

Fungi associated with urea-formaldehyde foam insulation in Canada

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Abstract

Sixty-eight fungal taxa were identified from samples of urea-formaldehyde foam insulation taken from Canadian residences. Mesophilic taxa were predominant, with *Penicillium* spp., *Trichoderma harzianum* and *Paecilomyces variotii* observed most frequently. Extensive or conspicuous growth also was seen for *Hormoconis resinae*, *Stachybotrys chartarum* and *Trichoderma viride* in some samples. The potential for these fungi to have contributed to the adverse health effects reported in some homes containing UF-foam insulation is discussed.

Introduction

Urea-formaldehyde foam insulation (UFFI) is an open cell foam prepared on site from a mixture of urea-formaldehyde resin, an acidic hardening agent and a propellant (usually compressed air). In Canada, UFFI has been used primarily in retrofitting older homes, and was usually injected into cavity wall masonry construction or into the empty spaces between studs of frame houses. An estimated 80000 homeowners had UFFI installed in their homes in Canada before the material was banned as a possible health hazard in December, 1982.

Fresh UF foam may contain 75% water by weight. Unreacted formaldehyde gas is released during the curing process. The reaction between the resin and hardening agent is reversible, causing the product to deteriorate continuously after installation. High temperatures and humidity accelerate deterioration of UFFI, leading to breakage of the foam cell walls and shrinkage of the foam [6]. Formaldehyde gas and other volatiles are released in the process.

Exposure to formaldehyde can cause eye, nose and throat irritation, headache, dizziness, nausea, nose bleeds, and, in high concentrations, bron-

chopneumonia and pulmonary oedema [5, 6]. Repeated or prolonged exposure may increase an individual's sensitivity to the gas. Sensitized persons may suffer serious asthmatic reactions at low concentrations. Unsatisfactorily high concentrations of formaldehyde have been recorded from some homes in which UFFI was installed. Although off-gassing was initially thought the probable cause of the reported adverse health effects in some UFFI homes, studies to date do not show a clear correlation between adverse symptoms and the concentration of off-gases from foam insulation. Consequently, other factors associated with UFFI, including the presence of fungi, have been investigated as concomitant causes of these adverse health symptoms.

Methods

The fungi were identified from urea-formaldehyde foam samples sent to the National Identification Service from September 1979 to October 1986. Data from 48 identification lots and a total of 140 foam samples were compiled. Most of the UFFI samples were taken by contractors or homeowners

according to instructions given in Bowen *et al.* [5]. Material was submitted for fungal analyses if discolored or if there was thought to be an evident fungal or "insect" problem. A test opening 30 cm high and spanning a stud space was made at the bottom of the wall containing UFFI. Samples of interior and exterior sheathing and UFFI were placed in separate sealed plastic bags. Large slivers of wood, if discolored or damp, were also collected for fungal analysis. Only fungi observed or isolated directly from UFFI are reported here.

The following procedures were employed in determining the presence of fungi on the UF foam. The entire sample was examined externally and internally for fungal colonization. Colonized regions were examined microscopically. Observations on spores and mycelium and their position in the foam and association with the degradation of the foam were recorded. Fungi were isolated and identified in culture by plating minute (ca. 1 mm diameter) particles of foam onto agar plates. Particles were selected both from discolored areas near the foam surface, and from the interior of the foam. Usually 60 particles were plated from each sample, two particles per plate, onto 10 plates each of 2% malt agar, potato-dextrose agar and malt agar with 20% dextrose. Occasionally more particles were plated from heavily colonized samples, and fewer from clean samples. Colonization rates ranged from 0–100% for the materials submitted. A few samples were submitted as aqueous or dilute methanol effluents passed through UFFI. One-ml aliquots of these extracts were plated onto 5 plates of each of the isolation media above. Most spores and conidia probably were not viable in these extracts. Very few fungi were cultured from the effluent samples. Direct microscopic observations on the UFFI extracts gave negative results.

