PCI Precast/Prestressed Concrete Institute

Avoidance of Mold

PCI designer's notebook

Avoidance of Mold

Introduction

Architects and engineers need to consider the potential for mold growth in all phases of building design, construction, operation, and maintenance. There is potential to develop some mold in any building and in any geographical area. Because of the possible health risks of mold and the enormous costs of mold claims and litigation, mold is a hot topic. Claimants have alleged negligent design and detailing, construction defects, or improper selection of materials susceptible to water damage or mold. The insurance industry generally excludes any property damage or bodily injury (health effects) coverage when defective design, construction, or operation of a building results in dampness or mold intrusion. The interface between construction defect litigation and insurance policies is complicated and highly fact specific, with courts in different states drawing radically different conclusions from similar policy language. Design professionals should take proactive measures to prevent water infiltration, excessive humidity, and condensation, which are the key factors in the development of mold. To this end, design firms need to educate themselves about how, why, and where mold grows, and what measures can be taken to reduce the threat of mold developing. Buildings in hot and humid climates have different problems and solutions related to mold from those either in cold climates or in areas with seasonal swings.

The owner and its design professionals should systematically consider the climate, temperature, relative humidity, type of envelope, dew points, outside air requirements, and intended occupancy of a structure when determining the probability of mold. With respect to building occupancy or type, single and multifamily housing, hospitality facilities, healthcare facilities, and schools pose the highest risk for mold growth for several reasons. First, opportunities for mold growth increase when there is a high turnover in occupancy, as often is the case in these property classes. These property classes also have uses and structural characteristics—many individually controlled HVAC systems, appliances, and plumbing systems, for example—that make them more susceptible to mold.

In order to reduce energy consumption after the oil crisis of the 1970s, buildings were being highly insulated (made airtight but without the benefit of adequate ventilation to control humidity). Insulation reduces the ability of a wall to dry after a water leak. It may also shift the dew point within the wall so that, if the condensation is not adequately drained or vented, mold growth and other water damage may occur.

When designing an energy-efficient building targeting longevity and sustainability, moisture and mold control should be part of the planning.

Mold in the Environment

Mold is a natural part of the environment. Molds are forms of fungi found year round both indoors and outdoors. Mold growth is encouraged by warm and humid conditions, although it can grow during cold weather. There are thousands of specimens of mold and they can be any color. Most fungi, including molds, produce microscopic (2 to 10 μm) reproductive cells called spores. These spores typically disperse through the air continually and settle on all building surfaces, where they can remain dormant for years. Given the right circumstances, they may begin growing and digesting whatever they are growing on in order to survive. There is no feasible or cost-effective method to completely eliminate fungal spores from the indoor environment.

Figure 1 Appearance of mold on drywall.

Mold needs four favorable conditions in which to germinate and grow:

- **Temperature range:** Temperatures that are best for humans are also ideal for fungi. Because the comfort range for people is well within the comfort range for mold, modifying the interior temperature is not an option for controlling mold growth. Ideal conditions for mold growth are species dependent, but tend to be in the range of 40 to 100 °F (5 to 38 °C). Little growth occurs below 40 °F (5 °C) or above 122 °F (50 °C). Mold spores can survive, but mold cannot grow, outside this range. However, mold can remain dormant and growth can resume when conditions become favorable again.

- **Oxygen:** Oxygen is required for mold growth. Hence, mold will not grow underwater, but it can grow if starved of oxygen for only a few hours at a time. In all practical cases, the required level of oxygen is readily available in buildings, even in cases of low-permeance building materials.

- **Food source:** While all building materials can act as a substrate for mold to grow on, only organic materials provide a food source (nutrients) to sustain mold growth. In buildings the food source is generally wood, paper, paper-faced drywall (**Fig. 1**) or other cellulose- or carbon-based material, carpeting, or batt insulation. Materials such as precast concrete, metal, plastic, and so-called paperless wall board do not provide a ready food source for mold as they are not organic. Building-material samples were tested according to MIL-STD 810E (same as ASTM C1338) by Bodycote Materials Testing Canada Inc. to determine fungal resistance.

Five fungal cultures were used:

- **Aspergillus niger** (American Type Culture Collection ATCC 9642)
- **Aspergillus flavus** (ATCC 9643)
- **Aspergillus versicolor** (ATCC 11730)
- **Penicillium funiculosum** (ATCC 11797), and
- **Chaetomium globosum** (ATCC 6205).

PCI designer'snotebook

The samples were examined at the end of a 28-day incubation period for the presence of fungal growth. The amount of fungal growth was rated according to the microbial test evaluation criteria in **Table 1**. The results of fungal-resistance testing are presented in **Table 2**.

