FUNGAL COLONIZATION OF BUILDING MATERIALS AND IMPACT ON OCCUPANT HEALTH

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May 5, 2002

Originally written for Botany 699 - Directed Research
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INTRODUCTION

Fungi are essential to the survival of our global ecology, but they may pose a significant threat to the health of occupants when they grow in our buildings. This paper explores the place of these fungi in the overall classification of life forms, lists species that are commonly found in buildings with moisture problems, describes conditions which foster their growth, and explains the potential health effects when indoor colonization occurs. The focus is on filamentous fungi, and their affect on indoor air quality.

It has been estimated that approximately 1/4 of the earth's total biomass is composed of fungi (Miller, 1992). About 200,000 fungal species have been described world wide (Reed and Farr, 1993), but an estimated 1-1.5 million species may exist (Hawksworth, 1991). They are in the air we breathe, and grow in virtually all organic substrates given favorable temperature and moisture conditions. Without fungi, nothing would rot and there would be no nutrients available for plant growth. The fungi are an essential part of the fabric of life which sustains us.

A few fungi are unicellular but most form long chains of cells called hyphae. A mass of hyphae is called a mycelium which constitutes the vegetative body of the fungus. The mycelium may be colorless or may contain melanin, a pigment which allows some fungi to withstand exposure to ultraviolet radiation. Filamentous fungi are an indispensable part of our global ecology, as they are responsible for breaking down dead organic matter into nutrients which sustain plant growth, and play an important symbiotic role with plants, helping them to absorb these nutrients. These filamentous fungi exist primarily as a vast network of microscopic threads that grow through organic matter, secreting enzymes to break down materials and release nutrients. The spores of most filamentous fungi are distributed through the air, spreading these species throughout the world.

CLASSIFICATION SYSTEMS

All life on Earth might be simplistically placed into three broad categories: producers (plants), consumers (animals) and decomposers (bacteria and fungi). Fungi are neither plants nor animals. They have been assigned to a kingdom of their own, but genetic and biochemical analyses indicate that fungi are more closely related to animals than to plants (Kendrick, 1992). Scientific classification of life forms is loosely based on this simplistic view, but classification systems are evolving and becoming more complex as new species are discovered, methods of genetic identification are developed, and known species are reclassified.

Living organisms have until recently been divided into five 'kingdoms': 1) the Monera (bacteria with out organized nucleus); 2) the Protoctista (single celled organisms with an organized nucleus); 3) the Animalia (multicellular organisms with organized nuclei without rigid cell walls that must obtain carbohydrates from environmental sources); 4) the Plantae (multicellular organisms with organized nuclei, with cellulosic, rigid cell walls, and with chlorophyll, allowing synthesis of carbohydrates from CO_2 and water); 5) the Fungi (multicellular organisms with organized nuclei, with chitinous rigid cell walls, that must obtain carbohydrates from environmental sources).

It is now thought that life can be classified into seven kingdoms, which fit into two broad categories; Prokaryotes (bacteria with one chromosome and no nucleus in cells, include two of the seven kingdoms) and Eukaryotes (plants, animals and fungi with one or more cells and or one or two sets of chromosomes with nucleated cells, contain the remaining five kingdoms). The seven kingdoms are further sub-divided by phylum, sub-phylum, class, order, family, genus, and species. For example, human beings belong to the kingdom Animalia, phylum Chordata, (no sub-phylum), class Mamalia, order Primates, family Hominidae, genus *Homo*, and species *Homo sapiens*. The species level describes the narrowest level of classification; that which can interbreed. Genus and species names are underlined or italicized by convention.

The two Prokaryote kingdoms include 1) Eubacteria and 2) Archaebacteria (both unicellular bacteria without a nucleus). The five remaining Eukaryote kingdoms include 3) Protozoa and 4) Chromista (unicellular with a nucleus), and 5) Plantae, 6) Animalia and 7) Eumycota (all multicellular organisms, also with nucleated cells). The Plantae (plants) are the producers, Animalia (animals) are the consumers, and Eumycota (fungi) are the decomposers mentioned earlier. Although there are species in Chromista which may be classified as fungi, these single-celled fungi are equipped with flagella for swimming in water, and do not affect the air quality in buildings. Our interest in fungal colonization of buildings and impact on occupant health limits us to the kingdom Eumycota. The kingdom of Eumycotan fungi are classified into three phyla: Chytridiomycota, Zygomycota, and Dikaryomycota.