Observations on the growth of fungi on UFFI

A list of the fungi identified from UFFI appears in Table 1. The fungi most frequently encountered were *Penicillium* spp., *Trichoderma harzianum*, *Paecilomyces variotii*, and several kinds of Basidiomycete anamorphs. Other fungi which occasion-

ally formed extensive or conspicuous growth in association with UFFI included *Amorphotheca resinae* (anamorph *Hormoconis resinae*), *Stachybotrys chartarum* and *Trichoderma viride*.

Conspicuous differences exist among fungi predominant on UFFI, and fungi predominant in other insulating materials or isolated from indoor air. Phylloplane fungi introduced from outside, or xerophilic fungi tend to be predominant in surveys of the indoor mycoflora. Miscellaneous observations from indoor air samples indicated that the following genera are most commonly encountered indoors in Canada: *Eurotium* spp., *Aspergillus* spp., *Rhizopus oryzae* Went. & Prinsen Geerl., *Cladosporium* spp., *Mucor* spp., *Penicillium* spp., *Chaetomium* spp., *Alternaria* spp. and (seasonally) Basidiomycete anamorphs, *Hormonema* spp., *Aureobasidium* spp., *Microdochium* spp., *Rhinocladiella* spp., and *Epicoccum nigrum* (unpublished data). Similar results have been reported from surveys in the United States [29, 41] and Denmark [19, 20]. Lustgraaf & Bronswijk [30] found xerophilic fungi in the genera *Eurotium*, *Aspergillus*, *Penicillium* and *Wallemia* to be predominant in house dust. Samson [38] listed 12 of the most common xerophilic species found in surveys of indoor environments in Europe. Of these 12 species, only the seven species with minimum water activity (a_w) > 0.76 (i.e. less xerophilic) were encountered from UFFI in the present survey. The five most xerophilic species (a_w < 0.76) were not found in association with the foam, although media for isolation of xerophilic fungi were employed in the current study. The majority of the species isolated from the foam, and the most predominant species, were mesophilic (a_w > 0.90). Predominant genera of fungi isolated in a study of fungi in loose-fill attic insulation in the United States were *Alternaria*, *Penicillium*, *Cladosporium* and *Fusarium* [14]. Of these genera, only *Penicillium* was commonly encountered on UFFI.

Conspicuous growth on UFFI was noted for relatively few fungal species. *Hormoconis resinae* grew luxuriantly on a few samples of foam in advanced stages of deterioration. Usually, this species appeared to grow preferentially on the foam rather than on adjacent substrates, and was apparent as a

Table 1. Fungal species present on urea-formaldehyde foam.

