Preventing MOLD by Keeping New Construction Dry

By Lewis G. Harriman III, Member ASHRAE, **Donald Schnell,** and **Mark Fowler**

When a new building smells moldy, the owner's first phone call is often to the building's HVAC designer. To most people, moldy odors suggest HVAC problems. But while the air system may indeed spread fungal odors, the HVAC system in new buildings is seldom responsible for generating them. In new construction, mold infestations usually are caused by moisture in building materials. That moisture can come from rain or snow before the building is closed in, or from leaking water pipes, wet concrete or condensation on surfaces like cold floor slabs during springtime.

Conventional HVAC systems are not designed to dry out construction-related moisture. The moisture load from wet materials is simply too large and the drying task too complex for systems that are intended for comfort air conditioning. The better plan is to dry materials quickly with aggressive drying if they get wet through nature or human error.

To understand why drying speed is important, it helps to consider life from the perspective of a mold spore. The spore needs a moist food source to grow. *Figure 1* illustrates the growth cycle.

When a spore lands on a moist food source, or when the food source it has landed on becomes wet, the enzymes that coat the outside of the spore go into solution. The enzyme solution then dissolves the food nearest the spore. The resulting nutrient-rich broth is drawn inward through the spore wall by the difference in osmotic pressures. The broth outside is dilute, and the material inside the spore is dry, so the nutrient broth traverses the spore wall to bring the osmotic pressures on either side of that spore wall into equilibrium. With nutrients inside, the spore can generate hyphae (thin root-like filaments), which are also coated with enzymes. These dissolve more of the moist food, and the fungus thrives. When the food source is plentiful and its moisture content high, fungal growth can be rather rapid.

For example, recent research has established that on ceiling tile and gypsum wallboard, mold can grow from germina-

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tion past the point of having branched hyphae in 48 to 72 hours.[1] That research, presented at the 2001 ASHRAE IAQ seminar, validated the guidance contained since 1999 in Standard S500 published by the Institute of Inspection, Cleaning and Restoration Certification.[2] The standard calls for starting the drying of any water-damaged materials within 48 hours to limit mold growth.

After materials become soaked, mold growth will not be prevented by merely keeping the relative humidity in the building below 60%, as an HVAC designer would do to prevent initial adsorption. In soaked materials, moisture will be supplied to the surface mold from inside the material rather than through adsorption from the surrounding air. Therefore, after actual wetting, the challenge is to remove excess moisture from inside the material as well as from its surface. This requires a combination of air movement across all wetted surfaces combined with very low humidity over an extended period—usually below 30% rh for several days or more than a week. The tools to accomplish this task were developed over the last 20 years in response to the needs of the insurance industry, which uses restorative drying to limit the cost of water damage claims after floods, fires and disasters.[3]