Chytridiomycota are also flagellated fungi evolved for swimming in aquatic environments, are of little concern in colonization of building materials or air quality, and will not be discussed further.

The phylum Zygomycota includes two classes: Trichomycetes (which live almost exclusively in the guts of arthropods, and are of little interest for indoor air quality) and Zygomycetes, which are further organized into four orders:

- Mucorales are a common saprobe, meaning they digest dead organic material.
- Entomophthorales belong to an order that infects insects.
- Kickexellales are an order that grows in bat, rat, and mice dung.
- Glomales live in a symbiotic relationship with plant roots.

Zygomycota are a phylum of terrestrial fungi which grow in filaments called hyphae, but they need damp (almost saturated) moisture conditions to survive. Their hyphal cells are thin skinned, and typically do not have cross-walls (septae). This causes them to wilt and collapse easily in dry conditions. While some species of the order Mucorales might grow in buildings, and spores or fragments of the other orders might be found indoors, they are of minor interest in air quality. The Zygomycota contains only two fungi that are commonly recovered from indoor air: *Mucor*, and *Rhizopus*.

The Dikaryomycota, like Zygomycota, are terrestrial fungi, but their hyphae have thicker walls, and are septate. Their septae, or cross-walls, act like tiny bulkheads to reduce the loss of cytoplasm if one cell wilts or becomes ruptured. Dikaryomycota species are some of the most drought tolerant organisms on the planet, some requiring only 70% relative humidity at the substrate surface to grow. Dikaryomycota is the phylum of primary interest in colonization of building materials. The phylum is divided into two sub-phyla: Ascomycotina and Basidiomycotina. Ascomycotina contains the majority of indoor fungi, but the Basidiomycotina also affect buildings or indoor air quality. Species are further identified and classified according to their method of reproduction and spore production.

Spores can be produced either asexually (anamorph stage) or sexually (teleomorph stage). Asexual reproduction is essentially cloning of a single cell. Sexual spores are the result of genetic recombination of two cells. Some fungi require both stages (e.g. the plant rusts). Most fungi that contribute to indoor air pollution reproduce primarily by asexual spores, with adaptation to changing environments occurring through mutations and hyphal fusions. The spores may be unicellular or contain up to 10-12 cells. Spores may be colorless and covered by mucopolysaccharides that allow them to be dispersed in water, or colored (with melanin or other pigments) and hydrophobic, with a waxy surface to keep them dry and aid their dispersion through the air. The asexual stage allows rapid production of spores to establish the fungal colony. The sexual stage occurs when conditions are favorable, and results in more durable spores which can spread the species over greater distances. When both teleomorph and anamorph stages are observed together, the result is a holomorph, and the species can be classified to the proper phylum. The spores produced by anamorph and teleomorph stages of the same species may appear quite different, and result in two different names for one species if they are not observed together.

Deuteromycetes or ‘Fungi Imperfecti’ (imperfect fungi) is a grouping included in most older classification systems for fungi whose sexual stages are not known, and classification is based on the pattern of asexual spore production alone. It is presumed that most of these fungi belong to the Ascomycota or Basidiomycota sub-phyla, in the phylum Dikaryomycota, but Deuteromycota is still considered to be a separate sub-phylum by many. Only the anamorph (asexual) stage has been observed in most of these species, in part because special environmental conditions might be required to produce the teleomorph (sexual) stage of reproduction, but also perhaps because some species have lost their ability to reproduce sexually altogether.

Ascomycetes, Basidiomycetes and Dueteromycetes are all ‘filamentous fungi’ which grow through hyphal filaments and produce spores to propagate. Those producing asexual spores directly on the mycelium are termed Hyphomycetes. Those producing fruiting bodies to contain the spores are called Coelomycetes. Most indoor fungi belong to the Hyphomycetes. Within this group, fungi are classified by the specific method of spore production. There are at least six different ways asexual spores are produced, and it requires considerable training to accurately place many fungi in the appropriate group. Simpler methods of classification involving spore morphology have been developed which are less accurate but more straightforward to apply. When the sexual stage of an imperfect species is discovered it should be reclassified to the proper phylum but commonly is not, to avoid the disappearance of the familiar name. This can result in a single species being classified into more than one phylum. Methods for genetic identification of DNA sequences might someday match all anamorphs with their teleomorphs and eliminate the classification of ‘imperfect fungi’. For now, the majority of fungi important to indoor air quality and colonization of building materials are known only by their anamorph stage, and are classified as ‘imperfect’ Dueteromycetes.