Species	Number of samples ^a	Method ^b
<i>Alternaria alternata</i> (Fr.: Fr.) Keissler	9	1, 2
<i>Amorphoteca resinae</i> Parbery anam. <i>Hormoconis resinae</i> (Lindau) v. Arx & de Vries	7	1, 2
<i>Antrodia serialis</i> (Fr.: Fr.) Donk	1	1
<i>Apiospora montagnei</i> Sacc anam. <i>Arthrinium</i> sp.	1	2
<i>Aspergillus flavus</i> Link: Fr.	2	2
<i>Aspergillus nidulans</i> (Eidam) Wint. group	1	2
<i>Aspergillus niger</i> Van Tieghem	4	2
<i>Aspergillus niger</i> group	4	2
<i>Aspergillus ochraceus</i> Wilhelm	1	2
<i>Aspergillus ornatus</i> Raper, Fennell & Tresner	5	2
<i>Aspergillus repens</i> (Corda) Sacc.	1	2
<i>Aspergillus sydowii</i> (Bain. & Sart.) Thom & Church	3	2
<i>Aspergillus ustus</i> (Bain.) Thom & Church	4	1, 2, 3
<i>Aspergillus versicolor</i> (Vuill.) Tiraboschi	3	2
<i>Aspergillus</i> spp. indet.	4	1, 2, 3
<i>Basidiomycotina</i> anam. spp.	12	1, 2, 3
<i>Botrytis</i> sp.	2	2
<i>Chaetomium globosum</i> Kunze	1	2
<i>Chaetomium</i> spp. indet.	3	2
<i>Cladosporium cladosporioides</i> (Fres.) de Vries	8	2
<i>Cladosporium herbarum</i> (Pers.: Fr.) Link	2	2, 3
<i>Cladosporium sphaerospermum</i> Penz.	2	2
<i>Cladosporium</i> spp. indet.	2	2
<i>Disporotrichum dimorphosporum</i> (v. Arx) Stalpers	1	2
<i>Doratomyces stemonitis</i> (Pers.: Fr.) Morton & G. Smith	1	2
<i>Epicoccum nigrum</i> Link	5	2
<i>Fusarium</i> sp.	1	2
<i>Geomyces pannorum</i> (Link) Sigler & Carmichael	2	2
<i>Hormonema</i> sp.	3	2
<i>Microsphaeropsis</i> sp.	1	2
<i>Monocillium mucidum</i> W. Gams	1	2
<i>Mucor</i> sp.	1	2
<i>Paecilomyces variotii</i> Bainier	18	1, 2
<i>Penicillium aurantiogriseum</i> Dierckx	8	1, 2
<i>Penicillium brevicompactum</i> Dierckx	1	2
<i>Penicillium chrysogenum</i> Thom	5	2
<i>Penicillium citreonigrum</i> Dierckx	3	2
<i>Penicillium citrinum</i> Thom	3	2
<i>Penicillium corylophilum</i> Dierckx	6	2
<i>Penicillium decumbens</i> Thom	7	2, 3
<i>Penicillium echinulatum</i> Fassatiová	1	2
<i>Penicillium fellutanum</i> Biourge	2	2
<i>Penicillium glabrum</i> (Wehmer) Westling	9	2
<i>Penicillium hirsutum</i> Dierckx	1	2
<i>Penicillium implicatum</i> Biourge	1	2
<i>Penicillium oxalicum</i> Currie & Thom	1	2
<i>Penicillium purpurogenum</i> Stoll	6	2
<i>Penicillium roquefortii</i> Thom group	4	2
<i>Penicillium simplicissimum</i> (Oud.) Thom.	1	2
<i>Penicillium spinulosum</i> Thom	7	2
<i>Penicillium verruculosum</i> Peyronel	1	2
<i>Penicillium waksmanii</i> Zaleski	4	2, 3

Table 1. Continued.

Species	Number of samples ^a	Method ^b
<i>Penicillium</i> spp. indet.	25	1, 2, 3
<i>Phoma glomerata</i> (Corda) Wollenw. & Hochapf.	1	2
<i>Phoma macrostoma</i> Mont.	1	2
<i>Pithomyces chartarum</i> (Berk. & Curt.) M.B. Ellis	4	2
<i>Sporobolomyces</i> sp.	2	2
<i>Sporothrix</i> sp.	1	1, 2
<i>Stachybotrys chartarum</i> (Ehrenb.) Hughes	4	1, 2
Sterile dark mycelium	2	2, 3
Sterile hyaline mycelium	6	1, 2, 3
<i>Trichocladium</i> sp.	1	1
<i>Trichoderma citrinoviride</i> Bissett	1	2
<i>Trichoderma harzianum</i> Rifai	24	1, 2
<i>Trichoderma viride</i> Pers.: Fr. aggr.	5	1, 2
<i>Tritirachium oryzae</i> (Vincens) de Hoog	1	3
<i>Ulocladium botrytis</i> Preuss	8	2
<i>Verticillium lecanii</i> (Zimm.) Viégas	1	2

^a Number of samples from which the species was detected (total of 140 samples). No fungi were isolated from eight samples.