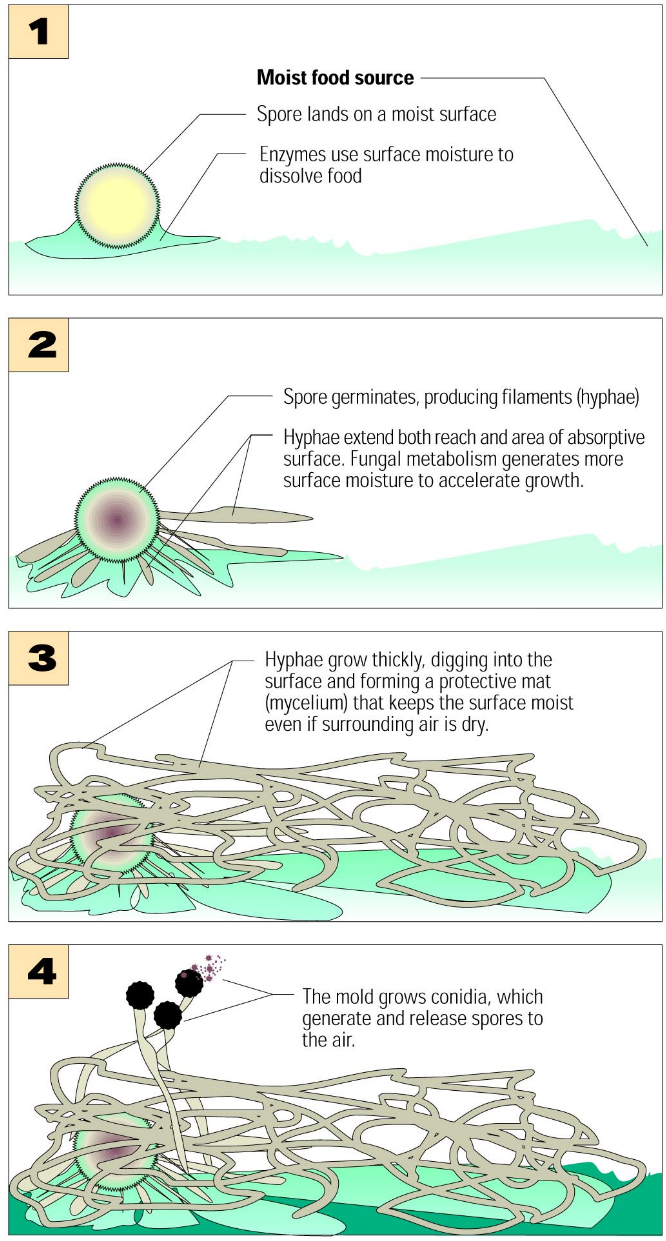

Figure 1: Mold growth cycle.

Construction Drying Equipment

HVAC designers have become familiar with some of this equipment because a variant has been applied to the problem of humidity control in commercial buildings. Desiccant dehumidifiers are the tool of choice for much construction drying, since they dry the air to very low dew points without cold-weather limitations. The desiccant units used for building drying are configured quite differently from those used in commercial buildings. Portable dehumidifiers are trailer-tolerant and will withstand the rugged environment of a construction site. Also, they are configured for the aggressive drying needed to bring the controlled space down to a low relative humidity.

Figure 2 shows a pair of portable desiccant dehumidifiers being used to keep a new school building dry in Austin, Texas to prevent mold on a fast-track project. Note that the units are being reactivated by propane contained in the large tanks in the rear of the photo. The principal energy requirement of desiccant dehumidifiers is for heat to reactivate the desiccant wheel. Using propane or natural gas for reactivation cuts the power requirement down to the point where portable generators can be avoided, saving the rental cost of that equipment.

In hot weather, mechanical dehumidifiers also are used for building drying. These typically use less electrical power than desiccant units, and do not require reactivation heat. Where a building is nearly dry and the contractor wants to make sure it stays that way, the lower cost and minimal power requirement of mechanical dehumidifiers is a significant advantage.

Figure 2: Construction drying equipment on a Texas job site.

Dry Air Must Reach Wetted Surfaces

Figure 3 shows how dry air is distributed through the construction zone. Note the use of inflatable plastic ducts rather than using the building's own air distribution system. This approach has several advantages. First, the building's HVAC system does not have to be turned on, which keeps construction dust out of its ductwork, cooling coils and filters. Second, the drying contractor can flow dry air towards the moist material directly, rather than hoping it will drift there through ductwork designed to cool and heat rooms rather than to dry wet concrete or wallboard. Third, the temporary dry air ductwork can be moved easily as the project progresses. Finally, the full warranty period on HVAC system components is preserved if that system can remain off until full commissioning and/or before occupancy.

Figure 4 shows the small portable centrifugal blowers called "air movers" in the drying trade. These are moved constantly. Some materials dry quickly and others require a higher airflow rate to dry properly. Part of the value provided by a drying contractor is the constant attention to measuring material moisture content and re-adjusting the position of air movers and dry air ductwork every day, to make sure all materials dry quickly and completely. Building drying technicians speak of "chasing the moisture" throughout the wetted area. This is critical. The building drying industry has discovered, through painful experience and occasional litigation, that simply supplying super-dry air to a wetted building does not ensure moisture leaves all materials quickly and equally.

Figure 3 (left): Temporary dry air ductwork. Figure 4 (right): Air movers.

Dry Air Must Be Contained

Figure 5 shows a typical temporary enclosure and doorway erected by a drying contractor to retain the dry air in the part of the building that needs it. Buildings under construction are usually wide open. Even after closing in, exterior doors are usually open for easy access. To dry out moist material, the drying air must be contained. Keeping doors closed is never popular with workers, but the irritation can be minimized through simple springs on lightweight swinging doors. Hermetic air seals are not necessary in building drying, but humid outdoor winds must be kept out of the area being dried.