Physiology:
Fungi carry on aerobic respiration (producing CO_2 and water) in ways similar to plants and animals but different in many steps. In addition to aerobic respiration, some fungi can ferment some substrates, resulting in alcohol or lactic acid rather than CO_2 production. Yeasts are well known fermenters, used in the production of beer and wine. Fungi digest their food outside of the fungal cell by excreting enzymes into the environment. Many of these enzymes are unique to the fungi, and allow degradation of extremely resistant substances (e.g., lignin, cellulose, and polyethylene). In addition to enzymes, the fungi produce “secondary metabolites” that either accumulate in the environment or are stored in the fungus. These metabolites may be involved in fungal invasive diseases, cause allergic reactions, or be toxic. The most carcinogenic natural substance known is aflatoxin B1, a fungal metabolite. In many cases, the benefit of these compounds to the fungus is not known, but benefits to human kind have been

derived. Beneficial metabolites include Penicillin (antibiotic) and Cyclosporin (an immunosuppressant used to prevent transplant rejection). Fungi also produce many volatile compounds during active growth which may be odiferous or irritating.

Ecology:
Fungi are responsible for most aerobic decay in nature. There are fungi that will use almost any non-living organic substrate, and a few that will invade plant and animal tissue. Some fungi occupy very narrow ecological niches. *Cryptococcus neoformans* can be abundant in dry, shaded (indoor) pigeon droppings, with little competition in this alkaline, high salt environment. Exposure to sunlight or soil containing amoebae causes rapid elimination of this fungus. *Histoplasma* also utilizes bird droppings but requires the presence of water and soil as well. When a spore with broad nutrient requirements (able to use a wide variety of substrates) encounters damp organic material indoors, it is able to germinate and grow, resulting in indoor contamination. Any substrate that contains reduced carbon compounds and other nutrients will support the growth of some fungus if it is damp. In general, fungi prefer dampness rather than standing water but some (*Fusarium*, *Phialophora*, yeasts) will grow in standing water. Many filamentous species are saprobes, which decompose dead plant material and break down organic material to produce nutrient rich soil. Others have established a symbiotic relationship with plants, helping root systems to absorb nutrients from the soil. Some Basidiomycete and Ascomycete species (mushrooms, truffles, morels) are edible, some cause wood decay. Some fungi are parasites, causing diseases of crops and trees such as *Phytophthora infestans* which caused the great potato famine in Ireland during the late 1800's (Large, 1962) and *Cryphonectria parasitica* which caused the blight that destroyed virtually all of the towering chestnut trees which dominated forests of the eastern United States in the last century (Anagnostakis, 1987). There are only a few fungi that can infect people, but there are many that can grow in buildings and have the potential to degrade indoor air quality.

FUNGI THAT COLONIZE BUILDING MATERIALS
A wide range of fungal species can normally be cultured from air and dust samples in all buildings, as spores are brought in on the air, or tracked in by animals and occupants. Many of these will colonize building materials, given the right conditions. Some of the most prevalent species which grow in moisture damaged buildings accross North America and Europe are listed in the following table.

Table 1. Common fungi from mold-damaged building materials

Chaetomium globosum	*Aspergillus sydowii*
Penicillium viridicatum	*Penicillium commune*
Eurotium herbariorum	*Paecilomyces variotii*

Penicillium aurantiogriseum	*Eurotium repens*
Penicillium citrinum	*Memnoniella echinata*
Stachybotrys chartarum	*Aspergillus versicolor*

(adapted from Flannigan & Miller, 2001)

Because different species thrive under different conditions and on different substrates, the prevalent species found in different buildings, or different places within a building, may vary widely. The following table ranks the frequency of species identified in bulk samples taken from four mold investigation projects in Hawaii. All of the species listed in Table 1 also showed up in the Hawaiian samples (shown in bold face), suggesting a strong similarity of species with other parts of the world. The list in one column is from samples taken from buildings that were flooded by storm damage and/or had persistent leaks, the other column lists species from samples where condensation problems occurred, related primarily to improper insulation of air conditioning chilled water pipes. Samples were cultured and identified by a qualified analytical laboratory. Species were counted and ranked by the author, not by the number of viable spores or colony forming units (CFU), but simply by the number of times a given species was identified (frequency). Where a colony could not be identified to the species level, the genus is listed. Where *Stachybotrys* spores were identified by microscope examination but did not result in growth on the culture plate, they were included and listed as 'non-viable'.

