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Introduction

The general public and the ASHRAE membership share a concern with the problems associated with excess moisture and mold in buildings. While not common compared to the number of buildings built every year, these problems are complex and are occasionally widely publicized. They seldom fall neatly into any single professional responsibility. Biology, medicine, engineering, architecture, construction, and building operation all contribute to understanding and managing moisture in buildings. When difficulties occur, they usually expose gaps between these disciplines, and sometimes expose shortcomings of our overall understanding of the behavior of moisture and its consequences.

However, within ASHRAE we have resources to help the public and the professional community understand the technical issues. Recently, the society has formed a technical committee (TC 1.12, Moisture Management in Buildings) to collect, synthesize, and present information in this area for the public benefit. The committee confidently looks forward to the day when these issues will not only be understood, but will also be placed into perspective with each other and assigned their appropriate weight with respect to other concerns. ASHRAE TC 1.12 invites questions as well as the support of the membership and the general public in achieving balance, completeness, accuracy, and utility in our ongoing efforts of research and technology transfer.

This collection of papers is an example of the combined efforts of the ASHRAE staff, the editor of the ASHRAE Journal, and members of TC 1.12. In some cases, current TC 1.12 committee members are represented as authors. In others, the staff or committee members suggested papers that they have found helpful in showing others how moisture behaves in buildings, what happens when there is too much of it, and how these problems can be avoided.

The papers have been divided into sections addressing different aspects of moisture management and mold. These papers are not, of course, the last word on these topics. They are simply a good beginning point for those who have a need to understand some of the basics.

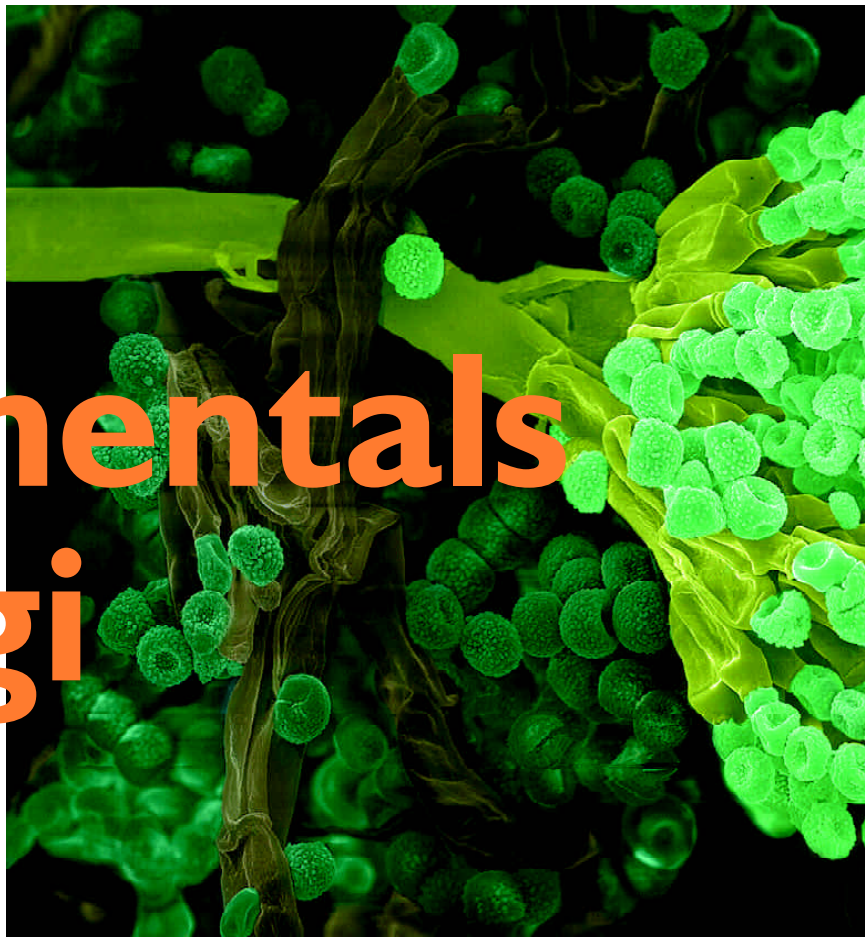
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Section I
Mold

ASHRAE Journal

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The Fundamentals Of Fungi



Penicillium growing on Romano cheese.

