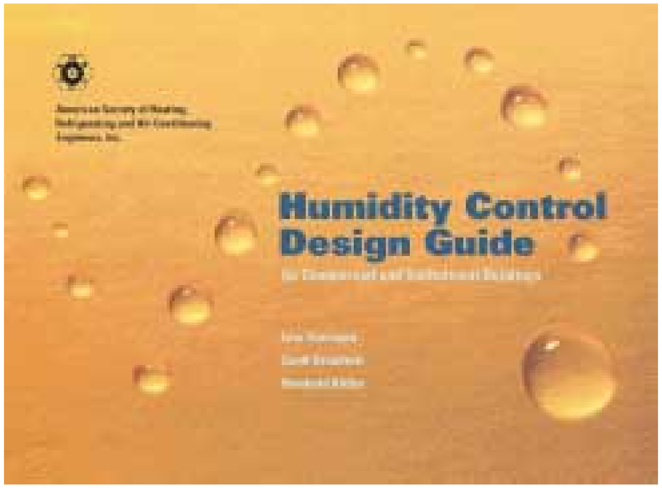


CHAPTER REPRINT

Humidity Control Design Guide

Harriman, Brundrett & Kittler

ISBN 1-883413-98-2

512 Pages • December 2001 • $120 List ($78 Member Price)

ASHRAE
American Society of Heating, Refrigerating and Air Conditioning Engineers
1791 Tullie Circle, NE
Atlanta, GA 30329 USA

(404) 636-8400
www.ASHRAE.org

Basics

1. Purpose, Assumptions & Terminology
2. Humidity Control Basics
3. Psychrometrics of Humidity Control

Humidity Effects

4. Human Comfort
5. Corrosion
6. Electrostatic Discharge
7. Mold & Mildew
8. Dust Mites & Insects
9. Bacteria & Viruses

System Design

10. Design Procedure
11. Estimating Dehumidification Loads
12. Estimating Humidification Loads

Equipment & Controls

13. Dehumidifiers
14. Humidifiers
15. Load Reduction Equipment
16. Building Pressure Management
17. Humidity Sensors & Controls

Applications

18. Schools
19. Office Buildings
20. Retail Buildings
21. Hotels
22. Restaurants
23. Museums, Libraries & Archives
24. Hospitals
25. Eldercare Buildings
26. Dormitories
27. Swimming Pools
28. Ice Rinks
29. Dry Air Storage
30. Laboratories

Design References

31. Weather Data for Design
32. Reference Material

Chapter 7
Mold & Mildew

By Lew Harriman & Berlin Nelson

Basics of Mold Growth — 100, 101

Moisture governs growth — 102, 103, 104

Mechanics of Mold Growth — 104, 105, 106, 107, 108, 109
- Four stages

Molds Common In Commercial Buildings — 110, 111, 112, 113, 114
- Typical species
- *Stachybotrys chartarum*

Mold In The Building And Its Contents — 115, 116, 117, 118
- Wall coverings
- Above & on ceilings
- Books, carpets, fabrics

Mold In The HVAC System
- Filters
- Drain pans
- Unitary equipment
- Duct work downstream of cooling coils
- Humidifiers

References — 119, 120

Fig. 7.1 Clouds of Fungal Spores
To reproduce, fungi release millions of spores. A single spore can regenerate the fungus, provided that it lands on a food source which has enough surface moisture to begin the growth cycle.

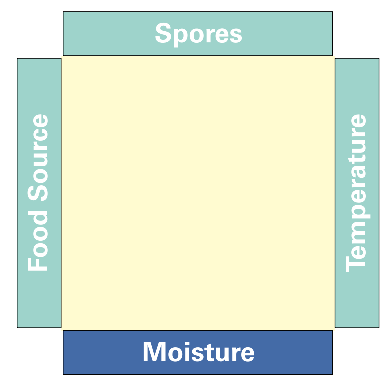


Fig. 7.2 "The Mildew Square"
This shape reminds designers that all fungi need four elements to grow and thrive. Of these, moisture in the food source is the most universal—and most preventable—component. (Peart 1989)

Basics of Mold Growth

When you walk into a building and smell a musty odor, you can be certain that mold and mildew are present in the building envelope, or in the duct work, or both. By the time the odor becomes perceptible, the problem is well-established. By understanding how a fungus grows, the HVAC designer can take steps to help avoid the problems these organisms create in buildings.

Mold is everywhere

Mold and mildew are fungi, which are essential to life on the planet earth. Without fungi, we would quickly be buried under a thick layer of dead tree trunks and leaves. Fungi pull apart all carbon-based debris, reforming the component particles into smaller molecules which can be digested by other life forms. Mycologists—those who study fungi—are still discovering new forms of fungus. At present, they know there are at least 64,000 varieties, and that these thrive on substances as unexpected as jet fuel and oil in fingerprints. In seasons which favor fungal reproduction, air outdoors is likely to contain 3,000 to 5,000 colony-forming units (cfu's) per cubic meter. In scrapings from inside air ducts, counts of 1 to 2 million spores per milligram of dust are common. Consequently, although filters can limit their number, some fungal spores are present in all buildings at all times.

Conditions needed for mold growth

In order to grow, mold needs four elements:

1. One viable spore
2. An acceptable temperature range
3. A usable food source
4. Adequate moisture in the food source

Fig. 7.3 Mildew In Books
When humidity is high, moisture is adsorbed into books. Moisture can build up, providing fungus with the solvent needed to dissolve the surface of the paper and promote growth.

These elements have been described graphically as a "Mildew Square" by Dr. Virginia Peart and Dr. James Kimbrough of the University of Florida. (1989, 1991) That graphic is shown in figure 7.2.

Spores are everywhere. Sooner or later, the right spore for the available food source will find its way to every surface.

Temperature is quite important. Each fungus has an optimal range of temperatures that allow growth. Beyond that range, growth is slow or impossible for that particular fungus, and other fungi will take over the food source. Indeed, when temperature changes kill the first fungi or make them dormant, other fungi will feed on the original fungi as well as on the abandoned food source.

The nature of the **food source** affects the type of fungi that can use it to grow. Thousands of fungi are equipped to digest cellulosic material such as wood, paper and cardboard. A smaller number of fungi are adapted to make use of organic material in oils, plastics or dust that collects on normally sterile surfaces such as metals and glass. For every carbon-based material, there is some form of fungus that can use it as a food source.

Of all essential elements, **moisture** is the simplest and most universal requirement for fungal growth. Without moisture, fungus cannot access the nutrients in its food sources. On dry surfaces, spores will remain dormant until adequate moisture appears.

In moderate temperature ranges and on easily-digestible food sources, many fungi will compete. One way they can compete is through "chemical warfare." Many fungi emit liquids and volatile organic gases that suppress the growth of their competitors. In some cases, the "musty odors" perceptible to humans reflect this fungal competition.

A dramatic example of the importance of moisture and the longevity of spores is seen in the desert tombs of the ancient Egyptians. Pigments that had been safe for many millennia deteriorated in a matter of a few years when moisture from human respiration increased humidity at the painted surfaces.

Mechanics of mold growth

Mold growth proceeds in 4 stages. The first is the most important in relation to humidity control in buildings and HVAC systems.

Stage 1 - Create nutrient broth

First, a spore lands on a food source. That spore remains dormant until the food source absorbs enough moisture at its surface to dissolve the hygroscopic enzymes that cover the surface of the spore. In this first stage of growth, moisture from the food dissolves the enzymes, which then act as corrosive catalysts, dissolving the food. Then the liquid nutrient broth under the spore is pulled back into the spore through a difference in osmotic pressure. The liquid nutrient outside the spore is less concentrated than the dry matter inside the spore. So liquid nutrient diffuses through the spore's exterior wall to equalize concentrations on both sides of that spore wall. *At this first stage of growth, the fungus is easily controlled. As long as the food source lacks sufficient moisture, the enzymes do not dissolve, so nutrients are not available to feed fungal growth.*

Stage 2 - Generate more absorptive surface

When sufficient moisture is available at the surface of the food, growth proceeds to the second stage. The fungus begins to extend its reach for nutrients by growing filaments called hyphae. As more nutrient solution is drawn into the hyphae, more filaments are grown, eventually forming a dense mat called the mycelium. Towards the end of this stage, the organism may become visible to the unaided human eye. Then, as the mycelium thickens it behaves as a vapor retarder, preventing the food surface from drying out, which would slow or halt growth.