^b Method of determining presence: 1, direct observation on foam; 2, culture from foam particle; 3, culture from foam filtrate.

conspicuous greyish-brown discoloration. The discolored area penetrated the interior of the foam, and extensive mycelium, conidiophores and conidia of this species were observed deep within the foam matrix and apparently associated with varying degrees of degradation of the foam. In one sample, however, *Hormoconis resinae* was isolated from asphalt impregnated paper in contact with UFFI with no evidence of extensive growth within the foam. This species is known to grow on petroleum products including kerosene, aviation fuel, asphalt pavements, and on creosoted wood and conifer resin [13].

Several foam samples had extensive growth of *Paecilomyces variotii*, evident as a yellowish to buff-colored or brownish discoloration on the foam surface. The pigmented area did not penetrate the foam very deeply, and mycelium of this species appeared to be mostly confined near the surface. Conidia of *P. variotii* were abundantly produced on the surface of the foam. This species has been reported to grow on synthetic rubber, creosoted wood [13], and on pharmaceutical emulsions [15] and cosmetics [35].

Trichoderma harzianum was frequently associat-

ed with diffuse and often extensive areas of greyish discoloration. The discolored areas were usually confined more or less to the surface of the foam, and, although there was occasional mycelial infiltration of the foam near the surface, the foam cells remained essentially intact. *T. harzianum* has been isolated from petroleum products including jet fuel [13]. *Trichoderma* also has been found tolerant to soil fumigation using formaldehyde and allyl alcohol [32].

To summarize, *H. resinae*, *P. variotii* and *T. harzianum*, all species capable of degrading hydrocarbons, produced the most extensive growths associated with UFFI. Since colonization was often more noticeable at the surface of the foam, adjacent substrates may have been important in supporting the growth of these fungi. However, these three species sometimes were noted to penetrate deeper into the foam matrix as the closed-cell foam structure broke down. Even if these species were not able to initiate degradation of the foam, it appeared that they could grow on products released as the foam deteriorated by the reversible chemical reaction of the acidic hardening agent with the UF resin. The breakdown of the closed cell structure

would increase the water absorption qualities of the foam, further accelerating both nonbiological and possible enzyme-mediated decomposition processes.

Colonies of various species of *Penicillium* often were apparent as small greenish or grey patches on the foam surface, usually less than 1 cm diameter. Colonization of the foam was limited to the surface and the discoloration did not penetrate the foam matrix. Conidiophores and conidia were abundant, but mycelium was usually relatively limited. Growth on hydrocarbons from fuel oil has been reported for *P. chrysogenum*, *P. citrinum*, *P. fel-lutanum*, *P. glabrum* and *P. spinulosum* [36]. *Penicillium aurantiogriseum*, *P. chrysogenum*, *P. glabrum* and *P. spinulosum* can degrade plasticizers and (or) plastic polymers [2, 39]. *P. chrysogenum* also has been found to degrade urea-formaldehyde fertilizer [33], and is tolerant to formaldehyde and some other fumigants [32].

Stachybotrys chartarum produced a very conspicuous and often extensive black sooty growth on the surface of several foam samples. The association of this fungus with the foam appeared to be superficial, and mycelium was not observed inside the foam matrix. The fungus appeared to grow preferentially on gyproc paper in contact with the insulation. *S. chartarum* was only observed on samples that were persistently wet. The same species also was isolated frequently from other materials in homes with severe moisture problems, and not associated with urea-formaldehyde foam insulation.

With few exceptions, growth of the other fungi listed in Table 1 was not conspicuous. Most of these species were only detected by their isolation from foam particles plated onto agar media.

Conspicuous discolorations on the foam surface often were attributable to foreign materials including animal hair, insect and mite faeces and parts of insects and mites, wood fiber and mineral particles in association with limited mycelia and spores of fungi. Occasionally other discolorations were noted, from dull-yellow to pink, for which no cause was determined.