Dirt and dust of an organic nature that accumulates on the surface of mold-resistive materials can sustain mold growth when the right temperature and humidity conditions prevail. However, dirt and dust can easily be removed from precast concrete through pressure washing before shipment, making it an ideal substrate for inhibiting mold formation. The dust that collects in buildings is primarily paper dust, skin flakes, and fibers from carpeting and clothing. Basically, the food sources for mold are ubiquitous and attempts to control microbiological growth by limiting the food source are generally not successful. The alkalinity of the surface also plays a role in the viability of mold growth. Most fungi require the pH of the substrate to remain within the bounds of about 5 to 8 (neutral to slightly acidic). Concrete has a high pH (10 to 13) and can control fungal growth.

- **Moisture:** Moisture control is the most important strategy for reducing mold growth. Mold growth requires a certain level of moisture on the surface of the food source. Sources of moisture include wet building materials; plumbing; wall, roof, and window leaks; condensation associated with high humidity or cold spots in the building; infiltration of humid air through walls; and improperly operating heating, ventilation, and air-conditioning (HVAC) or humidification systems. In some cases, mold growth generates moisture itself to help the process proceed.

Amount of Growth	% of Area Component Covered	Grade	Organic Substrates
None	0	0	Substrate is devoid of microbial growth.
Trace	1–10	1	Sparse or very restricted microbial growth and reproduction. Substrate utilization minor or inhibited. Little or no chemical, physical, or structural change detectable.
Slight	11–30	2	Intermittent infestations or loosely spread microbial colonies on substrate surface and moderate reproduction.
Moderate	31–70	3	Substantial amount of microbial growth and reproduction. Substrate exhibiting chemical, physical, or structural change.
Severe	71–100	4	Massive microbial growth or reproduction. Substrate decomposed or rapidly deteriorating.

Table 1 Microbial Test Evaluation Criteria.

Fungi typically require a surface relative humidity (RH) to 70 to 80%. Some molds can grown at 20 to 40% RH levels, but these species are less important in building problems, and their growth is slow, even on nutrient-rich surfaces. The design objective should be RH levels below 40% during the heating season and in the range of 50 to 60% during the cooling season for indoor comfort during all load conditions, both occupied and unoccupied. These levels constitute a safe margin below the minimum values of RH that would initiate mold growth.

Condensation can occur within the walls or roof of a building as well as on interior surfaces. To prevent condensation, surface temperatures must be kept above the air's dew-point temperature. Mold growth can be reduced where RH near surfaces can be maintained below the dew point. This can be accomplished by reducing the moisture content (vapor pressure) of the air, increasing air movement at the surface, or increasing the air temperature—either the general space temperature or the temperature at a building surface. The dew-point temperature increases as the air's RH increases, that is, humid air will condense at warmer temperatures than will drier air. Therefore, controlling indoor humidity levels helps prevent condensation.

Description of Sample	Grade	Amount of Growth
Drywall with white paint on one side	1	Trace
Water-resistant drywall	3	Moderate
Piece of 3 ¼ in. (83 mm) tongue & groove wood	3	Moderate
10 in. (250 mm) clay brick	0	None
Concrete block - unsealed	0	None
Concrete block with white primer paint	0	None
Concrete piece - broken/uneven	0	None
Source: Masonry Canada. 2004. Fungal Mould Resistance Testing (FMRT) of Common Building Materials According to MIL-STD 810E. Technical bulletin. Ontario, Canada: Masonry Canada.		

Table 2 Microbial Test Evaluation.

Condensation control focuses on preventing air flow (which can carry significant amounts of water vapor) through the building envelope; interrupting water-vapor diffusion, typically by using a vapor retarder; and maintaining temperatures above the dew point for surfaces exposed to moisture, typically by installing insulation or increasing circulation of warmer air. The first place condensation occurs is near a room's coldest surface. For example, a gap in insulation at the wall/ceiling interface results in a cold area where condensation is more likely to occur. Hence, ensuring the continuity of insulation and air and vapor retarders, if used, also helps prevent condensation.

Condensation can occur in either summer or winter, depending on climate and moisture conditions. A correlation exists between high outdoor dew-point temperatures (but not precipitation amounts) and incidences of mold. High mean dew-point temperatures (**Fig. 2**) are characteristic of most of the eastern United States, thus making these areas more susceptible to moisture-intrusion problems. Design strategies for moisture control under heating conditions often differ from those for cooling conditions, even though the basic principles of moisture transfer are the same. Recommendations for positioning air and vapor retarders relative to insulation and relative to each other depend on whether the building requires predominantly heating, cooling, or both. See Designer's Notebook (DN-15), "*Energy Conservation and Condensation Control*," at www.pci.org/publications for a complete discussion on condensation control and air and vapor retarders in precast concrete systems.