Stage 3 - Generate metabolic water

After the mycelium thickens, the fungus can generate and retain enough moisture through its normal metabolism to maintain growth. As food is metabolized, moisture is produced. This water combines with more enzymes to dissolve additional food. At this third stage, lack of moisture from the air will not limit growth. Fungus will grow

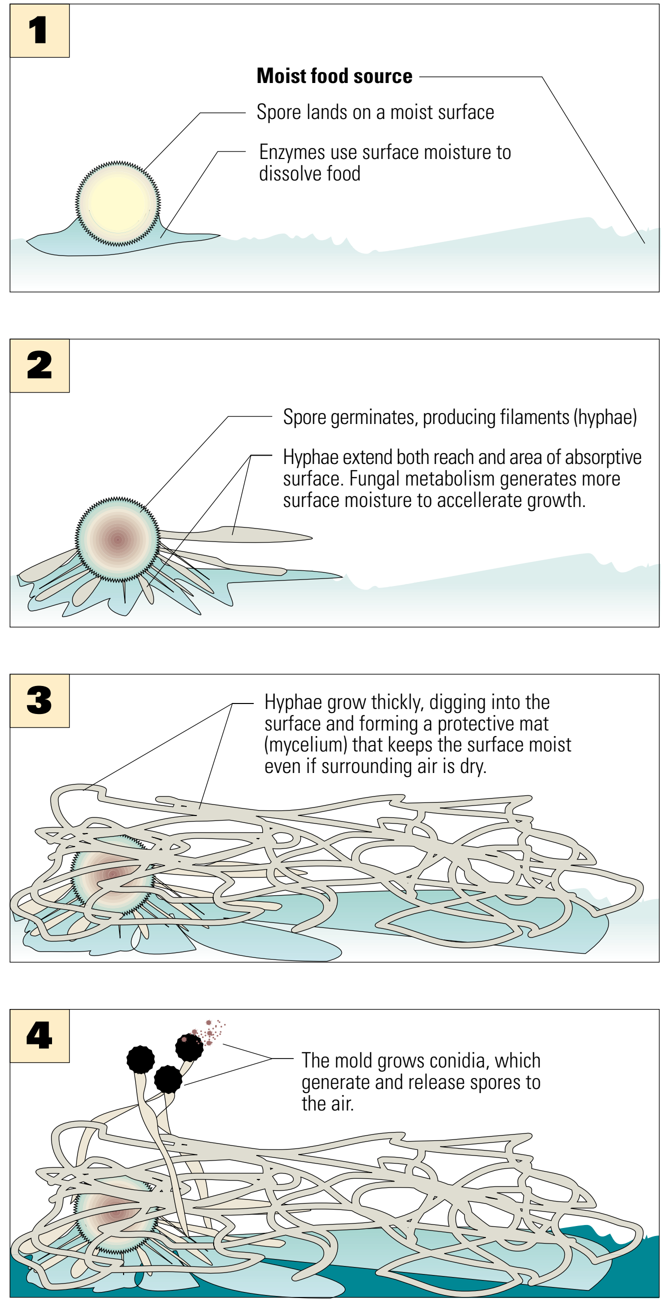


Fig. 7.4 Stages of Mold Growth

In early stages, the food source must be moist to initiate growth. In later stages, fungal metabolism supplies the needed moisture. (Kimbrough 1990) until it consumes the food, or until the temperature changes, or until it is killed by some other means such as ultraviolet light or a toxic chemical such as bleach. Unfortunately, at this stage, the hyphae extend *below* the surface into the bulk of the food. So even if fungal bodies on the surface are killed, the organism can regenerate from its components buried deep inside the food. This explains why remediation is so difficult after mold growth is firmly established. Surfaces that appear clean can re-grow mold when moisture returns to the food source.

Stage 4 - Reproduce

After the third stage of vigorous growth, the fungus has the resources necessary to reproduce. It forms fruiting bodies which generate spores by the millions. These are released to the air, often accompanied by perceptible vapors—the "musty odors" so common to HVAC systems in humid climates. Spores drift through the air to other food surfaces. The cycle repeats when the new food source has sufficient moisture to dissolve the spores' external enzymes.

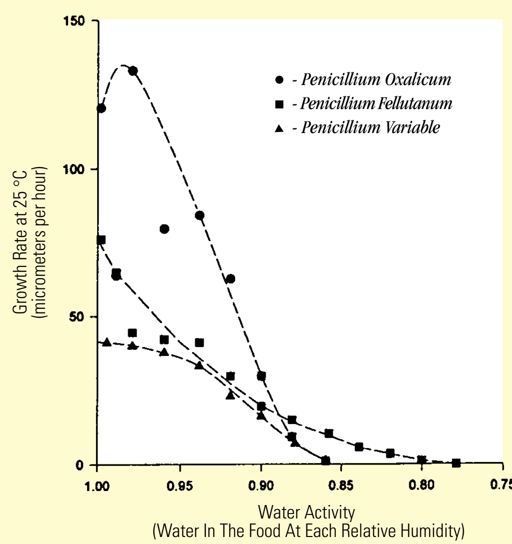


Fig. 7.5 Growth Rates

Vary by type of fungus. Each type thrives in a slightly different range of moisture content and temperature. (Flannigan & Miller 1993)

Controlling humidity to limit fungal growth

Given the fungal growth cycle, it's clear that keeping moisture out of food sources is an excellent way to prevent fungal growth from becoming established. Preventing actual condensation prevents the growth of the most hazardous species of mold, but there are thousands of fungi that do not need liquid water to germinate. No matter how the moisture arrives at the surface, the relative water content of the food, called the "water activity" is what limits mold growth.

Water activity describes the amount of water adsorbed by the specified material when it is in equilibrium with air at a given relative humidity. The term is somewhat confusing, because the mass of water it describes is not absolute. It varies widely, governed by the sorption characteristics of each material. For example, a "water activity" of 0.75 describes the amount of water absorbed by the material when the relative humidity of the air above its surface is 75%. But the mass of water absorbed in cotton at that humidity is 7% of the weight of the dry material, while wool adsorbs 13% of its weight at the same condition. The "water activity" for both materials is still said to be 0.75 when they are in equilibrium with air at 75% relative humidity.

Mycologists think in terms of water activity. HVAC designers think in terms of relative humidity. The two disciplines are very close to using the same concepts. However, the key point for HVAC designers to remember is that fungal growth is not directly governed by the relative humidity as reported by building controls. Air moisture is only relevant as it might influence the amount of water *absorbed into the material* used by the fungus as a food source. Several important implications become clear when this fact is understood.

For example, the HVAC designer will not make the common mistake of assuming that if relative humidity in the controlled space is 50%, the building is safe from mold growth. What really matters is the relative humidity at the *surface of the food*—which will be in the ductwork, the carpet or behind wall coverings and inside building cavities, not in the air at the center of the room where the humi-

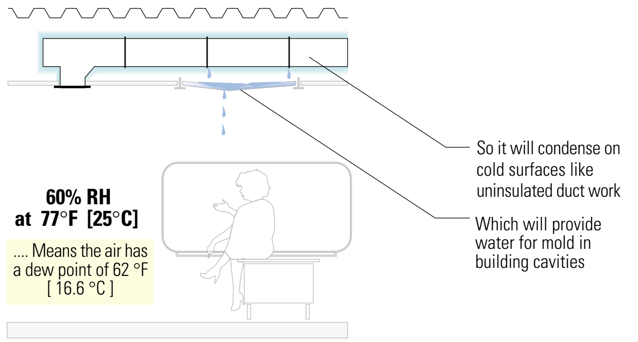


Fig. 7.6 Never Mind The rh... What's The Dew Point?

Cold surfaces and high dew points combine to produce condensation, which create more frequent and serious mold growth than simple high relative humidity.

distat might be located. Also, a central control system reporting a pleasant, safe relative humidity level of 50% tells the HVAC designer nothing useful—unless he is certain that there are no cold surfaces that will bring moisture out of the air and into the food source through condensation.

Further, the HVAC designer will realize that, when humidity rises to high levels every day, the air may be slowly "pumping moisture" into food sources. For example, library books absorb moisture but do not release it easily. When absolute moisture and temperature remain high for extended periods, such as when air conditioning is turned off during school vacations, the extra moisture needed to support fungus is added to the paper. With more moisture and an optimal warm temperature, mold growth appears to suddenly "explode" even though the relative humidity *in the room* may stay below the threshold limit for much of the day. Once started, fungal growth continues because the mycelium prevents moisture from leaving the material even when the humidity in the room is reduced. (Figure 7.3 shows the results of raising a library thermostat set point when there was no dehumidifier installed to keep the rh below 50% at all times.)

Also, the designer will not make the mistake of believing, as household wisdom might suggest, that preventing "stagnant air" will automatically prevent mold growth. If flowing air is humid, it will add moisture to materials, actually encouraging mold growth. But when the air is dry, household wisdom is accurate. Flowing dry air will retard mold growth because it removes moisture from the food.

In any case, the HVAC designer will not go wrong if he or she focuses clearly on the *material moisture content*. The relative humidity and dew point of the air are only relevant as they affect the moisture content of the fungal food source.

Molds Common In Commercial Buildings

Although there are over 645,000 species of fungus known to Mycologists, only a few dozen are thought to be both important and common in buildings. Fungi all have specific temperature, moisture and food source preferences, so it follows that the fungi that thrive in buildings will have preferences which reflect the characteristics of that environment.

Mycologists separate molds into informal categories according to their preferences for temperature and moisture. Xerophilic (dry-loving) molds do well at lower moisture levels than hygrophilic (moisture-loving) molds. Similarly, thermophilic (heat-loving) molds tolerate or thrive at temperatures above the limit of the human comfort range. Mesophilic fungi overlap the comfort range at both ends, and psychrophilic types prefer temperatures just above the freezing point of water. From these characteristics, it follows that as moisture, temperature and food sources change in a building and its HVAC systems, each species will compete more effectively at different times and in different places.