Table 2. Species Cultured from Samples Taken in Hawaii

Bulk Samples from storm & leak damage		Bulk samples from condensation damage	
From 705 bulk samples	**Freq.**	**From 150 bulk samples**	**Freq.**
non-sporulating isolates	411	*Cladosporium cladosporioides*	130
Eurotium herbariorum	142	***Stachybotrys chartarum***	68
Aspergillus sydowii	104	***Penicillium viridicatum***	49
Chaetomium globosum	88	non-sporulating isolates	48
Penicillium aurantiogriseum	88	(yeast)	44
Penicillium citrinum	76	*Penicillium chrysogenum*	44
Talaromyces flavus	69	(actinomycete)	34
Penicillium viridicatum	46	***Eurotium herbariorum***	33
Aspergillus versicolor	37	***Stachybotrys* (non-viable)**	31
Penicillium chrysogenum	30	***Aspergillus sydowii***	30
Mucor hiemalis	24	***Memnoniella echinata***	27
***Stachybotrys* (non-viable)**	23	***Penicillium commune***	27
Stachybotrys chartarum	22	*Penicillium solitum*	24
Penicillium species	20	***Chaetomium globosum***	18
(actinomycete)	18	***Eurotium repens***	17
Alternaria alternata	18	(bacteria)	15
non-sporulating clamp connections	17	*Aspergillus ustus*	14
Rhizopus species	11	*Penicillium janthinellum*	14
Trichoderma harzianum	11	*Penicillium* species	14

Bulk Samples from storm & leak damage		Bulk samples from condensation damage	
From 705 bulk samples	**Freq.**	**From 150 bulk samples**	**Freq.**
Mucor species	10	***Aspergillus versicolor***	11
Penicillium fellutanum	10	*Cladosporium herbarum*	10
Penicillium oxalicum	10	*Penicillium glabrum*	9
Memnoniella echinata	9	*Penicillium fellutanum*	8
Penicillium purpurogenum	8	*Penicillium variabile*	8
Cladosporium species	6	*Aspergillus niger*	7
Ulocladium botrytis	6	*Rhizopus nigrans*	6
Paecilomyces variotii	5	*Cladosporium* species	5
Penicillium corylophilum	5	*Penicillium olsonii*	5
(yeast)	4	*Penicillium spinulosum*	5
Aureobasidium pullulans	4	***Penicillium citrinum***	4
Cladosporium sphaerospermum	4	*Cladosporium sphaerospermum*	3
Aspergillus species	3	*Fusarium* species	3
Penicillium brevicompactum	3	*Mucor hiemalis*	3
Penicillium crustosum	3	non-sporulating clamp connections	3
Penicillium decumbens	3	*Penicillium oxalicum*	3
Aspergillus niger	2	*Verticillium* species	3
Cladosporium cladosporioides	2	*Acremonium strictum*	2
Eurotium repens	2	*Aspergillus ochraceous*	2
Monilia sitophila	2	*Aspergillus* species	2
Penicillium rugulosum	2	*Aspergillus wentii*	2
Phoma species	2	*Penicillium rugulosum*	2
(ascomycete)	1	*Tricothecium roseum*	2
Acremonium species	1	*Alternaria alternata*	1
Aspergillus fumigatus	1	*Aspergillus japonicus*	1
Aspergillus ochraceous	1	*Gliocladium roseum*	1
Aspergillus ustus	1	*Neosartorya fischen*	1
Cladosporium herbarum	1	*Penicillium corylophilum*	1
Fusarium oxysporum	1	*Phialophora bubaki*	1
Penicillium janthinellum	1	*Talaromyces flavus*	1
Penicillium olsonii	1	*Trichoderma harzianum*	1
Penicillium variabile	1		
Pithomyces chartarum	1		
Rhizopus nigrans	1		
Talaromyces species	1		