By Sarah Armstrong
and **Jane Liaw**

Anyone who has seen, either first-hand or in photographs, homes infested with large, oozing mats of black mold is understandably worried about the effects of mold on health. Since urban residents are usually indoors for as much as 90% of the time (and some groups for even longer), many people experience prolonged exposure to indoor contaminants such as fungi.[1]

This article reviews some of the biology of fungi (which include molds), adverse effects of fungi generally, factors favoring their growth indoors, and research into the health effects of indoor fungi specifically. Despite intense public interest in the subject, science is not yet sufficiently well developed to answer many basic questions about the potential health threat posed by indoor fungi, and no standards for exposure to molds have been promulgated.

Fungi Basics

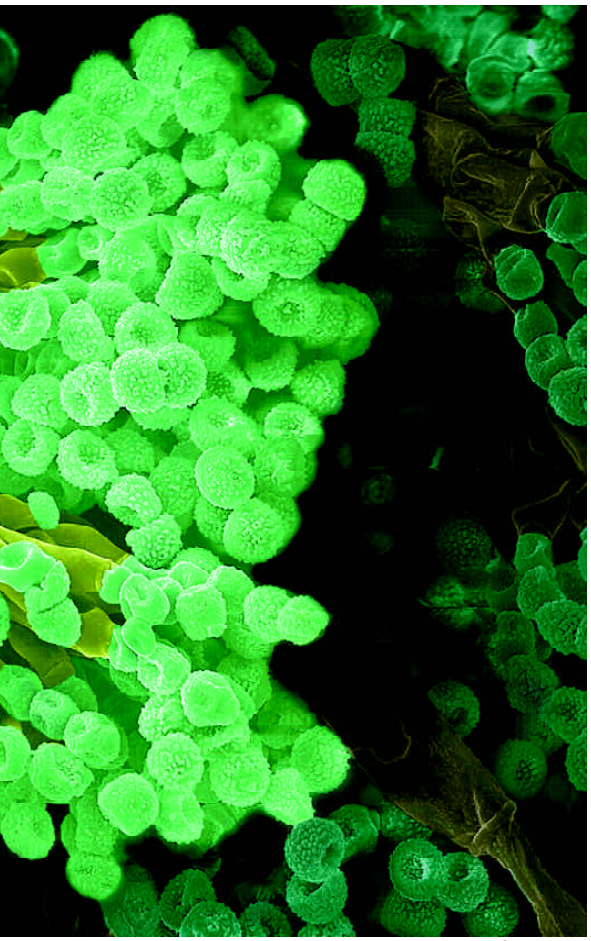
The fungi kingdom comprises single-celled or multicellular non-motile organisms that cannot make their own food. They rely on other organisms or their environments for nutrients. For example, fungi will colonize soil, food, wood, other organisms — indeed, almost any carbon-based material that supplies appropriate nutrients and water. Fungi exhibit a diversity of forms, undergo complicated life cycles, and occupy a spectrum of environments.

In general, fungi actively growing indoors can exist as yeasts or molds. Yeasts are single-celled organisms that may reproduce by budding or simple mitosis. Molds are more complex, developing large colonies (mats or balls) of multicellular filaments, called hyphae. Some hyphae penetrate the material that is being used for food, making removal difficult. Others lie on the surface and develop reproductive structures when conditions are appropriate. Both molds and yeasts can produce spores that are more resistant to drying than the "parent." Many of these spores disperse easily in the air, can remain dormant for extended periods, and then germinate when conditions become appropriate.[2] Indoor molds thus present the potential for exposure to whole or fragmented spores and hyphae, as well as emitted volatile chemicals.

Certain fungi provide valuable resources for humans, such as food (e.g., mushrooms) and antibiotics. Others perform important functions, such as leav-

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> 'Despite intense public interest in the subject, science is not yet sufficiently well developed to answer many basic questions about the potential health threat posed by indoor fungi, and no standards for exposure to molds have been promulgated.'