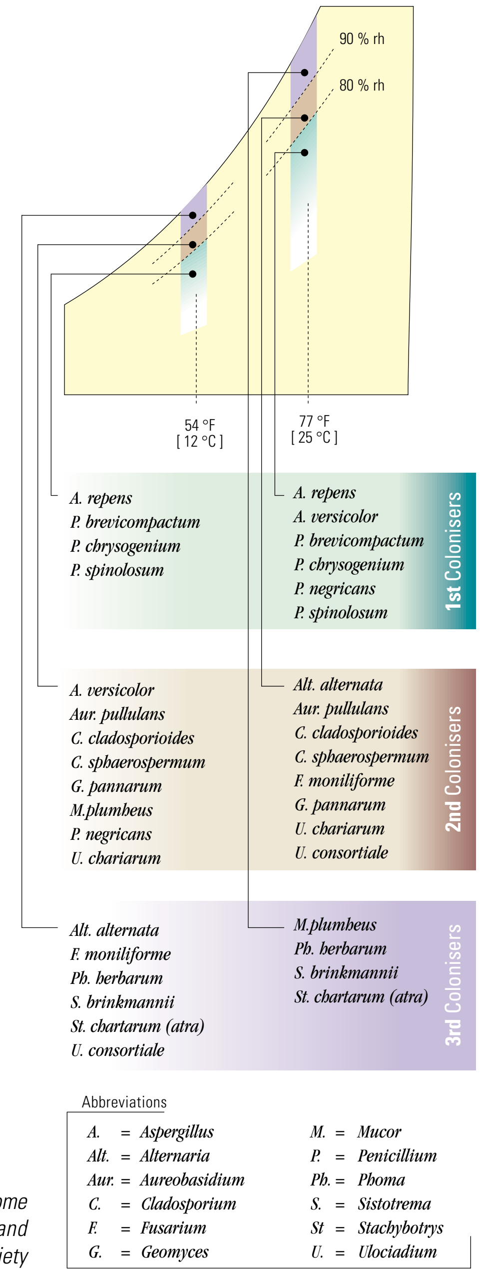


Fig. 7.7 Fungal Demographics Change With Water Availability

As the moisture content of any food source changes, different fungi become more successful competitors. In a building, the moisture content and temperature of each material may change with the seasons, allowing a variety of fungi to thrive at different times. (Flannigan & Miller 1993)

Figure 7.7 shows the species of mold which usually colonize plywood and composition board and the paper facing of gypsum board. One quickly observes that the "demographics" of the fungal population change dramatically with relatively small changes in temperature and moisture. This means that a building envelope, which contains not one but dozens of different combinations of temperature and moisture, will provide an ideal environment for dozens of fungi simultaneously. Each species may be dormant during part of the year or in part of the building, but thrive at other times and in other places.

Not all fungi are of equal concern to the designer and the occupants of the building. Many fungi grow slowly, so that ill effects take years or decades to cause problems. Other fungi have negligible effect on either health or structural strength of the building. Also, the effects of some fungi are simply unknown at present. In general, human health is of somewhat more immediate concern than structural problems, because health is affected more quickly than the building's structure.

The heath effects of fungi are currently in debate. Mycologists, physicians, public health professionals and attorneys are in constant conflict about the nature, mechanisms and dimensions of human health effects from fungal infection of buildings and HVAC systems. *Aspergillus*, *Penicillium* and *Stachybotrys* all produce toxic compounds and have all been implicated in health problems in buildings, but conclusive evidence is hard to identify. (Burge 1987, Fink 1976, Miller 1992, Staib 1987)

What is *not* in debate is that mold growth in buildings is neither healthy nor structurally wise, and the HVAC designer and architect should avoid designs that promote fungal growth. Still in debate is the *dimension* of the problems they cause, and to what degree fungal growth can be tolerated. The following section describes one of the fungi most frequently implicated in health problems, and the involvement of one plant pathologist, Dr. Berlin Nelson of the North Dakota State University, with problems associated with that fungus.

Mold in schools forces removal of Forks kids

Courtesy of the Fargo Forum

Fig. 7.8 Stachybotrys chartarum

This fungus is toxic to humans and animals, and has been implicated in health problems associated with condensation and water damage in buildings.

Stachybotrys chartarum (formerly Stachybotrys atra)

Berlin Nelson, Ph.D.
Department of Plant Pathology, North Dakota State University at Fargo

This monograph appeared in February 1999 as an feature article on apsnet.org. It is republished here through permission of Dr. Nelson, who retains the copyright.

Stachybotrys chartarum is a fungus that has become notorious as a mycotoxin producer causing animal and human mycotoxicosis. Indeed, over the past 20 years in North America, evidence has accumulated implicating this fungus as a serious problem in homes and buildings and one of the causes of the "sick buildings syndrome." In 1993-1994, there was an unusual outbreak of pulmonary hemorrhage in infants in Cleveland, Ohio, where researchers found *S.chartarum* growing in the homes of the sick infants. This incident has increased the awareness of home/building molds and brought this fungus to the attention of the medical community. In May 1997, for example, the *Journal of the American Medical Association* carried a news article titled "Floods carry potential for toxic mold disease" (Marwick, 1997). Newspaper articles such as "Fungus in 'Sick' Building" (*New York Times*, May 5, 1996) or "Mold in schools forces removal of Forks Kids" (*Fargo Forum*, June 1997) and the closure and extensive renovation of several courthouses in Florida, due to molds, are recent testimonials to the importance of indoor molds to human health.

As a plant pathologist-mycologist I became involved with the issue of home and building molds because of the enormous flood in the Red River Valley in 1997. In Grand Forks, ND, over 9,000 homes were flooded and a major part of the town was under water from the Red River. Immediately after the flood I became a member of an advisory group (that included scientists from the Center for Disease Control, National Institute for Occupational Safety and Health, US Public Health Service, and the Environmental Protection Agency), to help city officials deal with microbial problems associated with a major flood. After several years of dealing with this issue, I am struck by the common occurrence, and sometimes the extensive growth of

S. chartarum, and the lack of knowledge by the general public and the health care community about this fungus. This is not to imply that it is a widespread and serious problem, but there is a public need for readily available information on molds. Because *S. chartarum* is toxic, it merits special attention.

The Fungus - *S. chartarum*

Stachybotrys chartarum (synonyms = *S.atra, S.alternans*) was first described as *S.atra* by Corda in 1837 from wallpaper collected in a home in Prague. It is a member of the Deuteromycetes, order Moniliales, family Dematiaceae, and is common on plant debris and in soil. The taxonomic treatment of the genus by Jong and Davis, 1976, is a good reference on identification. The fungus grows well on common mycological media such as potato dextrose (PDA) or cornmeal agar, and sporulates profusely forming dark masses of conidia (figure 7.8).

The fungus is relatively easy to identify because of the unique phialides of the genus and conidial morphology of the species. Conidiophores are determinate, macronematous, solitary or in groups, erect, irregularly branched or simple, septate, dark olivaceous, and often rough walled on the upper part. The phialides are large, 9 to 14 µm in length, in whorls, ellipsoid, olivaceous, and often with conspicuous collarettes. Conidia are ellipsoidal, unicellular, 7-12 x 4-6 µm, dark brown to black and often showing a ridged topography when mature. The ridged nature is readily apparent with scanning electron microscopy, but can also be observed with an oil immersion lens at 1000 x. (figures 7.9 and 7.10) At lower power magnification the spores appear verrucose. Young spores and some mature spores may be smooth.

Fig. 7.9
Conidia of S. chartarum

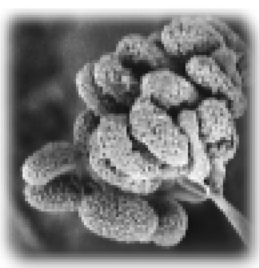
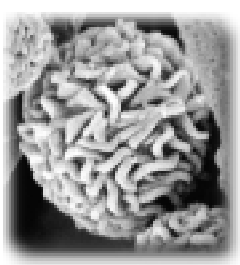


Fig. 7.10
Closeup of Conidia



The phialides produce conidia singly and successively into a slime droplet that covers the phialides. Eventually the slime dries and the conidia are covered with the slime residue and remain on the conidiophore as a mass or ball of spores. The spores are, therefore, not readily disseminated in the air compared to other fungi such as Aspergillus. However, when the fungus and substrate dries and is disturbed by agitation or air movement, conidia can become bioaerosols.

S.chartarum growing on natural or man made substrates can often be identified by a person familiar with its growth pattern. However, there are some very dark dematiaceous Hyphomycetes which look similar. Therefore microscopic examination of the fungus is needed to confirm identification. When the fungus is freshly growing, the characteristic phialides and conidia are easy to observe, but when dry, the phialides collapse, are more difficult to observe, and emphasis must be placed on morphology of conidia. The fungus is strongly cellulolytic and will grow under conditions of low nitrogen. A simple way to grow the fungus is to streak some conidia onto wet Whatman filter paper in a petri dish and within a week spores are produced. If you make a small ridge with the paper and place spores on it, the conidiophores will grow at an angle and allow a side view of conidial formation with a stereoscope. This is a convenient method to determine if spores are in chains to distinguish *Stachybotrys* from *Memnoniella*. Also, the filter paper method will allow isolation of *S.chartarum* away from many other fast growing, but non-cellulolytic fungi, that would out-compete *S. chartarum* on rich media.

Mycotoxins produced by *S. chartarum*

Mycotoxins and other biologically active compounds produced by *S.chartarum* are the reason why this fungus is of concern to human health. Mycotoxin poisoning by this fungus is referred to as stachybotryotoxicosis. *Stachybotrys chartarum* produces six types of macrocyclic tricothecenes: roridin E, satratoxins F, G and H, trichoverrols, trichoverrins, verrucarol and verrucarin J. The satratoxins are generally produced in greater amounts than the other trichothecenes, but all compounds are produced in low quantities. They occur in all parts of the fungus. One isolate was reported to contain about 15 ppm trichothecene in the conidia. The difficulty in obtaining, identifying and purifying these toxins has slowed studies on their biological activity. Macrocyclic trichothecenes are highly toxic.

In addition, the fungus produces 9-phenylspirodrimanes (spirolactones and spirolactams) and cyclosporin which are potent immunosuppressive agents. Jarvis et al. (1995) suggested that the combination of trichothecenes and these immunosuppressive agents may be responsible for the observed high toxicity of this fungus.

History of problems with *S. chartarum*

In the Ukraine and other parts of eastern Europe during the 1930's, there were unusual outbreaks of a new disease in horses and other animals that was characterized by symptoms such as shock, dermal necrosis, leukopenia, hemorrhage, nervous disorders and death. In 1938, Russian scientists determined the disease was associated with *S.chartarum* (then known as *S.alternans*) growing on the straw and grain fed to the animals (Fig.7.11)

Fig. 7.11 Stachybotrys on Hay

In addition to wall board facing, the fungus colonizes wet hay easily, which then represents a hazard for animals and for agricultural workers.