CONDITIONS THAT ENCOURAGE GROWTH

The species found on building materials depends on available moisture, temperature and food source, but primarily on moisture. Their growth on culture plates depends on the handling of samples, type of culture medium used, temperature and moisture conditions during culturing, and competition between species on the culture plate. The prevalence of species in culture medium is therefor not necessarily indicative of their prevalence in the building. For example, *Stachybotrys* spores are relatively difficult to culture, do not remain viable as long as many other species, and are easily overgrown by other species on culture plates (Amman, 2000). In Table 2 above, *Stachybotrys* ranks much higher in the condensation damaged buildings than in the storm or leak damaged buildings, because continuous condensation maintains the wet conditions favored by this species giving it a competitive advantage. Storm saturated materials can quickly grow large areas of wet-loving *Stachybotrys*, but as they slowly dry out other species become predominant. *Stachybotrys* spores eventually become non-viable as materials dry, but as illustrated in the first column of Table 2, the non-viable spores might be found more frequently in samples than viable spores. This is significant because their dry spores are more likely to become aerosolized than spores from active growth.

The primary factor in mold growth is available moisture in the substrate, which is measured as an equilibrium relative humidity at the surface where growth occurs, commonly expressed as water activity (a_w). At an a_w of 0.65 (65% RH at the surface), no significant fungal growth can occur. Damp materials (a_w 0.65 to 0.85) which are subject to bio-deterioration can support growth of relatively xerophilic (dry-loving) fungi such as *Eurotium* spp., *Aspergillus versicolor* or *Wallemia sebi*. Materials that are chronically wet (a_w >0.9) are dominated by hydrophilic fungi such as *Ulocladium*, *Stachybotrys*, *Chaetomium*, and *Fusarium* spp., which are sometimes referred to as "signature flood fungi" (Morey et al., 2000; Morey, 1997). Table 3 lists some common species and their preferred moisture conditions.

Table 3. Water Activity Levels for Some Common Species

Table 3. Generalized sequence for potential colonization of susceptible substrates by molds studied (Grant et al., 1989)
Brian Flannigan and J. David Miller, "Humidity and Fungal Contaminants", in *Bugs Mold & Rot II*, BETEC, 1993

Aw level in substrate	**Species of molds colonizing substrates at:**	
	12Cº (54º F)	**25Cº (77º F)**
<0.80	Aspergillus repens	Aspergillus repens
	Penicillium brevicompactum	Aspergillus versicolor
(Primary colonizers)	Penicillium chrysogenum	Penicillium brevicompactum
xerophilic	Penicillium spinulosum	Penicillium chrysogenum
		Penicillium nigricans
		Penicillium spinulosum
0.80-0.90	Aspergillus versicolor	Alternaria alternata
	Aureobasidium pullulans	Aureobasidium pullulans
(Secondary colonizers)	Cladosporium cladosporioides	Cladosporium cladosporioides
slightly xerophilic	Cladosporium sphaerospermum	Cladosporium sphaerospermum
	Geomyces pannarum	Fuserium moniliforme
	Mucor plumheus	Geomyces pannorum
	Penicillium nigricans	Ulociadium chariarum

Aw level in substrate	Species of molds colonizing substrates at:	
	12Cº (54º F)	25Cº (77º F)
	Ulociadium chariarum	Ulociadium consortiale
>0.90	Alternaria alternata	Mucor plumbeus
	Fuserium moniliforme	Phoma herbarum
(Tertiary colonizers)	Phoma herbarum	Sistotrema brinkmannii
hydrophilic	Sistotrema brinkmannii	Stachybotrys chartarum (atra)
	Stachybotrys chartarum (atra)	
	Ulociadium consortiale	

It is important to note that moisture directly affects active growth, but has a much lesser effect on viability of spores. While air-dried mushroom spores can survive a year at room temperature, spores of Aspergillus and Penicillium may remain viable more than 12 years under similar conditions (Miller, 1992).

POTENTIAL HEALTH EFFECTS

Why should we be concerned about fungal growth in buildings, aside from the obvious undesirability of having our homes digested by microbes? Recent large scale epidemiological studies have shown an association between adverse human health effects and dampness in buildings (Miller and Day, 1997). Further studies suggest that fungal exposure can exacerbate asthma symptoms, trigger allergic reactions, elicit an immune system response, cause invasive and opportunistic infection in humans, and may also cause toxic disease (Ponikau, 1999; IOM, 2000; Burge, 2000). Human health effects include 1) infection, 2) allergy, 3) irritation, and 4) toxicity.