Pathogenic fungi

True pathogenic fungi were not isolated from any of the samples. A few opportunistic pathogens were isolated, although relatively infrequently. These included *Aspergillus flavus*, which can cause lung infections, endocarditis, bladder infections, dermatomycosis, orbital and ear infections; *Aspergillus niger*, which can cause bronchopulmonary aspergillosis, aspergilloma (noninvasive colonization of preformed cavities in the lungs and sinuses), otomycosis and orbital infections; *Aspergillus sydowii*, which is rarely a cause of otomycosis and onychomycosis; *Paecilomyces variotii*, which has been isolated in endocarditis and lacrimal sac infections; *Phoma glomerata*, which can cause granuloma of the foot, mycoses of the hand and genital tract, otomycosis, and rhinitis; and *Aspergillus nidulans*, which can cause maduromycosis, otomycosis and onychomycosis. These fungi rarely, if ever, infect healthy individuals. Patients with invasive forms of these diseases are almost always predisposed to infection from an existing debilitation such as malnutrition, leukemia, lymphoma, or administration of cytotoxic drugs or steroids. However, the isolation from UFFI of fungi capable of producing trichothecenes and other mycotoxins with immunosuppressive properties increases concern for infection by opportunistic fungi and other pathogens.

With the possible exception of *Paecilomyces variotii*, none of these potentially pathogenic species produced sufficiently large amounts of inoculum in association with the foam to cause serious concern for infection. All of these species occur fairly commonly on other substrates in residences, and they are normal constituents of the air spora of many homes. Very large concentrations of *P. variotii* conidia occasionally were produced on the surface of UFFI. Conidia of *P. variotii* are produced in fragile, dry chains and are readily dislodged in air currents. Normal air movement through the stud spaces coupled with the steep spore concentration gradient could cause conidia of this species to migrate into the living spaces of the home. This process may accelerate as the foam shrinks or disintegrates increasing the rate of air-flow through the cavity.

Allergenic fungi

Fungi are known to be important causes of asthma, however fungal aeroallergy is a difficult research subject. Little is known about the identity and quantity of fungal antigens in the air. Limited information is available on which fungal species are important, whether spores or other fungal propagules are the major air-borne allergens, nor on the relative importance of mould allergens to other aeroallergens. Reliable standard fungal allergen extracts are not available for provocation testing, so it is difficult to correlate signs and symptoms of asthma with exposure. Fungal growth releases enzymes and other antigens into the substrate on which the fungus is growing. Allergic bronchopulmonary aspergillosis is an example of a case where these metabolic antigens are more important than spore antigens in causing disease. Metabolic antigens produced by fungi in association with UFFI and carried away in air currents as the UFFI disintegrates may contribute to asthma symptoms. Many of the homes retrofitted with UFFI also were draftproofed. This would reduce the rate of air exchange, increasing humidity and the potential for fungal growth, and also reducing the dilution of aeroallergens by fresh outside air entering the home.

Two kinds of allergic reactions are commonly attributed to exposure to fungal antigens. Type I reactions (Coomb's classification), exhibiting symptoms of bronchial asthma, appear in atopic individuals who can become sensitized to one or more fungal (AgE) antigens occurring at normal concentrations in the air spora. Type III reactions, producing allergic alveolitis and seen in nonatopic individuals, requires intensive exposure for sensitization. Large-spored fungi such as *Alternaria* and *Cladosporium* are more frequently involved in Type I reactions, which occur in the upper airways of the respiratory tract immediately after exposure to the fungal antigens. Type III reactions usually involve small-spored fungi such as *Penicillium*, and the reaction is delayed 4–14 hours after exposure and occurs in the deeper parts of the lung.