Intensive studies were then conducted resulting in the first demonstrated toxicity of *S. chartarum* in animals. Horses were actually fed cultures of the fungus. The contents of one petri plate resulted in sickness and the contents of 30 petri plates resulted in death. Horses seem to be especially susceptible to these toxins; 1 mg of pure toxin is reported to cause death. The Russians coined the term stachybotryotoxicosis for this new disease. Since then, stachybotryotoxicosis has been reported on numerous farm animals from various parts of the world, especially in eastern Europe, but is apparently rare (if even reported) in North America.

In the early 1940's reports of stachybotryotoxicosis in humans appeared in Russia. People affected where those who handled or were in close contact with hay or feed grain infested with *S.chartarum.* Some of these individuals had burned the straw or slept on straw-filled mattresses. Common symptoms in humans were dermatitis, pain and inflammation of the mucous membranes of the mouth and throat, a burning sensation of the nasal passages, tightness of the chest, cough, bloody rhinitis, fever, headache and fatigue. Some members (volunteers?) of the teams investigating this disease rubbed fructifications of the fungus onto their skin to determine its direct toxicity. The fungus induced local and systemic toxic symptoms similar to those observed in naturally occurring cases.

Between the 1950's and the 1980's there were continued publications on stachybotryotoxicosis but few that indicated a potential problem with *S.chartarum* in homes and buildings. In 1986, Croft et al. reported an outbreak of trichothecene toxicosis in a Chicago home. Over a 5-year period, the family complained of headaches, sore throats, flu symptoms, recurring colds, diarrhea, fatigue, dermatitis and general malaise. Air sampling of this home revealed spores of *S.chartarum*. The fungus was found growing on moist organic debris in an uninsulated cold air duct and on some wood fiber ceiling material. *The home had a chronic moisture problem that favored mold growth. Extracts from the duct debris and contaminated building materials were toxic to test animals and several macrocyclic trichothecenes were identified in the extracts. When the mold problem was corrected, these symptoms associated with trichothecene toxicosis disappeared.*

Since the paper by Croft et al (1986), there have been numerous reports of *S.chartarum* in homes/buildings in North America, but few definitive studies implicating the fungus as the cause of mycotoxicosis. One important paper by Johanning et al. (1996), reported on the health of office workers in a flooded New York office building with high concentrations of *S.chartarum* on sheetrock. The study concluded "... self-reported health status indicator changes and lower T-lymphocyte proportions and dysfunction as well as some other immunochemistry alterations were associated with onset, intensity and duration of occupational exposure to toxigenic *S.chartarum* combined with other atypical fungi."

In 1993-1994, a cluster of cases of pulmonary hemorrhage and hemosiderosis in infants occurred in Cleveland, Ohio. Because this is rarely observed in infants an intensive study into the cause of the problem was initiated. There were several factors associated with this outbreak, but an important finding was that all homes of these infants had high levels of total fungi and *S.chartarum* (based on air and surface sampling) (Etzel et al., 1998). Furthermore, isolates of *S.chartarum* from the homes were shown to produce trichothecenes. The homes had previously sustained water damage, which resulted in the mold contamination. This incident brought *S. chartarum* to the attention of the medical community and has highlighted the potential problem with indoor molds. There is controversy, however, about the role of *S.chartarum* in human poisoning in the Cleveland incident and as it relates to indoor molds in general. There have been few toxicological or epidemiological studies; thus some members of the scientific community believe a solid causal relationship has not been firmly established. The Centers for Disease Control recently issued a report critical of the study conducted in Cleveland.

The levels of exposure to *S.chartarum* required to cause human mycotoxicosis, especially from the inhalation of spores, are unknown. We should remember, however, that the accumulation of data over the past 60 years tells us that one should not handle materials contaminated with *S.chartarum* without proper safety procedures. Experience also strongly indicates that indoor environments contaminated with *S.chartarum* are not healthy, especially for children. A useful web site about the Cleveland incident is: http://gcrc.meds.cwru.edu/stachy/default.htm

Where *S. chartarum* occurs indoors

Stachybotrys chartarum is most commonly found in homes or buildings which have sustained flooding or water damage from broken pipes, roof leaks, sewage backup, condensation, etc. Spores are found in the soil and introduced along with floodwaters or dust and dirt entering with water from a roof leak, etc. It is most common on the paper covering of sheetrock (fig. 7.12) but can be found on wallpaper, ceiling tiles, paper products, carpets with natural fibers, paper covering on insulated pipes, in insulation material, on wood, and on general organic debris. Because leaks can occur behind walls and in covered ceiling areas, the fungus may grow profusely, but not be readily visible. It can also be found in ducts if organic debris is present.

Wet conditions are required to initiate growth. The fungus will usually produce large amounts of conidiophores and conidia giving the substrate a black appearance that can be slightly shiny when fresh and powdery when dry. I have observed fungus growing profusely on sheetrock a week after floodwater was drained from a building.

Detection of *S.chartarum* is usually by visual inspection and/or air and surface sampling. Because this fungus is not readily airborne, air sampling in a contaminated indoor environment may show low levels of spores in the air. Inspection of potential sites of contamination, especially in covered/protected places, is necessary to determine where the fungus occurs and the level of contamination. Fungus is often hidden in the walls, ceiling or floor with no visible evidence within the room interior. However, spores can escape through small holes and cracks to contaminate the room air.

If areas contaminated with *S.chartarum* are discovered, do not attempt to solve the problem without following recommended safety procedures for working with toxic molds, especially if contamination is heavy. Workers should use powered air purifying respirators (PAPR) along with proper covering of the skin and eyes. Get advice if there is a serious problem. Disinfecting the surface of contaminated materials, a common reaction to deal with molds, may kill the fungus on the surface, but mycelium within the substrate will often

Fig. 7.12 Stachybotrys In Buildings
Is common after water damage and when condensation drips inside walls. The mold is hazardous. Remediation workers and occupants must take care to avoid inhaling spores, and skin contact should also be avoided.

survive and grow again. Also, mycotoxins may accumulate in contaminated material. Removing contaminated materials is usually the best option. **To prevent further mold development, correct the moisture problem or *S. chartarum* might return!**

Acknowledgments: Thanks to the Electron Microscopy Center at North Dakota State University for the scanning electron micrographs. All other photos are by Berlin Nelson.

Selected references concerning stachybotrys chartarum

Croft, W. A., Jarvis B. C., and Yatawara, C. S. 1986. Airborne outbreak of trichothecene toxicosis. Atmos. Environ. 20:549-552.

Etzel, R., Montana, E., Sorenson, W., Kullman, G., Allan, T., and Dearborn, D. 1998. Acute pulmonary hemorrhage in infants associated with exposure to *Stachybotrys atra* and other fungi. Arch. Pediatr. Adolesc. Med. 152:757-762.

Forgacs, J. 1972. Stachybotryotoxicosis. Pages 95-128 in: Microbial Toxins. S. Kadis, A. Ciegler, and S. Ajl, eds. Volume 8, Fungal Toxins. Academic Press, New York.

Fung, F., Clark, R., and Williams, S. 1998. *Stachybotrys*, a mycotoxin-producing fungus of increasing toxicologic importance. J. Toxicol. Clin. Toxicol. 36:79-86.

Jarvis, B., Salemme, J., and Morais, A. 1995. Stachybotrys toxins. 1. Natural Toxins 3:10-16.

Jarvis, B., Sorenson, W. G., Hintikka, E., Nikulin, M., Zhou, Y., Jiang, J., Wang, S., Hinkley, S., Etzel, R., and Dearborn, D. 1998. Study of toxin production by isolates of *Stachybotrys chartarum* and *Memnoniella echinata* isolated during a study of pulmonary hemosiderosis in infants. Appl. Environ. Microbiol. 64:3620-3625.

Johanning, E., Biagini, R., Hull, D., Morey, P., Jarvis, B., and Landsbergis, P. 1996. Health and immunology study following exposure to toxigenic fungi (*Stachybotrys chartarum*) in a water-damaged office environment. Int Arch. Occup. Env. Health 68:207-218.

Johanning, E.,and Yang, C. S., eds. 1995. Fungi and bacteria in indoor environments. Proceedings of the International Conference, October, 1994, Saratoga Springs, New York. Eastern New York Occupational Health Program, Latham, NY.

Jong, S. C., and Davis. E. E. 1976. Contribution to the knowledge of *Stachybotrys* and *Memnoniella* in culture. Mycotaxon 3:409-485.

Marwick, C. 1997. Floods carry potential for toxic mold disease. JAMA 277:1342.

Sorenson, W. G., Frazer, D. G., Jarvis, B., Simpson, J., and Robinson, V. A. 1987. Trichothecene mycotoxins in aerosolized conidia of *Stachybotrys atra*. Appl. Environ. Microbiol. 53:1370-1375.

Wyllie, T. D., and Morehouse, L. G., eds. 1978. Mycotoxic Fungi, Mycotoxins, Mycotoxicoses - An Encyclopedic Handbook. Volume 2. Marcel Dekker, Inc, New York.

Mold In The Building Envelope & Contents

As the previous section suggests, the most serious problems with fungi in buildings occur when large amounts of liquid water are available along with warm temperatures, as occurs after floods, fires, broken pipes or water leaks in the building envelope. None of these are within the control of the HVAC designer.

However, the HVAC designer often affects mold and mildew problems in the building envelope and its contents. Common mold and mildew symptoms influenced by the HVAC design decisions more than by water leaks can include:

- Purple, pink or black stains on wall covering
- Mold & mildew in attics, behind pictures, in building cavities and on ceiling tile
- Mold & mildew on books, carpets and furnishings

High humidity is a source of water for fungus, but droplets carry more water into the food more quickly. So condensation is a special concern. This is true whether the problem occurs in the ducts themselves, or in the building envelope. Reviewing the mechanism of each problem will help the HVAC designer make better decisions.