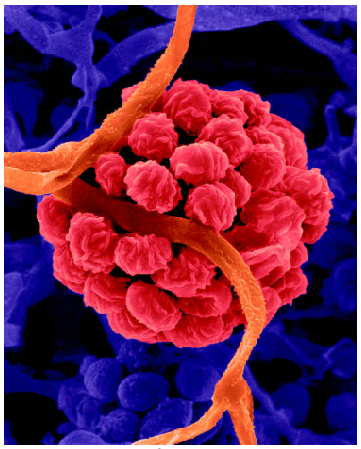
ening of bread, ripening of cheese, and fermenting of sugars into alcohols.

Fungi are ubiquitous, occurring in soil, in and on plants and animals, in air, and indoors. In buildings without active fungal growth, total spore concentrations of 3,000 to 10,000 spores/m^3 (85 to 285 spores/ft^3) can be found in the air. In heavily infested homes, total spore concentrations can exceed 30,000 spores/m^3 (857 spores/ft^3). Approximately 10% of the spores may be viable, or capable of growing on collection media.[3] The most common molds found in indoor air are *Cladosporium*, *Penicillium*, and *Aspergillus*, but many others may also occur. The specific collection of fungi in an indoor environment depends on the species present outside and on the particular conditions favoring (or disfavoring) growth of individual species indoors.

Fungi are usually stressed, if not killed, or may go dormant if exposed to ultraviolet light and low atmospheric humidity. Moisture is needed for germination of spores and continued growth of the fungus. Moisture requirements depend on the species, substrate, and temperature.

Potential substrates for mold growth include wood, paper, and textiles, and are numerous in buildings. Some molds will even grow on substrates that provide no nutrients, such as steel or fiberglass, as long as nutrients and water are present in the air or in dust settling on the molds.[3]

The most important risk factor for heavy mold growth indoors is excess water. Other sources of high air and/or substrate humidity are infiltration through foundations, leaks in roofs, walls, or windows, improperly designed or maintained HVAC systems, condensation, and poor circulation.[3,4] Since spores are ubiquitous, water-damaged areas should be dried within 24 to 48 hours to prevent germination and subsequent mold growth.[5]



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Stachybotrys as photographed using an electron microscope.

Health Effects

At levels normally encountered, most fungi entering the body are harmless to humans. However, some may harm health either through infection, production of toxins, or over-stimulation of the immune system.[6] Examples of each toxic mechanism follow:

• Fungal infections range from the relatively benign, such as athlete's foot or vaginal yeast infections, to the dangerous, such as pulmonary histoplasmosis and systemic infections by yeasts or *Aspergillus* species in immunologically compromised people.

In people with competent immune systems, infections occur chiefly on the skin or other exposed membranes and in the lungs. However, fungi sometimes enter the bloodstream, either on their own or during medical procedures. Even in the absence of infection, humans are colonized by a variety of fungi, such as yeast that typically occur in the vagina where their growth is held in check by bacteria.[7,8]

• Some components of fungi or fungal metabolites are toxic to humans. Aflatoxin, for example, is a powerful liver toxin and carcinogen when ingested. Aflatoxin is made by *Aspergillus* molds that grow on improperly stored grain. Many other fungal metabolites (also called mycotoxins) are documented toxins in laboratory animals or livestock, if not in humans.[9] These mycotoxins include ochratoxins, trichothecenes, and

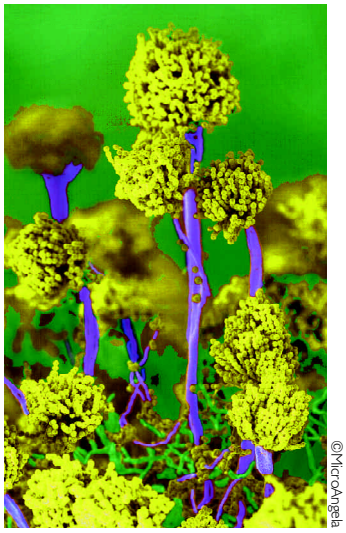
fumonisins. Importantly, there is little evidence that mycotoxins cause illness when inhaled, as opposed to ingested, except for aflatoxin.[10]

• Lastly, fungi or their components are known to cause several hypersensitivity reactions involving the immune system, such as allergy, asthma, and hypersensitivity pneumonitis (HP). All of these responses occur following inhalation of fungi or fungal antigens (small protein sequences). More than 60 species of fungi can cause chronic allergies.[3] *Penicillium* and *Aspergillus* species are common indoor fungi that cause asthma.[12] HP, a hypersensitvity disease of the lungs that frequently manifests as fever, cough, and chills with inflammation of the lung tissue, is caused by exposure to a variety of antigens, many of which are derived from fungi.[13] Importantly, dead as well as live fungi can trigger hypersensitivity responses if their antigens are intact.