Infection:

Most fungi use non-living material (saprophytes) but a few are pathogens and will invade human tissue. Some saprobes can also cause infection and impact the health of building occupants. Fungi that cause human disease often exist in both mycelial and a unicellular yeast form. These are called “dimorphic” fungi. The conversion is often related to temperature. At room temperature the fungi are mycelial, at body temperature they are yeast-like (Rippon, 1998).

Four general types of infectious disease are caused by fungi: 1) cutaneous infections; 2) subcutaneous mycosis; 3) systemic mycosis, where the fungus is disseminated throughout the body in an otherwise normal host, and 4) opportunistic infections, where the fungus invades human tissues when the host defenses are impaired. Cutaneous and subcutaneous mycoses are not considered airborne diseases. The common airborne systemic mycoses include: 1) Histoplasmosis (agent: *Histoplasma capsulatum*); 2) Coccidioidomycosis (agent: *Coccidioides immitis*); 3) Blastomycosis (agent: *Blastomyces dermatitidis*), and 4) Paracoccidioidomycosis (agent: *Paracoccidioides braziliensis*). None of these fungi are routinely transmitted from indoor reservoirs and normally grow in soil or are carried in by birds or bats, but Histoplasmosis and Blastomycosis have occurred when infected substrates are disturbed near interiors or when unusual situations allow growth of the organisms indoors. When the human immune system is compromised, opportunistic pathogens may invade human tissues. The most familiar of these fungi are *Cryptococcus neoformans* which colonizes pigeon droppings and *Aspergillus fumigatus*, which is a ubiquitous fungus that is a primary agent of decay at elevated temperatures (greater than 40°C, 104°F). Other molds (especially some species of *Fusarium*) can cause disease in immune-compromised individuals such as cancer patients, burn patients or people with AIDS (Miller, 1992). Any fungus that is able to grow at the elevated temperature of the human body and is able to utilize the particular compounds present may be an opportunistic pathogen. Some Aspergillus, Bipolares, Epicoccum, and Paecilomyces species may become pathogenic given the opportunity. A normal immune system is well equipped to prevent such invasions but reduced immune function may result in disease. Primary factors which decrease immune function include diseases (AIDS and some forms of cancer) and immuno-suppressive medication (e.g., steroids, Cyclosporin).

Allergy:
A wide range of fungal species are related to antigenic and allergenic disease. It is thought that all mold species are potentially allergenic given adequate exposure, but *Alternaria*, *Aureobasidium*, *Chaetomium*, *Cladosporium*, *Epicoccum*, and *Ulocladium* all contain known allergenic species. Although wood decay fungi are not normally associated with indoor air quality, their spores are some of the most potent of the fungal allergens. Antigens are substances that induce an immune response. An antigen is called an allergen when it stimulates production of immunoglobulin E (IgE) antibodies. Fungi produce a variety of compounds that are potentially antigenic and allergenic. Sensitization normally occurs through airborne exposure. Two types caused by airborne fungal antigens are allergic disease (asthma and rhinitis) and hypersensitivity pneumonitis. Some fungi can grow in the thick secretion that builds up in the lungs of some asthmatic patients. These fungi do not actually invade the human tissue, but grow in the mucous and produce antigens (and possibly toxins) that cause disease. The most common fungus causing this disease is *Aspergillus fumigatus*. Fungi need not be alive and culturable to be antigenic. Methods that rely exclusively on viability may overlook serious cases of contamination.

Mucous Membrane and Trigeminal Nerve Irritation:
Fungi produce metabolites and secondary metabolites, depending on conditions and the substrate being digested. Some of these are given off in gaseous form, as volatile organic compounds (VOCs), which may be particularly pungent or unpleasant metabolic products. Even toxic gas can be released, depending on the species and substrate on which it grows. For example, a fungus growing on wallpaper released the highly toxic gas arsine, from arsenic containing pigments (Gravesen et al., 1994).