Purple, pink or black stains on wall covering

This symptom is visible evidence of the presence of mold and mildew behind the wall covering. Stains appear on the front side because fungal enzymes have dissolved some of the pigments in the material, and the pigmented liquid has soaked through to the front. Stains take the form of either black dots, or more fluid-like marks that look like grape juice or dark coffee had been spilled on the wall.

Staining often occurs in humid climates when the building wall is under negative pressure. The classic example is in hotels. Continuous toilet exhaust creates a very slight suction on the guest room. Even though the corridor may be under positive air pressure, the exterior wall is often negative with respect to the outdoors. So humid air is pulled into the building cavities. Then the humid air is trapped, prevented from entering the room by impermeable vinyl wall covering. When the room air conditioner turns on, it chills the wall surface below the dew point of air trapped in the walls. So the water condenses in the adhesive and paper wallboard facing behind the wall covering, and mold begins to grow, eventually staining the walls and generating musty odors. This mechanism explains why stains are often located near wall-mounted cooling units, or on exterior walls, or on the demising walls that separate rooms but which connect to the exterior wall spaces. (AH&MA 1990 and 1991, Odom 1992, Gatley 1990, Shakun 1990)

A continuous negative air pressure of even as little as 0.008" [2 pa] has been shown repeatedly to cause enough humid air infiltration to cause millions of dollars of water damage in walls of hotels. (AH&MA 1991, Odom & Dubose 1992)

The way to avoid this problem is to *seal all exhaust and return air ductwork*, so that exhaust fans do not accidentally pull suction on the building cavities that the ductwork passes through. Also, each room needs a *direct* feed of *dry* makeup air, so that the exterior wall

Fig. 7.13
Pink/Purple Stains and Black Spots
Stains are often evidence of mold growth. Humid air in building cavities condenses behind impermeable wall covering. With that moisture, fungi grows in the wallboard paper facing, and in the adhesive that attaches the wall covering. Stains are the result of fungal enzymes dissolving pigments in the wall covering. Black spots are evidence that mold is growing on the exterior surface. After removal by cleaning staff, the stains will reoccur until moisture is removed from the wallboard. (Kimbrough, 1990)

Fig. 7.14 Mold On Furniture

When humid air leaks into buildings, it is often trapped by cool surfaces of furnishings pushed against the wall near an electrical outlet, a cooling unit or near other penetrations like window frames and pinholes that hold nails to support pictures. Mold grows in the moist fabric, on the wall itself or on moist wood or paper surfaces. (Kimbrough, 1990)

of each room is under positive rather than negative air pressure. Then only dry air leaks into building cavities, not humid air.

In theory the problem is reversed in cold climates. Since the air inside the building is more humid, one would not want that air to be pushed into the walls. But in fact, this is seldom a problem in hotels. These buildings are notorious for being under negative air pressure, and achieving positive air pressure in the rooms is a significant challenge. Without special attention, cold-climate hotel rooms are likely to be under negative air pressure, so humid indoor air is less likely to infiltrate into building cavities.

Mold & mildew above ceilings, on walls and ceiling tiles

In both humid and cold climates, mold can grow above ceilings and inside walls. The mechanisms and remedies are slightly different in each climate.

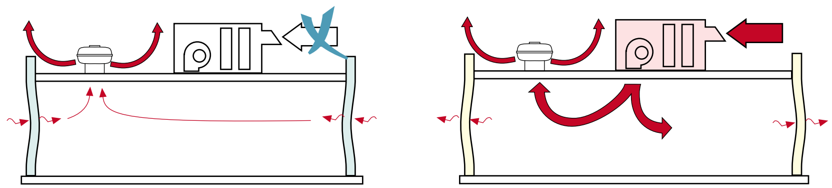
In humid climates, the problem can be caused by the same negative air pressure described above. Some HVAC component causes suction, humid air is pulled into the building, where it eventually provides enough moisture for mold and mildew to grow. A classic example is a simple one-story commercial office building or retail store with a dropped ceiling and no return air duct work. The ceiling plenum is expected to act as a return path for the system.

However, since the HVAC fan pulls a suction on the space above the ceiling, the entire exterior wall is under a negative pressure, which pulls humid air into the building. Then moisture condenses on cold duct work or on cold pipes inside the walls or above the ceiling. The first symptoms may include sagging ceiling tile, dark spots (mold) appearing on those tiles or musty odors that do not seem to come from the HVAC system. If air leaks are large and the suction is great, the first symptom may be condensation dripping from cold supply air diffusers onto occupants. Such problems have been reported in restaurants in humid climates. Exhaust air volumes are very large, and owners sometimes believe they can save energy by shutting off the ventilation preconditioning part of the HVAC system, not realizing that the exhaust will simply pull unconditioned air through the building wall and through the doors.

Another puzzling problem that occurs in humid climates is mold growth behind curtains, behind hanging pictures and on the backs of furniture pushed against a wall, as shown in figure 1.14. These are also caused by humid air leaking into the building because of negative internal air pressure. Humid air leaks through the inside wall at either the nail that hangs the picture, or through an electrical outlet behind a chair pushed against the wall. The picture or chair is relatively cool because it is inside an air conditioned space. So the incoming humid air is very close to saturation as it drifts across the surface of the wall or chair. Since the object is pushed against the wall, and stays put, little or no dry air from inside the room flows against the humid surface to remove moisture. So mold grows on the moist, hidden surfaces near or on the wall.

Curtains may grow mold for similar reasons. While windows are usually quite airtight, the pre-hung units are not always sealed to the exterior of the building. Problems are frequent under the sill, where a crack is difficult to see during installation. Air leaks into the room through that crack, and perhaps through similar cracks in the mounting of the though-wall air conditioner. Whenever the air conditioner cools the room, it blows cold air near the curtains, which then absorb moisture from the incoming humid leakage air. Mold grows on the back of the curtains, where the moisture content of the material is highest.

All of these problems can be avoided by ensuring that the building cavities are under positive air pressure with dry air. This demands sealed exhaust and return ductwork, so that fans do not pull a suction on building cavities. Also, dry ventilation air should be delivered directly to rooms with exterior exposures as opposed to relying on



Insufficient Make-up Air
Creates negative pressure which sucks untreated air through the building wall, causing mold and mildew in building cavities.

Slight Excess of Dry Make-up Air
Ensures that treated air rather than outdoor air will fill the building cavities, keeping them safe from condensation, mold and mildew.

Fig. 7.15
Humid Climates Need Positive Indoor Air Pressure
However, in cold climates, a neutral or slight negative internal air pressure helps avoid forcing humid air into cold building cavities where it can condense to feed mold growth.

exhaust fans to pull air into external rooms from interior corridors. That tempting low-cost strategy seldom provides positive pressure at the exterior wall.

In cold climates, mold and mildew problems are caused by humid air from *inside* the building being pushed and pulled into cold building cavities. In low-rise commercial buildings in cold climates, the classic problem begins when there is *no* return duct work. The roof-mounted heating/air conditioning unit pulls a suction on both the building cavities near the exterior wall and on the conditioned space below a dropped ceiling. Cold air comes through cracks in the exterior wall, chilling those wall cavities. Humid air is pulled from the conditioned space. The moisture in the humid air condenses when it contacts cold surfaces above the ceiling, and on cold surfaces in the walls. The more water, the faster the fungus grows.

In moderate climates, condensation is not common. With smaller amounts of condensed water, and with cool temperatures, the number of fungi that can thrive is limited. But the environment may change dramatically in the spring. Rising temperature allows more forms of