Drying Concrete

In every yard of concrete, nearly 50 gallons (190 L) of water is excess to the curing process. Concrete "cures" through hydration. The cement particles need a certain amount of water to develop strength, which is accomplished through a huge increase in surface area. For example, a pea-sized piece of cement has a total surface area of about 2,000 cm^2 (2 ft^2). During hydration (curing) the granule's surface increases nearly 1,000 times to about 2,000,000 cm^2 (2200 ft^2).[4] After an acceptable strength is reached, the excess free water becomes a potential liability—not to the concrete, but to the interior finish.

Most concrete used in commercial construction reaches 70% of its final strength after 30 days. After that point, excess moisture must be removed so that flooring and interior gypsum board can be installed. At this point, the job superintendent has four choices:

1. Apply the flooring and install the gypsum and hope that no mold will grow.
2. Wait for the concrete to dry through natural convection
3. Seal up the surface so moisture remains in the concrete
4. Use dehumidifiers to dry the material more rapidly than it would through natural convection.

Of these, installing the flooring and wallboard before the concrete is dry is sometimes a costly choice, because it can lead to lawsuits. Also, excess moisture voids some flooring warranties. Waiting is often the next most expensive since it usually puts the project behind schedule and drives up completion costs. Sealing can be very effective, especially when simply no time is left for drying. Drying is becoming popular because it costs about 80% less than the cost of vapor-sealing the wet concrete. For example, floor-sealing costs are usually between \$1 and \$8/ft^2 (\$10 and \$86/m^2). Drying costs range upwards from \$0.15 ft^2 (\$1.60 m^2) but seldom rise above \$1 ft^2 (\$10 m^2).

Using natural convection, the time needed to dry a concrete slab depends on the weather and on the slab's thickness, density and moisture content. In humid seasons, such as in Seattle during the winter or Houston in the summer, open air drying can hold up work for three to four months or longer. Dehumidifiers make the drying time much shorter and more predictable. With that equipment, concrete usually dries in three to six weeks from a water emission rate of 8 to 9 lbs/24 hrs/1,000 ft^2 (39 to 44

Figure 5: Temporary door to contain dry air.

Figure 6: Maple flooring after high humidity.

kg/24 hrs/1000 m^2) down to the 3 to 4 lb (1.3 to 1.8 kg) level required by the warranties of most flooring manufacturers.[5]

Maple Flooring Installation

New schools often contain a maple sports floor in the gymnasium. First, the concrete underslab must be dried to demanding specifications. Then the wood flooring strips must be brought to equilibrium with the center of the humidity range they will encounter over their service life. *Figure 7* shows what can happen if the humidity is not controlled during construction as well as during summer shutdown. The floor, installed during winter in Iowa, expanded when uncontrolled summertime humidity caused the flooring to expand beyond its design limit.

To prevent such problems, the Maple Flooring Manufacturers Association has established environmental specifications during installation as well as during service. Humidity must be held between 35% and 55% rh at all times, and ideally it should be kept at the center of that range during installation to minimize potential damage during subsequent seasonal extremes.[6]

This specification is a challenge because often a construction schedule for a school demands beneficial occupancy by the start of the school year in late summer—just when the outdoor humidity is at its peak. Dehumidifiers make it a trivial matter to meet the MFMA specification. Bringing the dehumidifier on site slightly earlier also lets the flooring contractor slowly and gently bring the wood to the appropriate equilibrium moisture content before installation begins. Such control is especially useful when the wood has been stored or shipped under less than ideal circumstances.

Drying Wallboard Joints

Rainy weather creates a problem for installing and finishing gypsum wallboard. In a damp climate like Vancouver, BC, Canada, the rain load on the vertical surface of exterior walls has been estimated to be about 116 lbs/ft^2/yr (400 kg/m^2/yr).[7] Some of that water inevitably ends up in the materials as the building is being constructed. It's easy to visualize the volume of water that fills the cavities of open concrete block walls after the typical afternoon rainstorms of South Florida. That water slows construction and increases mold risk in gypsum walls. The first symptom is the delayed schedule.