The spores of a wide range of fungi have been shown capable of inciting allergic reactions. Species

most commonly causing bronchial allergies are widely distributed and produce large numbers of readily airborne spores or conidia. Fungal species most often implicated in allergic alveolitis produce massive concentrations of spores or conidia in certain situations, causing intensive exposures when the substrate on which the fungus is growing is disturbed. An increased concentration of antigens in the air spora might be attributable to fungi growing and sporulating in association with UFFI in some situations.

Paecilomyces variotii and *Hormoconis resinae* occasionally produced very large numbers of dry conidia which could cause allergic reactions if the conidia were carried by drafts into the living spaces of the building. IgE antibodies to proteins of *P. variotii* have been found in workers handling feed proteins derived from this fungus [27]. *Stachybotrys chartarum* and *Trichoderma harzianum* produced extensive growths which were not always limited to the foam or to the interface between the foam and adjacent materials. In some situations, and particularly in walls with severe moisture problems, these species could grow out of the insulated cavity and into the living space of the building. Increased exposure to antigens produced by these two species could result, even though they have wet spores or spores which aggregate into relatively large masses when dry, and thus not as readily disseminated by air currents.

Mycotoxins

Table 2 lists fungal species associated with UFFI which are known to produce mycotoxins. Toxins are not necessarily produced by all strains of the species listed in Table 2. The environmental conditions within the wall cavity in which the fungi are growing may or may not be amenable to the production of mycotoxins by these species. Since most known mycotoxins have very low volatility, exposure to mycotoxins would most likely be by inhalation of conidia or other propagules of the fungi which have been liberated into the living spaces of the building. However, information on the occurrence of air-borne mycotoxins is very limited. There is

Table 2. Toxins produced by fungi associated with urea-formaldehyde foam.

Fungus	Mycotoxins ^a
<i>Alternaria alternata</i>	tenuazonic acid, altenusin
<i>Aspergillus flavus</i>	aflatoxins, sterigmatocystins, aflatrem, cyclopiazonic acid, β -nitropropionic acid, kojic acid, aspergillilic acid
<i>Aspergillus nidulans</i>	nidulotoxin ^b , sterigmatocystin ^b
<i>Aspergillus niger</i>	malformins, nigragillin
<i>Aspergillus ochraceus</i>	emodin ^b , ochratoxins ^b , penicillic acid ^b
<i>Aspergillus sydowii</i>	sterigmatocystin ^c
<i>Aspergillus ustus</i>	sterigmatocystin, deoxybrevianamide E, austamide, kojic acid, austdiol, austin
<i>Aspergillus versicolor</i>	sterigmatocystins, versicolorins, cyclopiazonic acid, averufin ^b
<i>Chaetomium globosum</i>	chaetoglobosins, chemotin
<i>Cladosporium cladosporioides</i>	cladosporin ^d
<i>Cladosporium herbarum</i>	epicladosporic acid ^c
<i>Epicoccum nigrum</i>	flavipin ^c
<i>Paecilomyces variotii</i>	patulin ^f , byssochlamic acid ^d , byssotoxin A ^d
<i>Penicillium aurantiogriseum</i>	penitrems, cyclopiazonic acid, patulin, penicillic acid, xanthomegnin, viomellein, ochratoxin A ^g
<i>Penicillium brevicompactum</i>	mycophenolic acid ^b
<i>Penicillium chrysogenum</i>	penicillic acid, citrinin, PR-toxin ^h , roquefortin-C ^h
<i>Penicillium citreonigrum</i>	citrinin, citreoviridin
<i>Penicillium citrinum</i>	kojic acid, citrinin, citreoviridin ^f
<i>Penicillium corylophilum</i>	gliotoxin ⁱ
<i>Penicillium decumbens</i>	decumbin
<i>Penicillium fellutanum</i>	citrinin, citreoviridin
<i>Penicillium implicatum</i>	citrinin
<i>Penicillium purpurogenum</i>	rubratoxins, kojic acid
<i>Penicillium simplicissimum</i>	verruculogen, penicillic acid, decumbin, fumitremorgins ^h , viridicatum toxin ^h
<i>Penicillium spinulosum</i>	spinulosin
<i>Penicillium verruculosum</i>	verruculogens, TR-2, verruculotoxin
<i>Penicillium waksmanii</i>	gliotoxin ^c
<i>Pithomyces chartarum</i>	sporidesmins
<i>Stachybotrys chartarum</i>	satratoxins, verrucarins ^{j,l} , roridin E ^j , trichoverrins ^l
<i>Trichoderma harzianum</i>	trichodermin ^k , trichodermol ^k
<i>Trichoderma viride</i>	trichodermin, trichodermol ^k , viridiol, T ₂ toxin, gliotoxin ^b