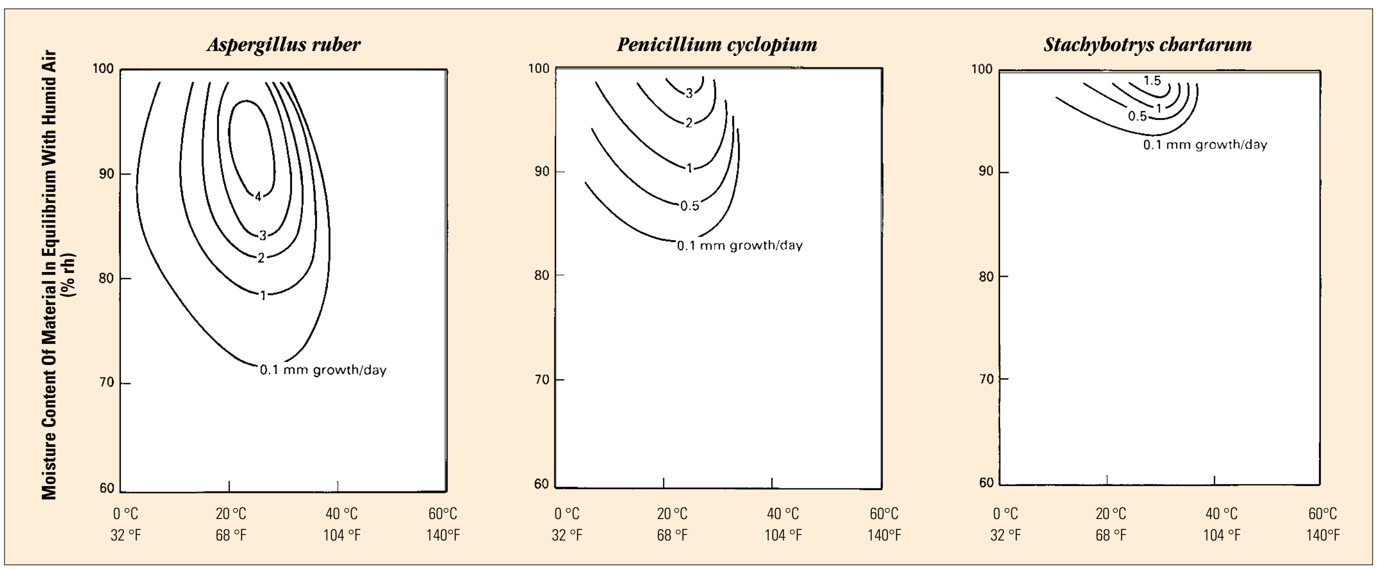
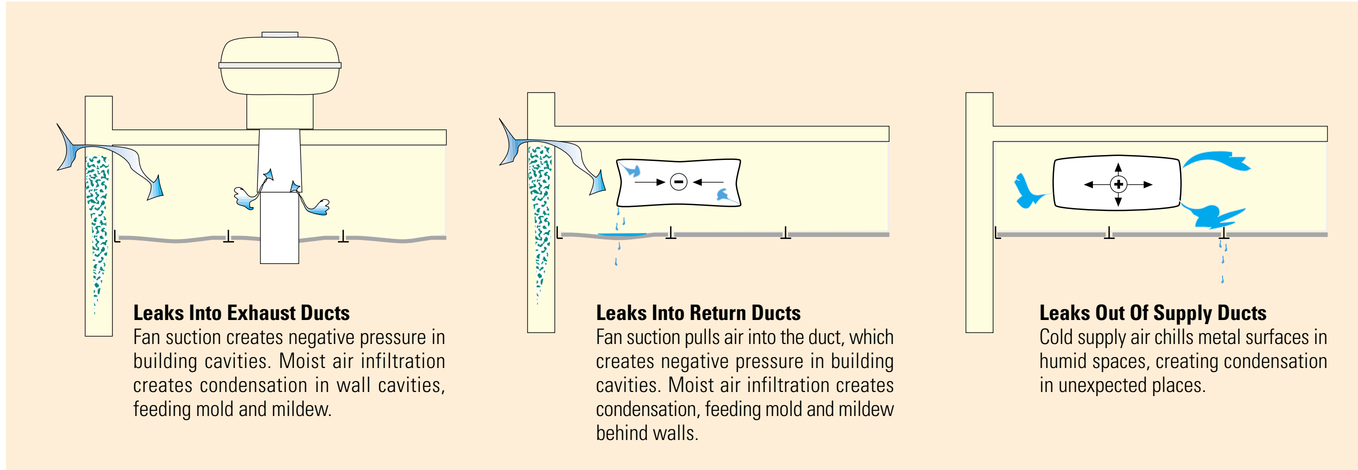


Fig. 7.16 Fungal Growth Rates Vary
Fungi grow at different rates, controlled by their individual characteristics, and by the amount of moisture and heat available to support their metabolism. (Brundrett, 1990)

Fig. 7.17 Seal All Duct Work

Sealing all the ductwork avoids suction in the building envelope, which would pull in humid air or allow it to contact cold surfaces in building cavities.



fungi to grow, including those that may thrive on smaller amounts of moisture. Springtime problems may actually be the result of wintertime condensation.

In cold climates, guidance for limiting problems is slightly different. The building exterior should still be as airtight as possible, and as in humid climates all return air ducts and exhaust ducts must be sealed. But the HVAC designer should not allow humid air to be blown into building cavities. The building should be under neutral air pressure with respect to the outdoors for as many hours as possible during the cold season. If anything, the exterior wall could be under a very *slight* negative air pressure with respect to the outdoors. Note this is a very difficult goal to achieve without overdoing it, which would chill the wall cavities to the point where surfaces become cold enough to condense water.

Joseph Lstiburek, Ph.D, P.Eng, the well-known Building Scientist has humorously summarized this advice; "In hot climates the building's *gotta* be a blowhard, but in cold climates it's better to suck."

Fig. 7.18 Moldy Books

This book came from an elementary school in Houston, Texas. To "save energy", the thermostat in the library was reset to a high temperature during summer vacation. But outdoor air ventilation was not reduced, nor was there any dedicated dehumidifier installed to keep the rh below 50%. Since the humid ventilation air was not dried, it "pumped" moisture into the books, allowing prolific mold growth. More than a thousand volumes had to be cleaned or replaced.

Mold in books and carpets

Problems above are usually caused by condensation. But mold can grow without gross water droplets. High relative humidity near the food surface is enough to allow growth.

Libraries

Libraries and used-book stores are often notorious for musty odors, which indicate mold growth. Books are a special case. They absorb moisture at high humidity, but fail to give it up when humidity drops—unless the humidity drops well below 30% rh.

So in a library, the books breath in moisture whenever the humidity is high. This can happen often, for example when the building is closed and the air conditioning system is turned off, or when the thermostat is reset to such a high temperature that no dehumidification is accomplished by the cooling coils. On each cycle of high humidity, the books gather slightly more moisture. Eventually, they accumulate enough to allow mold growth. The problem is accelerated when the HVAC system feeds only "temperature-tempered" outdoor air to the building. For example, if the thermostat is set back to 80°F

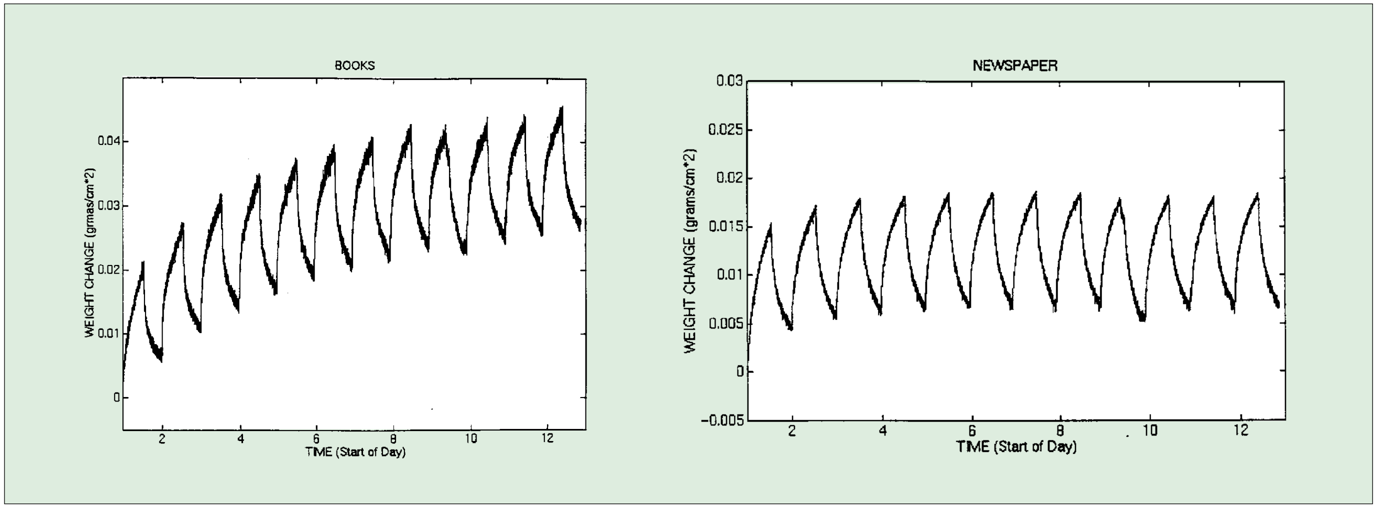


Fig. 7.19 Books Accumulate Moisture

Unlike newspaper and other thin-layer materials, books accumulate moisture and do not give it up easily. In this experiment, both materials were cycled between air at 40% rh and air at 90% rh every hour. Note that the newspaper released its moisture when exposed to 40% rh air. But the books steadily gained water. To dry books effectively, air must be well below 40% rh.
(Bailey et al. 1994)

[26.7°C] during unoccupied periods, and the ventilation air pre-cooling is set back to the same temperature, the incoming ventilation air cannot be dehumidified (at least in North America, Europe and Northern Asia, where there are no design dew points above 78°F [25°C]). Therefore during humid months, the ventilation system would pump immense amounts of water vapor into the building—and then into the books. Thrifty school administrators sometimes return from summer break to find prolific mold growth in books after having "saved energy" by shutting off air conditioning or by raising its set point temperature.

The solution for libraries is to maintain the relative humidity below 50% at *all* times, regardless of the temperature. This strategy generally requires a separate, dedicated dehumidifier, which responds to a humidistat rather than to a thermostat. The incoming ventilation air is usually the best location for that dehumidifier, since the outdoor air is by far the largest moisture load in a library.

Carpets

When carpets are soaked in humid climates—as during periodic cleaning in eldercare facilities—they can grow mold if they are allowed to stay wet. The relative humidity and air velocity at the carpet surface determine the drying rate. If air is stagnant at the floor level, and if the humidity is high (as happens in facilities without dedicated dehumidifiers) then drying time may extend indefinitely, and mold can grow. Preventing this problem is simple, as long as the budget allows for a separate dehumidifier in the system. If that is impractical, then the cooling system can be forced to operate by a humidistat, and heat added back into the air from waste heat such as a standby boiler or other low-cost source.

In rare circumstances, carpets can also grow mold in cold climates. In hotel construction and in military dormitories, there have been examples of concrete floor slabs that extend outboard of the building envelope, creating a thermal bridge to the cold weather. In those buildings, the cold slab just inside the building condenses water from the air, providing moisture for mold in the carpet. Often, cold climate mold problems are caused by such thermal bridges.

