reponen, T., A. Nevalainen, M. Jantunen, M. Pellikka, et al.: Normal range criteria for indoor air bacteria and fungal spores in a subarctic climate. *Indoor Air 2*:26–31 (1992).
5. Hyvärinen, A., T. Reponen, T. Husman, S. Rautiala, et al.:. "Concentrations and Genera of Fungal Spores in Mold Problem Houses." Paper presented at First Finnish Conference of Environmental Sciences, Kuopio, Finland, October 1993. pp. 306–313.
6. Lacey, J. and B. Crook: Fungal and actinomycete spores as pollutants of the workplace and occupational allergens. *Ann. Occup. Hyg. 32*:515–533 (1988).
7. Hyvärinen, A., T. Reponen, T. Husman, J. Ruuskanen, et al.: Characterizing mold problem buildings—concentrations and flora of viable fungi. *Indoor Air 3*:337–343 (1993).
8. Platt, S.D., C.J. Martin, S.M. Hunt, and C.W. Lewis: Damp housing, mold growth and symptomatic health state. *Br. Med. J. 298*:1673–1678 (1989).
9. Waegemaekers, M., N. van Wageningen, B. Brunekreef, and J.S.M. Boleij: Respiratory symptoms in damp houses. *Allergy 44*:192–198 (1989).
10. Husman, T., O. Koskinen, A. Hyvärinen, T. Reponen, et al.: "Respiratory Symptoms and Infections among Residents in Dwellings with Moisture Problem or Mold Growth." Paper presented at the 6th International Conference on Indoor Air Quality and Climate, Helsinki, Finland, July 1993. pp. 171–174.
11. Koskinen, O., T. Husman, A. Hyvärinen, T. Reponen, et al.: "Respiratory Symptoms and Infections among Children in a Day-Care Center with Mold Problem." Paper presented at the 6th International Conference on Indoor Air Quality and Climate, Helsinki, Finland, July 1993. pp. 231–237.
12. Spengler, J.D., L. Neals, S. Nakai, D. Dochery, et al.: "Respiratory Symptoms and Housing Characteristic." Paper presented at the 6th International Conference on Indoor Air Quality and Climate, Helsinki, Finland, July 1993. pp. 165–170.
13. Johanning, E., P.R. Morey, and M. Goldberg: "Remedial Techniques and Medical Surveillance Program for the Handling of Toxigenic Stachybotrys atra." Paper presented at the 6th International Conference on Indoor Air Quality and Climate, Helsinki, Finland, July 1993. pp. 311–316.
14. Maunsell, K.: Concentration of airborne spores in dwellings under normal conditions and under repair. *Arch. Allergy 5*:373–376 (1954).
15. Hunter, C.A., C. Grant, B. Flannigan, and A.F. Bravery: Mold in buildings: the air spora of domestic dwellings. *Int. Biodeterior. Bull. 24*:81–101 (1988).
16. Kalliokoski, P., T. Reponen, A. Nevalainen, and M-L. Katila: "Improper Use of Ventilation May Cause Severe Health Hazard in Hospitals." Paper presented at the 5th International Conference on Indoor Air Quality and Climate, Ottawa, Canada, 1990. pp. 523–527.
17. Pasanen, A-L., P. Pasanen, M.J. Jantunen, and P. Kalliokoski: Significance of air humidity and air velocity for spore release into the air. *Atmos. Environ. 25A(2)*:459–462 (1991).

18. Palmgren, U., G. Ström, G. Blomquist, and P. Malmberg: Collection of airborne micro-organisms on nuclepore filters: estimation and analysis—Camnea method. *J. Appl. Bacteriol. 61*:401–406 (1986).

19. Blakeslee, A.F.: Lindners roll tube method of separation cultures. *Phytopathology* 5:68–69 (1915).

20. American Public Health Association: *Standard Methods for the Examination of Water and Wastewater*, 15th ed. Washington, DC: American Public Health Association, 1980.

21. Andersen, A.A.: New sampler for collection, sizing and enumeration of viable airborne particles. *J. Bacteriol.* 76:471–484 (1958).

22. Pasanen, A-L., T. Juutinen, M.J. Jantunen, and P. Kalliokoski: Occurrence and moisture requirements of microbial growth in building materials. *Int. Biodeterior.* 30:273–283 (1992).

23. Eduard, W., J. Lacey, K.Karlsson, U. Palmgren, et al.: Evaluation of method for enumerating microorganisms in filter samples from high contaminated occupational environments. *Am. Ind. Hyg. Assoc. J.* 50:427–436 (1990).

24. Reponen, T., A. Hyvärinen, J. Ruuskanen, T. Raunemaa, et al.: Comparison of concentrations and size distributions of fungal spores in building with and without mould problems. *J. Aerosol. Sci.* 25:1595–1603 (1994) .

25. Miller, J.D., A.M. Laflamme, Y. Sobol, P. Lafontaine, and R. Greenhalgh: Fungi and fungal products in some Canadian houses. *Int. Biodeterior.* 24:103–120 (1988).

26. Pasanen, A-L.: Airborne mesophilic fungal spores in various residential environments. *Atmos. Environ.* 26A(16):459–462 (1992).

27. Verhoeff, A.P., J.H. van Wijnen, B. Brunekreef, P. Fischer, et al.: Presence of viable mould in indoor air in relation to house damp and outdoor air. *Allergy* 47:83–91 (1991).

28. Nevalainen, A., A-L. Pasanen, M. Niininen, T. Reponen, et al.: The indoor air quality in Finnish homes with mold problem. *Environ. Int.* 17:299–302 (1991).

29. Jaakkola, J. and A. Tossavainen: Altisteet työssä 29. Kvartsi. Työterveyslaitos. Työsuojelurahasto. Helsinki 1993. [In Finnish with Swedish summary]