^a mycotoxins reported for each species are from Cole and Cox [8], unless indicated otherwise.

^bCiegler and Vesonder [7]; ^cMoreau [31]; ^dBetina [3]; ^eBamford *et al.* [1]; ^fEngel and Teuber [16]; ^gBeuchat [4]; ^hFrisvad [18]; ⁱMull *et al.* [34]; ^jEppley *et al.* [17]; ^kIshikawa *et al.* [24]; ^lCroft *et al.* [12].

evidence that mycotoxins may be concentrated in the spores of some fungi [44, 45]. Croft *et al.* [12] reported a case of trichothecene toxicosis, apparently from contact with airborne conidia of *Stachybotrys chartarum*, which was found growing in ventilation ducts in a home in Chicago.

Only a few of the known mycotoxin-producing species produced significant growth in association with the foam insulation. Species of *Fusarium*, *Aspergillus* and *Penicillium*, which are among the best known mycotoxin producers, were not ob-

served to grow prolifically in association with the UFFI. Significant growth of *Paecilomyces variotii* and *Hormoconis resinae* was observed occasionally in association with UFFI. Both of these species produced abundant conidia which could become airborne and enter the living spaces of the building. *Hormoconis resinae* does not appear to have been examined for toxins. Information on mycotoxins in *P. variotii* is limited, although mycotoxins have been reported from closely related species. This species is a suspected agent of toxicosis, although

the relationship of the production of antibiotics and toxic activity has not been determined [31].

Trichoderma harzianum was isolated fairly commonly from UFFI and has the potential to grow onto other substrates and possibly out of the wall cavity into the living space. Mycotoxins which have been reported for this and related *Trichoderma* species include several trichothecenes that are acutely toxic. *Stachybotrys chartarum* infrequently grows luxuriantly on the foam interface, preferring to grow on other substrates including the paper backing of gypsum wallboard. This species also is likely to grow out of the wall cavity under conditions of excessive moisture and invade the living space of the residence. This species is known to produce potent mycotoxins which can become airborne in the conidia [12, 22].

Trichothecenes produced by *Stachybotrys* and *Trichoderma* are potent inhibitors of protein synthesis. Toxic effects include dermatitis, respiratory irritation and distress, cardiovascular effects including lowered blood pressure, and immunosuppressive effects. Subjects immunocompromised by exposure to trichothecene mycotoxins could become susceptible to colonization of airways and lungs by bacteria or other common household disease agents of relatively low virulence. Apart from the study by Croft *et al.* [12], there is little evidence that mycotoxin-producing fungi growing in residences mediate disease. However, this possibility warrants further investigation in the context of the adverse health effects of UF foam.

Volatiles produced by fungi

Strong and pungent musty odors were frequently associated with UFFI in various stages of decomposition. These samples usually were discolored beige to brownish or greyish-green. The fungus most frequently isolated from samples with strong pungent odors was *Trichoderma harzianum*. Conidia, chlamydospores and mycelium of this fungus also were observed inside the foam matrix. *Aspergillus* species also were isolated at high frequencies from a few samples with pungent odors. Samson [38] reported problems associated with

odors produced by mould growth in the Netherlands, with symptoms including headaches, eye, nose and throat irritation or fatigue. Similar problems associated with mouldy odors have been reported in homes insulated with UFFI in Canada.