Mold In The HVAC System

All HVAC systems have mold and mildew in the duct work. This is true regardless of the system type, its degree of filtration or its geographic location. However, this does not mean that all HVAC systems create mold-related problems for occupants. To create a problem, even one as relatively benign as musty odors, the mold growth in the system must be prolific. "Problem levels" of fungal growth can be avoided through a combination of everyday good design and maintenance practices. Common problems are presented below in order by increasing cost and complexity of their solutions.

Mold on filters

Most filter media is chosen because it is inert. Fibrous glass paper, polyester batting and glass fiber matting are all poor food sources for fungus. ASHRAE-sponsored research and industry studies have repeatedly shown that fungus does not grow well on newly-installed filter media. Therefore, so as long as filters are changed regularly and have fairly clean media in the air stream, they are not likely to provide a good growth environment for mold and mildew. Filters create problems under two circumstances, both of which are easily avoidable.

First, if the filters are not changed frequently, they collect a plentiful supply of food for fungus. Even then, problems are not common unless the clogging is constant for months or years, or the dirty media is exposed to relative humidity over 90% or actually soaked with liquid droplets. (Ahern 1992, Kemp et a.l 1995, Kemp et al. 1995, Pasanen 1991)The solution to mold and mildew on most filters is simple: replace the media. As long as the designer has made sure the media is accessible, the solution to such problems is within the control of the owner's operations staff.

Second, an entirely design-related problem is created when filters are placed immediately downstream of cooling coils or humidifiers. Then the "mold food" as well as the spores collected in the filter are constantly receiving moisture from humid air. Mold will grow on and through the filter media, releasing spores on the other side. This problem is unfortunately quite common. The best solution is to ensure that filters are never installed immediately downstream of cooling coils or humidifiers. But that solution is not always possible in the real world. HVAC designers do not always have the luxury of placing wet components where good design practice suggests.

When there seems no alternative to placing filters downstream of cooling coils, the designer should consider:

1. Placing filters as far downstream as possible
2. Placing filters in all the return air grills, so they can be easily accessed for replacement and so their particulate loading is visually apparent to any room occupant.
3. Making certain that coil face velocities are low, and that fin spacing is wide, to avoid carrying over liquid droplets into the air and onto the filters.
4. Installing a mist eliminator between the coil and the filter to keep water droplets out of the media
5. Warning the owner that downstream filters will need to be changed much more frequently, perhaps with a filter alarm light set at a smaller pressure difference than others, along with a sign on the filter access that makes the point to the maintenance staff.

The same steps would be taken when filters must be installed downstream of humidifiers. But in that circumstance, the designer also has many types of humidifiers to choose from. Some perform better in this position than others. The manufacturers may be able to suggest equipment that will minimize the potential for mold growth in closely-coupled filters.

Mold in and around drain pans

Drain pans under cooling coils are a common source of mold and mildew problems. If the drain pan does not actually drain water—for whatever reason—mold and mildew will certainly grow in the pan and spread through the duct work to the occupied spaces. Also, if water leaks or spills *out* of the drain pan, mold and mildew will grow in the soaked food source. The problems fall into three categories: maintenance, pan design and drain line installation.

If the drain line is clogged—as happens when dirt collects in the line—then the pan can overflow. But this problem is simple to solve with either compressed air or a plumber's snake. Also, keeping the filters changed keeps dirt and fibers from collecting in the drain pan, reducing the potential for a clogged line.

Drain pan design, until recently, has not been the object of much attention by manufacturers or by those who specify equipment. So older equipment designs do not always have drain pans under coils. Often, if a drain pan is in place, it is not long enough to catch droplets blown off cooling coil fins, or not sloped to its drain in two directions, creating standing water in parts of the pan which never drain. Fortunately, correcting such problems is quite simple in new construction. Simply specify that all cooling coils shall have drain pans sloped all the way to their drains, and specify that the manufacturer shall certify that the length of the pan is adequate to capture water droplets coming off the coil when the system is operating at the peak dew point design condition.

In the past, condensate drain lines sometimes received less than adequate attention from designers and installers. The first indication of a problem might be water dripping out of the duct work onto desks and occupants. Common problems have included:

- No drain line or no connection to the line. Either the designer fails to specify a drain line, or the contractor fails to install it. The solution is obvious: there must be a drain line, and it must be connected—through a trap—to the drain pan.
- No trap, or an improperly-designed trap in the drain line. Without a trap, condensation cannot drain from the unit. The fan suction holds water in the pan until it overflows. The solution is to have a trap with a stem height greater than the pressure of the fan. (The stem height is the vertical distance between the *outlet* of the trap and the *bottom* of the drain pan)
- Drain line not connected to a drain. Drain lines that feed water into building cavities are surprisingly common. The contractor must be certain the drain line actually connects to a drain.

Mold in unitary equipment

Fan-coil units and other room-mounted unitary equipment do not always have filtration protecting the finned coil surfaces. Dust builds up on the surface over the heating season. When the coil condenses moisture in the cooling season, water becomes available to fungal spores in the dust, and mold begins to grow.

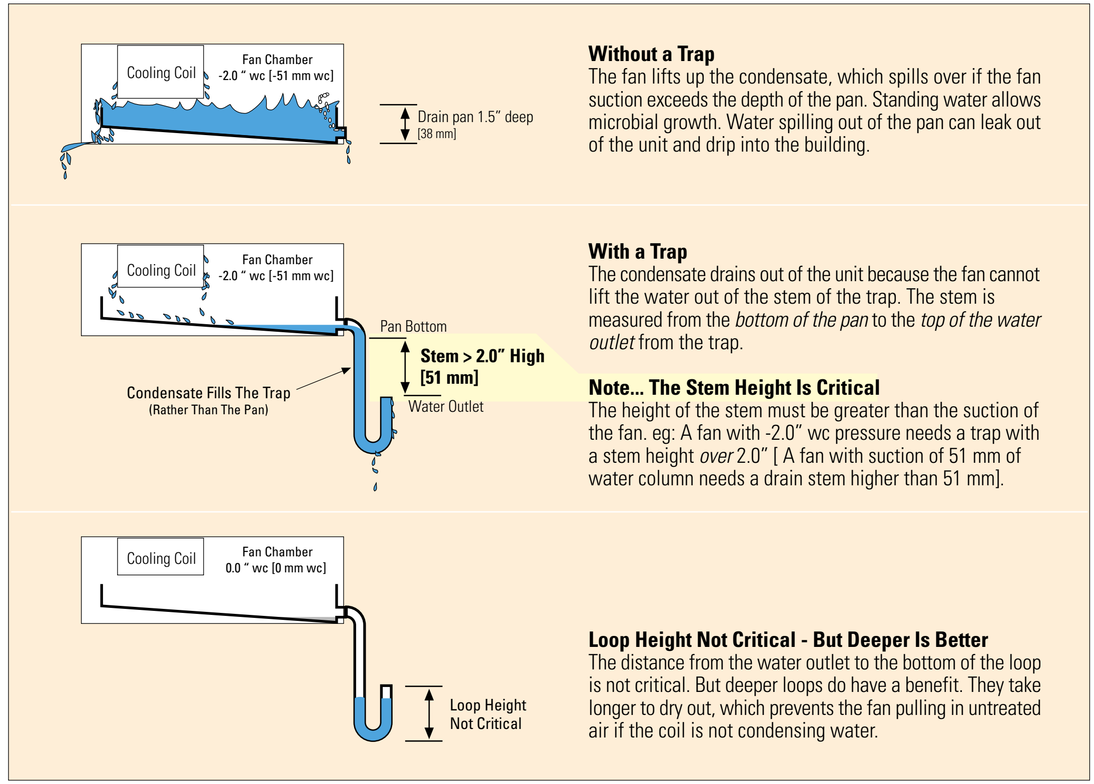


Fig. 7.20
Traps For Coils In Units With A Draw-Through Fan Position
A trap with a high stem is essential to proper drainage of water from condensate pans. Without a trap, the fan pulls water up, out of the pan and into the ductwork, providing ample water for fungal growth.

This common problem can be solved by both maintenance and design. The designer can specify equipment with easy-to-replace filters, and which contain coils which the manufacturer can demonstrate are cleanable in-place. The building operations staff can ensure that filters are indeed replaced or cleaned on a monthly or bimonthly schedule, and ensure the coils are cleaned once a year using the manufacturers' procedures.

In the real world, this simplistic and obvious advice is not always possible to follow. The designer may be forced by other considerations to select equipment that does not have replaceable filters, and/or does not have cleanable coil surfaces. In that case, the designer and owner must simply accept the probability of mold and mildew in the unit. Room air filtration can extend the time until a problem develops, but it will seldom eliminate the potential problem entirely. Designers and owners of buildings where occupant health is compromised—such as hospitals, clinics and eldercare facilities—should carefully weigh the health risks of mold and mildew against any apparent benefit of low-cost unitary equipment that cannot be filtered or cleaned.

Mold in ductwork downstream of cooling coils

Cooling coils produce condensation and high-humidity air. Dust accumulates on the inside of duct work. That combination of dust and humidity eventually leads to mold and mildew growth in duct work downstream of cooling coils (Morey 1990, Thomann 1996). As a practical matter, all duct systems have mold, but very few cause problems. That's evidence that it is not necessary to eliminate mold growth entirely. It is simply important to limit the growth to harmless levels. This can be accomplished easily—or made nearly impossible—by design decisions.