Besides infection, mycotoxins, and immune stimulation, indoor fungi might, in theory at least, also cause illness by release of volatile organic compounds such as alcohols and ketones, or cell wall components such as glucans.

The recent health concerns raised by non-occupational, indoor fungi exposure are chiefly respiratory and pulmonary symptoms or diseases such as nasal irritation, allergic or non-allergic rhinitis, hypersensitivity pneumonitis, and pulmonary hemorrhage, as well as malaise and fatigue. Notwithstanding the numerous case reports, epidemiologic studies, and reviews on the subject, difficulties in establishing a causal link between these illnesses and exposure to indoor fungi (or specific fungi) include:

1. Existence of non-fungal causes of these illnesses;
2. High prevalence of some of the conditions, such as rhinitis, in the general population;
3. Scarcity of appropriate exposure assessment methods for fungi and their components; and
4. Difficulty of proving cause and effect with case reports and epidemiologic studies.



Penicillium mold on bread.

Few animal studies relevant to the risk assessment of indoor air effects of mold have been undertaken[14] and toxicologic data regarding inhaled molds are sparse. One study of mice found that exposure to *Stachybotrys chartarum* spores caused a change in the activity of an enzyme, which in turn could lead to lung dysfunction.[15]

Epidemiologists, who study patterns of illness in populations, have conducted the majority of research relevant to the effects of indoor molds on health. Epidemiologists have generally used indoor dampness as a potential indicator of indoor fungi exposure, rather than any direct analysis of molds. A Nordic Interdisciplinary committee recently reviewed sixty-one such investigations.[16] "Dampness" indicators included "visible mold," "damp stains," "condensation on window panes and/or walls," "flooding," "water damage," and "smell/odor." Often, research subjects made their own environmental assessments, which might have been inaccurate or inconsistent. In general, dampness in buildings appeared to be associated with an increased risk of health effects such as cough, wheeze, asthma, airways infections, tiredness, and headache. However, with the exception of dust mite exposure, it was not known what aspects of "dampness" might have been responsible for the health effects observed.

In one example of a dampness investigation, Dales et al.[17] received questionnaires from the families of almost 15,000 children (83% response rate) in 30 Canadian communities. "Dampness," defined as presence of mold or mildew during the preceding year, presence of wet spots (excluding basement) and flooding or leaks in the basement, was present in 38% of the homes. To gauge possible over- or under-reporting of symptoms, the investigators included questions about major accidents or severe illness unrelated to the chest. They found significant associations between "dampness" and all health endpoints of interest, including asthma, chest illness, eye irritation, nausea, vomiting, and headache. The strongest association was found between cough and the number of damp spots.

It is unclear by what mechanisms fungi are responsible for the association between dampness and ill health, or even whether fungi are responsible at all.[18] Because dust mites and bacterial endotoxins are also commonly found in homes and are also known to cause symptoms or disease, both are plausible confounders of the association between mold and diseases.[19]

Some dampness studies have attempted to account for dust mite exposure. For example, Bornehag et al.[16] note that in the studies they reviewed, associations between "dampness" and health sometimes occurred in areas with little mite exposure, such as parts of Scandinavia where the indoor climate is dry during winter. In another investigation, researchers visited the homes of 403 Canadian school children and found a statistically significant increase in several respiratory symptoms associated with reported mold growth, even after adjusting for subject characteristics, dust mite antigens, and endotoxins.[19]

Clearly, more studies are needed to clarify the role of molds generally, or of specific types of mold, in causing specific indoor illnesses.

Susceptibility of Children

Reactive airways diseases (such as asthma) in children have been increasing in many countries. There is evidence that indoor mold growth is an important risk factor. Children are es-