Figure 7 shows that at 60°F (16°C) and 85% rh, it will take about three days to dry the joints. In contrast, the warm dry air from a dehumidifier can bring the air to 80°F (27°C) and 20% rh, an environment that dries the joints in about six hours. In other words, the joints dry before each work shift is finished. That speed and predictability often saves the general contractor time and money.

Perhaps equally important, using dry air during interior wall installation reduces the risk of hidden mold after the project is complete. Any moisture problems become obvious during construction. Joints that fail to cure quickly in a dry air environment are usually being fed by moisture from some hidden source such as water leaks in the exterior envelope, pipe leaks or overly wet concrete block walls.

IAQ Investigations and Mold Remediation

Since wet construction materials can end up creating odors in new buildings, the HVAC designer may be called on to investigate the indoor air quality. Given our current understanding of building-related mold, any IAQ investigator would be wise to follow the guidance given to doctors by their Hippocratic oath, namely: "First, do no harm."

The insurance, construction, property management, real estate and restoration industries are in great turmoil with respect to mold. Recent litigation has led to large monetary awards in favor of building owners and building occupants for damage caused by mold. Of course, these are complex cases, so it is seldom clear which part of the construction team bears the most responsibility for the problem. Also, the medical and legal communities are debating the exact relationship between mold exposure and human health. However, several important facts are not in dispute:

1. Fungal particulate is the chief concern. Mold found in buildings sometimes generates toxic compounds that coat the surface of its spores and hyphae. At the very least, these cause

allergic reactions in those who have become sensitized. More serious health consequences depend on the extent of the exposure, the type of toxin and the susceptibility of each individual. For example, about 20% of the U.S. population is allergic to penicillin, indicating these 55 million people are sensitive to that particular fungal by-product.[8,9]

2. Mold spores are easily lifted into the air by air currents above the moldy surface or by bumping the surface itself. Many years of evolution have designed the spores to do just that.

Drying Time For Taped Drywall Seams (hrs)

Relative Humidity (% RH)	Air Temperature (°F) 40	50	60	70	80	90
90	216	144	102	72	49	36
80	114	78	54	38	27	19
70	84	54	38	26	19	14
60	60	42	29	20	14	10
50	48	36	24	17	12	9
40	43	29	20	14	10	7
30	38	26	18	12	9	6
20	34	24	16	11	8	6

Figure 7: Drying times for drywall seams.[13]

3. Spore concentrations on moldy wallboard can range between 1,000,000 to 10,000,000 spores per square inch (1550 to 15 500 per mm^2).

4. It is not prudent to breathe high concentrations of spores or fragments from building-related mold, nor is it wise to let large numbers of these particles contact your skin.

To plan any IAQ investigation, it helps to understand what must be done to remove mold after it is located. One mold remediation instructor suggests this visual analogy: "On a microscopic scale, a moldy surface resembles a huge field full of dandelions... all in seed. Using a HEPA vacuum, the mold remediator must first suck all seeds off each stalk before they can become airborne... and then he must come back to eradicate all the stalks and roots."[10] Just like blowing on dandelion seeds, it is easy to lift millions of mold spores into the air and cause a larger problem.

Anyone who is investigating IAQ problems should keep in

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mind these facts and their implications. When moldy odors are the basis of the complaint, it's wise to assume that mold is somewhere in the building even if it is not immediately visible. Nobody should casually dig into walls suspected of harboring mold. Roughly stripping wall covering or prying moldy gypsum board off the wall with a crowbar will spread contamination through the room and air-handling system. Such carelessness can turn a $5,000 mold remediation project into one costing $20,000 in a few moments.

If mold is found, further investigations should be conducted using good practices for mold remediation procedures.[9] Even with contamination covering less than 10 ft^2 (0.93 m^2), these procedures require personal protective equipment at the "minimal" level, consisting of an N-95 respirator, gloves and goggles. Contamination over 10 ft^2 (0.93 m^2) suggests at least limited containment of the affected area, plus "limited" personal protective equipment including respirator, disposable overalls and eye protection. When contamination exceeds 100 ft^2 (9 m^2), current best practices recommend full containment of the affected area plus negative air pressure, HEPA filtration inside the containment, and full personal protective equipment including full-face respirator with HEPA filter, disposable body clothing, headgear and foot coverings—popularly described as a "moon suit."