Mold control is primarily about controlling moisture to levels and durations appropriate for the material used. The general strategy is to construct and operate buildings in such a way that materials do not get wet enough to support mold growth, or to ensure that those materials that get wet will dry quickly, and to not provide sufficient food value to support mold growth. Usually, if moisture or high humidity is not addressed within 24 to 48 hours, mold can begin to grow exponentially. Precast concrete does not exhibit structural damage or deterioration from moisture. In addition, the site's natural ventilation will normally dry out concrete, eliminating moisture as a source of mold growth.

Without all of these four elements, mold cannot grow and spread. And of these, moisture is the easiest and only practical way to control mold growth because of the pervasive nature of nutrients and a temperature range suitable for mold growth. It is also the only one that can be controlled while maintaining comfortable operating conditions for humans.

Health Effects of Mold Exposure

Molds release microbial volatile organic compounds (VOCs), which cause mold's musty smell, and produce allergens and, under certain conditions, toxins. The allergens and toxins are not airborne themselves but can be carried in flight with the mold spores. It is these allergens and toxins that have the potential to cause medical issues for occupants.

Most building occupants experience no health effects from the presence of mold. However, some individuals with underlying health conditions may be more sensitive to molds. For example, individuals who have allergies or respiratory conditions such as asthma, sinusitis, or other lung diseases may be more easily affected. Similarly, persons who have a weakened immune system tend to be more sensitive to mold.

With mold growth, occupants may begin to report odors, and some may complain of a variety of health problems. The most common health effects associated with mold exposure include allergic reactions. Symptoms include sneezing, runny nose, skin and eye irritation, coughing, congestion, and aggravation of asthma symptoms. The types and severity of symptoms depend, in part, on the types of mold present, the extent of an individual's exposure, the ages of the individuals, and their existing sensitivities or allergies. Therefore, for people in general, it is not possible to determine safe or unsafe levels for airborne concentrations of mold or mold spores.

Figure 2 Mean dew-point temperature isoclines for July and August (1946–1965) from the Climatic Atlas of United States. (Source: *National Climatic Data Center 2003*)

Even without substantial scientific data to establish a direct link between mold exposure and health effects, those particularly sensitive to certain types of mold can react so severely that claimants have litigated and obtain significant personal injury and property damage awards. Therefore, as long as there is a question regarding how mold may affect human health, claims will continue to arise and lawsuits will continue to be brought against anyone involved in the design or construction of a building that facilitates the growth of mold.

The building enclosure, the primary barrier to wa-

PCI designer'snotebook

ter intrusion, is often implicated in mold problems because it is exposed to a range of moisture sources, including rain and condensation. The decision to use a particular building-envelope system does not determine a building's likelihood of having moisture and mold problems. Many exterior envelopes are time tested (such as precast concrete) and will perform well when properly designed and installed.

Designers should evaluate the placement of fenestration, changes in plane, and the transition points of each material to determine if the proposed envelope system can be designed and installed to prevent water intrusion. Using multiple materials on the envelope multiplies the risk of water intrusion. Both the building-envelope and HVAC decisions made during the design process affect the amount of moisture and potential for mold. A design change in one system may have a dramatic effect on the performance of another system. For example, increased thermal insulation may change dew-point location with possible condensation in the wrong location. If both building pressurization and envelope are planned appropriately, future mold problems are unlikely.

Although the outer portions of precast concrete walls are exposed to wetting, mold is not a problem. Molds do not require sunlight (because they do not use photosynthesis) and in fact their growth is limited by sunlight (ultraviolet radiation [UV]). The UV intensity of bright sunlight typically slows or kills fungal growth both because the light warms (and hence dries) the surface, and because of the high UV intensity. In contrast, the inner portions of an enclosure are exposed to less wetting but are more prone to mold growth because they are kept warm year round. Interior finishes are often made of moisture-sensitive materials and are more affected by the interior environment.

Construction Phases

Moisture problems created by outside-air infiltration and vapor diffusion are negligible during construction. Other than rainwater leaks, moisture problems are generally not introduced until the building's air-conditioning (AC) system begins operating. Significant moisture and mold problems are often attributed to the so-called drying out of the building. In reality, however, such problems are rarely associated with moisture being released from new construction materials, unless the materials are not allowed to completely dry without being covered or hidden.

In the process of selecting building materials for a structure, consideration should be given to how a material reacts when exposed to free water or water vapor. Poorly chosen construction materials, often based on cost considerations or availability, may affect a building's integrity. Materials should be compatible with the regional environment and installed by knowledgeable workers. Contractors must take the initiative to refuse delivery of damaged, dirty, or moldy materials (in the case of timber and drywall).