The big problems come with large amounts of water, and large amounts of fungal food. Eliminate both of those, and the problems are small or nonexistent. But both must be eliminated to prevent problems. For example, filtration reduces the amount of fungal food. But if water droplets drift off the coil onto that small amount of food, fungus will flourish. Likewise, if no water drifts off the coil, but dust accumulates in heavy layers, the high humidity air will eventually provide enough moisture to support prolific growth. Finally, if both filtration is good and water droplets eliminated, but the duct surface traps all available dust and humidity, the mold problem is delayed, but still inevitable. Consequently, the best way to avoid problems downstream of cooling coils it to address all of the following cautions in the design:

1. Avoid high air velocity and narrow fin spacings in cooling coils that must remove moisture. When air speeds through narrow fin spaces, or when the face velocity is high, condensed water is blown off the coil into the air. Specify fin spacings at least as wide as 12 fins per inch, and air velocities below 400 fpm. [Wider than 5 fins per cm and velocities below 2 m/s]
2. Avoid tall coils. When the coil is tall, the lower part accumulates a great deal of condensation from above, making it very probable that air will blow water off the fins even when they are spaced far apart. Avoid coils over 3.2 ft high [1 metre high]. When the ductwork demands a tall configuration, split the coil horizontally into two units, and install a drain pan beneath both units.
3. Place filters between particle sources and coils. Locate easy-to-change filters so they are between the source of the particles and the cooling coils. This will keep coil surfaces clean, saving energy and avoiding fungal food accumulation on coils and downstream in humid air. In some cases, locating filters immediately behind the return air grills is the most practical way to keep them dry and to provide easy access for replacement.
4. Immediately downstream of cooling coils, specify smooth metal duct work with access doors for cleaning. Insulate these sections on the *outside* rather than the inside of the duct. Internal insulation and sound lining downstream of

cooling coils is notorious for trapping dust and growing mold at very high rates. Specifying a smooth metal surface in this location, along with access doors for cleaning, will avoid the worst problems that have been recorded with respect to mold and mildew in HVAC systems. The ideal length of the smooth section will depend on the velocity in the duct. Higher velocity carries any water droplets further downstream, so longer smooth sections are appropriate. As a minimum, the smooth and accessible section should extend 8 duct diameters downstream of the coil, allowing the air to return to smooth flow, so that particles are less likely to drop out and deposit on duct walls.

Mold downstream of humidifiers

Designers, contractors and owners do not always pay close attention to guidance from manufacturers of humidifiers. Consequently these devices have sometimes been associated with avoidable mold and mildew problems in duct work. One must keep in mind that humidifiers are designed to add moisture—exactly what mold and mildew need for growth. So the duct work downstream of humidifiers demands careful attention if problems are to be avoided.

The most important design rule is to *seek and follow manufacturer's guidance* regarding duct work downstream of the specified humidifier. Requirements vary between types of equipment. Atomization-type units need smooth, accessible duct work for a longer distance than steam-dispersion units, because large, cold droplets are not absorbed by air as quickly as hot steam vapor. Also, some types of equipment require a drain in the duct work after the humidifier, as some "fallout" water is expected and must be prevented from flowing through the supply duct. Beyond the manufacturer-specific guidance, some clearly good practices are useful to keep in mind when constructing the specification:

1. Avoid obstructions downstream of humidifiers. If turning vanes, for example, are mounted close downstream of humidifiers, moisture is likely to condense as the air pressure changes slightly when it contacts the vanes.
2. Avoid porous insulation and sound lining near humidifiers. Porous surfaces collect dust and moisture, and grow mold. Use external insulation and smooth metal duct downstream of humidifiers.
3. Provide cleaning access downstream of humidifiers. Cleaning is always needed downstream of humidifiers. Be sure to provide that access in the duct layout.

References

Ahearn, D.G. et al. *Colonization studies of various HVAC materials*. Proceedings of the 1992 ASHRAE IAQ Conference, October 1992, San Francisco, CA. ASHRAE. ISBN 0-910110-94-8.

Bailey, D.W. et al. *Investigation of dynamic latent storage effects of building construction and furnishings* (ASHRAE Research Project 455-RP). 1994. Project report with Appendices.

Brundrett, Geoffrey W. , *Moulds, Chapter 4 of Criteria for moisture control*. 1990. Butterworth & Co., Reed International. London. ISBN 0-408-02374-0.

Burge, Harriett A., *Approaches to the control of indoor microbial contamination*. 1987. Proceedings of the ASHRAE IAQ Conference, May 18-20, 1987, Arlington, VA. ASHRAE. Atlanta, GA. ISBN 0-910110-51-4.

deRoos, Jan A. *Summary of mildew problems encountered in hotels in South Texas*. January 9th, 1989. School of Hotel Administration, Cornell University, Ithaca, NY.

Fink, Jordan N. et al. *Interstitial lung disease due to contamination of forced air systems.* Annals of Internal Medicine 84:406-413, 1976.

Flannigan, Brian and Miller, J.David., *Humidity and fungal contaminants.* 1993. Proceedings of the Bugs, Mold & Rot II workshop on control of humidity for health, artifacts and buildings. November, 1993. National Institute for Building Sciences. Washington, DC.

Flannigan, Brian. *Approaches to assessment of the microbial flora of buildings.* Proceedings of the 1992 ASHRAE IAQ Conference, October 1992, San Francisco, CA. ASHRAE. Atlanta, GA. ISBN 0-910110-94-8.

Gatley, Donald P., *Mold and condensation behind vinyl wall covering*. 1990. Gatley & Associates, Atlanta, GA.

Kemp, Stephen J. et al. *Filter collection efficiency and growth of microorganisms on filters loaded with outdoor air.* ASHRAE research project 625-RP. ASHRAE Transactions, 1995. V.101., Pt. 1. Paper #3853. ASHRAE, Atlanta, GA.

Kemp, Stephen J. et al. *Growth of microorganisms on HVAC filters under controlled temperature and humidity conditions.* ASHRAE research project 625-RP. ASHRAE Transactions, 1995. V.101., Pt. 1. Paper # 3860. ASHRAE, Atlanta, GA.

Kimbrough, James W., *Mildew/Moisture Control. Problem avoidance in new and existing hotels/motels.* February 6th, 1990. Koogler & Associates Environmental Services. Gainesville. FL

Miller, J.David. *Fungi and the building engineer*. Proceedings of the 1992 ASHRAE IAQ Conference, October 1992, San Francisco, CA. ASHRAE. Atlanta, GA. ISBN 0-910110-94-8.

Mold & Mildew in Hotels and Motels - Survey Results. 1991.. American Hotel & Motel Association. Washington, DC.

Morey, Phillip. R, Williams, C.M., *Porous insulation in buildings: A potential source of microorganisms*. Proceedings of the 1990 ASHRAE IAQ Conference, Toronto, ONT. ASHRAE. Atlanta, GA.

Odom, J. David, III., *Designing and constructing mildew-free hotels*. 1994. CH2M/Hill Consulting Architects and Engineers. Orlando, FL.

Odom, J. David, III., DuBose, George and Fairey, Phillip. *Moisture problems: Why HVAC commissioning procedures don't work in humid climates*. 1992. Proceedings of the 8th Symposium on improving building design in hot & humid climates. May, 1992. Texas A&M University, College Station, TX.

Pasanen, Pertii. et al., *Criteria for changing ventilation filters*. Proceedings of the 1991 ASHRAE IAQ Conference, Washington, DC. Sept. 4-8 1991. ASHRAE. Atlanta, GA. ISBN 0-910110-83-2

Peart, Virginia. *Mildew and moisture problems in Florida.* February 1989. Institute of food and agricultural sciences. University of Florida, Gainesville, FL.

Robertson, L.D., *Monitoring viable fungi and bacterial concentrations to identify acceptable levels for common indoor environments.* Proceedings of the 11th Symposium on improving building design in hot & humid climates. June, 1998. Texas A&M University, College Station, TX.

Schleibinger, H. et al., *Occurrence of microbially produced aldehydes and ketones (MVOC's) from filter materials of HVAC systems—field and laboratory experiments.* Proceedings of the 1995 ASHRAE IAQ Conference, Denver, CO. October 22-24 1995. ASHRAE. Atlanta, GA. ISBN 1-884313-30-3.

Shakun, Wallace. *A review of water migration at selected Florida hotel/motel sites.* Proceedings of the biennial symposium on improving building practices in hot & humid climates. October 1990. Texas A&M University, College Station, TX.

Staib, Freiderich et al., I*ndoor air mycology: aspergillosis, mucormycosis and cryptococcosis caused by fungal spores from indoor air*. Indoor Air '87. Proceedings of the 4th International Conference on Indoor Air & Climate. Berlin, West Germany. 17-21 August 1987 (Volume 1. ISBN 3-89254-033-0.

Thomann, Wayne R., Tulis, Jerry J., *Fungal contamination of HVAC surfaces: The role of the dew point in microbial amplification.* Proceedings of the 1996 ASHRAE IAQ Conference, Baltimore, MD October 6-8 1996. ASHRAE. Atlanta, GA. ISBN 1-883413-41-9

Transcript of the Hotel Mood & Mildew Roundtable Discussion. March 1st, 1990. Executive Engineer's Committee. American Hotel & Motel Association. Washington, DC.

Special Thanks

This chapter could not have been written without the landmark field research accomplished during the 1990's by Dr. Virginia Peart and Dr. James Kimbrough of the University of Florida, and by J. David Odom III and George DuBose of CH2M/Hill of Orlando, Florida, as well as by Donald Gatley and Wallace Shakun of Georgia and Joseph Lstiburek of Building Science Inc in Westford, MA. Also, the Executive Engineers Committee of the American Hotel and Motel Association provided the original impetus to look at mold in North American buildings from a multi-disciplinary perspective. Their focus on the problem was catalyzed by the persistence and generosity of Mr. Jones of MMI Hotel Management of Jackson, Mississippi. Finally, the first broad-based, quantitative research of the problem was performed for the AH&MA through funding provided by the Gas Technology Institute in Chicago and by the Munters Companies in Amesbury, MA.

Photos

Figures 7.1, 7.13 and 7.14: © James Kimbrough, University of Florida

Figures 7.8 through 7.14: © Berlin Nelson, North Dakota State University