These remediation recommendations are currently in flux, as building scientists and doctors learn more about the ecology of building-related mold and its toxic effects. As of the publication of this article, there are two accepted standards in the United States to guide mold remediation: "Guidelines on assessment and remediation of fungi in indoor environments" (New York City Guidelines), and "Mold remediation in schools and commercial buildings" (Environmental Protection Agency Guidelines). Of these, the EPA guidelines are more current. They go beyond the pioneering New York City document to include guidelines for investigating mold that is concealed behind interior surfaces. HVAC professionals who plan to make IAQ investigations a part of their professional practice will benefit from obtaining both of these brief and well-written publications and reviewing them carefully.

The HVAC Designer's Role

The good news is that not all IAQ problems in new buildings are caused by the HVAC system design or operation. The better news is that if building materials can be kept dry during construction, the risk of mold growth is significantly reduced.

Going a bit further, the HVAC designer can reduce the risk of his system creating mold in the building envelope by several means, all of which are described in detail in the new ASHRAE *Humidity Control Design Guide for Commercial & Institutional Buildings*..[11] For example, the designer could:

1. Specify that all return air ductwork and all exhaust air ductwork be sealed tight with mastic, instead of being allowed to pull air into the ductwork through its joints. This will avoid suction behind walls and ceilings, which in turn avoids humid outdoor air being pulled into building cavities, providing the moisture that feeds mold.

2. Do not allow open plenum returns above dropped ceilings unless the plenum is sealed tightly with respect to the exterior walls and roof. Such plenums are always under suction, which leads to continuous humid air infiltration through any cracks in the external envelope. And there will always be cracks.

3. Specify that (except when the outdoor temperature falls below 20°F [–7°C]) the system supply more ventilation air to the building than is exhausted. Also specify that this outdoor air be dried down to at least a 50°F (10°C) dew point before it is allowed to mix with return air. This will keep dry air leaking out, rather than allowing humid air to leak inward through the inevitable cracks in the exterior envelope (provided that the designer has also been firm about sealing all negative pressure ducts and plenums!)

4. Specify that the buildings HVAC system shall not be operated during construction. If that is impossible, specify that the general contractor shall clean all filters, duct and equipment surfaces (including cooling coils) to the same level of cleanliness as unused equipment.

Architect, General Contractor and Construction Drying

The owner, architect and general contractor have the real control over moisture in materials. If any of these organizations have had difficulties with late projects due to wet weather, or mold problems in the first two years after construction, they may wish to take a more proactive approach to speeding construction and reducing mold risk. Steps to consider include:

1. Specify that all gypsum wallboard be installed with a fire sealant bead of 3/8 in. (9 mm) between the floor and the bottom edge of the gypsum. This avoids the common problem of water from accidental spills or floor cleaning wicking up into the wall to feed mold behind the cove molding at the base of the wall. The sealant eliminates the air path that reduces the fire protection and acoustical barrier properties of walls.

2. Specify that the moisture content (or water vapor emission rate) of all concrete block walls be measured and documented by the general contractor, and that no gypsum board be hung on those walls until the moisture content of the blocks in the wall measures the same as the identical type of block that has been stored away from any rain exposure.

3. Specify that the moisture content of the taped and sanded gypsum board walls be measured and documented by the general contractor at two locations on each wall: the bottom edge and halfway between floor and ceiling. Specify that the interior finish may not be applied until the moisture content of the wallboard is below 0.4% on a gypsum moisture meter or below 12% on a wood meter.[12]

4. Specify that the moisture content of the concrete floor slab shall be measured as soon as the building has been closed-in and as soon as the slab temperature can be brought within the 65°F to 75°F (18.3°C to 23.9°C) temperature required for

the measurement. If the moisture content is excessive, the air above the concrete shall be held below 30% rh until the material is dry enough to meet the specification established by the flooring manufacturer.

5. Specify that the general contractor provide humidity control to the standard defined by the Maple Flooring Manufacturers Association during the installation of any wooden flooring or any fine wooden cabinetwork.

Summary

Mold problems in new construction are obviously preventable since few new buildings have such problems. Owners have a right to expect that a new building will be free of mold.

Excess moisture in materials causes mold. Preventing moisture intrusion is a multidisciplinary responsibility, but keeping the materials dry, and drying them out if they should become wet are the most important tasks. In addition to better specifications from the architect and HVAC designer, the construction drying techniques described by this article can be useful tools in that effort.

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