VOCs result in moldy odors and may cause irritation of the mucous membranes of the eyes and respiratory system. Fungal volatile compounds may also impact a "common chemical sense" which responds to pungency. This sense is associated with the trigeminal nerve, which responds to pungency (not odor) by initiating avoidance reactions, including breath holding, discomfort, or odd sensations such as itching, burning and skin crawling. Decreased attention, disorientation, diminished reflex time, dizziness or other effects can also result from exposure. Fungal VOCs may be a primary cause, or contribute to compounds given off by other building materials. Higher levels of VOC exposure from any source are mucous membrane irritants and can affect the central nervous system, resulting in headache, attention deficit, inability to concentrate or dizziness. (Amman, 2000)

Toxicity:
Many molds produce mycotoxins and antibiotics, which are secondary metabolites. It is thought that these poisons are produced to provide a competitive advantage over other fungi and bacteria to limit the growth of competing colonies, or to kill them so that they can be digested and consumed. Nearly all mycotoxins are cytotoxic, disrupting cell structures and interfering with vital cellular processes such as protein, RNA, and DNA synthesis. Though intended to damage competing microbes, these metabolites are also toxic to the cells of higher plants and animals, including humans. Not all molds produce mycotoxins, but many do. Toxigenic molds vary in their mycotoxin production depending on the substrate on which they grow (Jarvis, 1990). Almost all mycotoxins have an immunosuppressive effect and increase susceptibility to infectious disease. The effect is compounded by cytotoxin's damage to aleveolar microphages (Amman, 2000). Some mycotoxins are among the most carcinogenic substances known; others may increase susceptibility to cancer. Molds which produce toxins pose excess health risk compared to other molds though the level of exposure to toxic molds that will result in disease is also not yet clearly understood (Miller, 1998).

Fungi need not be alive and culturable to leave toxins which may remain in the environment long after the fungus is dead. Sampling methods that rely on viability may overlook toxic contamination. On the other hand, the presence of a toxigenic fungus does not imply the presence of toxins due to variability in toxin production. One must analyze for the toxin directly.

Toxigenic fungi found in moisture damaged buildings are most commonly *Penicillium*, *Aspergillus*, and *Stachybotrys* species. The toxic metabolites from Penicillium include nephrotoxic citrinin (produced by *Pennicillium citrinum*, *P. expansum* and *P. Viridicatum*), nephrotoxic ochratoxin from *P. cyclopium* and P. *viridicatum*) and patulin (from *P. expansum*). Toxins from *Aspergillus* species include aflatoxins produced by *Aspergillus parasiticus* and *A. flavus*, sterigmatocystin from *A. versicolor*, and tremorgenic toxins in the conidia of *A. fumigatus* (Smith and Moss, 1985). Aflatoxin exposure has been linked to liver cancer. Inhalation of some mycotoxins has been shown to be many times more toxic when inhaled than when the same toxin is introduced intravenously. Aflatoxins are potent natural carcinogens, but diagnosis may be difficult due to their ten year latency (Miller, 1992). *Stachybotrys chartarum (atra)* produces macrocyclic tricothecenes, which have been attributed to causing health symptoms including headache, sore throat, hair loss, flu symptoms, diarrhea, fatigue, dermatitis, general malaise, and psychological depression (Croft et al., 1986; Jarvis, 1995). Health effects related to inhalation of trichothecenes may also be difficult to diagnose, as they affect immune suppression, resulting in other variety of diseases (Miller, 1992). Many other species which grow in buildings can produce a variety of other toxins though their occurrence may be less common, including those from *Alternaria*, *Epicoccum*, *Fusarium*, *Paecilomyces*, *Trichoderma*, and a few *Cladosporium*.

CONCLUSIONS

Fungi play an essential role in our global ecology and survival of plant and animal species, but can also pose a significant health risk when they are permitted to grow in buildings. Control of indoor growth depends on control of moisture sources. Architects and building designers must pay particular attention to details which might admit moisture or result in condensation problems, but building occupants and maintenance personnel must also remain alert to signs of moisture damage. The variety of potential health effects, the variety of fungal species that may impact human health, and the variability in susceptability of individuals makes establishment of specific ‘safe’ exposure limits difficult or impossible. Presently, all mold growth in interior spaces should be considered undesirable and a potential health hazard. Where fungal growth is found, it should be properly cleaned or removed using appropriate containment and personal protective equipment for protection of building occupants and remediation workers, following guidelines recently established by a number of associations and public agencies (Macher et al., 1999; NYC, 2000; EPA, 2001).

ACKNOWLEDGMENTS

Discussion of fungal classification systems was adapted from Bryce Kenderick, Harriet Burge, and lecture outlines prepared by George Wong.

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