Aliphatic alcohols and ketones appear to be the most predominant volatiles produced by moulds. Short-chained alcohols, ketones and aldehydes are produced by many fungi [42]. *Trichoderma* has been shown to produce acetaldehyde, ethanol, acetone and ethylene in culture [43]. The most conspicuous odor compounds identified from moulds to date are 1-octen-3-ol, with a characteristic mushroom odor, and 2-octen-1-ol, which may be responsible for the unpleasant musty odor of many fungi [9, 21, 25, 26]. The characteristic "coconut" odor of some strains of *Trichoderma* has been identified as 6-pentyl- α -pyrone, produced also by *Aspergillus* [9, 11, 28]. Geosmin (1,10-dimethyl 1-9-decalol) produces a distinct earthy odor, and has been identified from *Aspergillus versicolor* [23]. 3-octanone, with a citrus-like odor, is produced by *Aspergillus*, *Penicillium*, *Trichoderma*, *Gliocladium* and *Paecilomyces* [21, 26, 37]. Other volatile compounds produced by these genera include ethyl-acetate, iso-butanol, n-butanol, 3-methylbutanol, iso-amylalcohol, phenylethyl alcohol, 3-octanol, 1-octanol, octane, thujopsene, nerolidal, 4-methylbenzaldehyde, phenylacetaldehyde, 2-methylphenol, and numerous unidentified components [9, 10, 21, 25, 26, 40].

A great diversity of volatile compounds are produced by fungi. Seifert and King [40] identified 50 volatile compounds from *Aspergillus clavatus*. Many volatile fungal metabolites remain to be identified, and the interactions among fungi, their metabolites and substrates, which contribute to the complex of mouldy odors, has been little studied. The physical effects of inhaled fungal volatiles are not known. Consequently, the significance of these volatile compounds in producing the adverse health symptoms associated with mouldy odors has not been established.

Remedial measures for reducing fungal health hazards in UFFI homes

The main factor contributing to fungal growth in association with UFFI is believed to be the presence of excess moisture in the insulated cavity. The source could be from water released during the curing process, condensation on the surface of the UFFI, or from leaks. Excess moisture increases the rate at which the foam deteriorates, apparently further encouraging the growth of some fungi. Correcting the moisture problem and drying the insulated cavities should reduce or eliminate potential health problems associated with fungal growth.

Remedial measures for correcting UFFI-related problems in wood-frame homes have been proposed by Bowen *et al.* [5]. They recommend procedures for identifying and correcting moisture problems, and for drying wet cavities. Measures proposed for reducing formaldehyde gas concentrations in residences also should lower the concentrations of spores, volatiles and other fungal metabolites originating inside UFFI insulated cavities. These procedures include sealing the interior of UFFI insulated walls, increased passive ventilation, forced-air ventilation to reduce the negative pressure differential inside the living area, and improved air filtration. Protective measures advised for persons handling UFFI also should be followed in handling or removing fungal contaminated materials. The application of effective fungicides following UFFI removal may introduce additional health risks and is not recommended. Adequate drying of the cavity should eliminate problems of fungal growth, particularly since xerophilic fungi were not predominant on UFFI samples.

There is no direct evidence that fungi associated with UFFI have caused, or contributed to, the adverse health symptoms reported for some residences in which UFFI was installed. However, fungal species which can grow profusely on UFFI are capable of producing potentially air-borne allergens, mycotoxins, and other metabolites which could enter the living area and contribute to the observed symptoms. Additional research is required, particularly to correlate allergic symptoms with exposure to specific aeroallergens, to investigate the

production of air-borne mycotoxins, and to identify volatiles produced by fungi in these situations and determine their effects on human health.

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