Reducing the potential for moisture- and mold-related problems during construction generally requires a thorough understanding of moisture-related construction problems, proper attention to construction sequencing, effective temporary control of space conditions, and diligent testing and monitoring to identify problems before extensive damage has occurred. Typically, the most serious weather-related construction moisture problems result when the final stages of construction are completed in the summer or early fall. Because ambient humidity levels are higher during these times, materials are less likely to dry naturally before being enclosed in a structure.

There are three stages of construction: the exposed phase, the partially enclosed phase, and the controlled phase. If the goal is to achieve the lowest level of risk for mold formation, then the single most important point in the construction schedule may be the point at which the contractor seals the building envelope.

During the exposed phase, the foundation, the frame, and everything else are exposed to the elements but the natural ventilation of the site will normally dry out any materials that get wet. To minimize the potential for mold growth, it is important to develop a proactive plan to minimize the risk of water damage and wet surfaces due to external factors such as rain, snow, flooding, and high RH during the exposed and partially enclosed (contractor will normally begin to rough-in the interior and may install some of the finishes) phases. Appropriate construction sequencing avoids installing moisture-sensitive materials before the building is enclosed. The installation of protective barriers or temporary enclosures across building-envelope openings (walls, roof, and basement) and open areas to accommodate construction elevators/hoists and window installation is recommended. The use of water-resistant materials in areas susceptible to moisture also reduces the risk of mold growth. These decisions affect both the construction cost and schedule, and should be fully considered. Wet areas and materials should be dried within 24 hours of exposure.

Fireproofing materials for steel are normally installed during either the first or second phase of construction, even though this material may have a high potential for absorbing and retaining moisture and could serve as a substrate for mold. Precast concrete eliminates the need for and cost of additional fireproofing measures.

Installation of drywall or other interior finishes on or near cast-in-place concrete that is being cured, adjacent to spray-on fireproofing or insulation, or within an area of high humidity will result in water damage.

The contractor should not close in any areas that are not appropriately dried, or that are likely to become wet due to incomplete protection from moisture. Also, the contractor should take appropriate precautions to protect moisture-sensitive materials during storage and construction.

If the goal is to minimize the risk of mold formation, then the single most important point in the construction schedule may be when the contractor completes and seals the building envelope. At that point, the construction process enters the controlled phase and the contractor can begin to install drywall and other finishes.

It is particularly important that the owner and design professionals analyze the construction schedule. The earlier the construction schedule requires a contractor to begin work on finishing the interior (before the building is fully enclosed), the greater the risk of permitting water to enter or accumulate on porous or organic materials, or in places that accommodate mold formation. It also becomes important to pay particularly close attention to selected finishes. Materials that require long lead times or take longer to install will delay the completion of the envelope.

Prefabrication of precast concrete components allows vital construction elements to be manufactured early in the construction process as soon as drawings are approved, ensuring that units are ready for erection as soon as foundation work or the supporting structure is completed. The speed of erection of precast concrete systems also allows for faster completion of the building shell in almost all weather conditions, often cutting weeks and months from the schedule, allowing construction to get into the dry more quickly. This, in turn, allows interior trades to begin work earlier. The fast enclosure results in less weather or material damage during construction to mold-susceptible materials.

Sometimes contractors use drying techniques such as fans, natural ventilation, indirect fired heaters, dehumidifiers, desiccant dehumidifiers, or the HVAC system (if operational) to dry areas where they are installing or applying certain finishes, particularly if water is visible in those areas. Drying techniques may not control the temperature or humidity of the interior space. Thus, these techniques should be reviewed and used appropriately to reduce the potential of mold growth during construction.

Also, construction moisture should not be trapped in assemblies by the indiscriminate use of vinyl wall coverings (which may be impermeable). Vinyl wall coverings can cause the water vapor in drywall to condense and encourage mold to grow in wall cavities or in insulation. Foil-faced fibrous cavity insulation and foil-backed gypsum sheathing can also keep buildings from drying out when they get wet.

During the final stages of construction, the mechanical systems are usually not performing at optimal levels. It is critical that no additional moisture be added to the building during this time, especially from the outside. In addition, any temporary controls of the building HVAC systems must prevent the building from achieving negative pressurization. Maintaining positive (or at least neutral) pressure will help prevent moisture from intruding from outside air into the roof or ceiling and wall cavities. A plan for temporary controls may include statements such as the following:

- The contractor shall energize, operate, and maintain HVAC equipment before the interior finishes are installed. After the building or room is fully weatherized and before interior finishes are applied, the HVAC system shall be operated 24 hours per day for a minimum of three days, until a constant temperature of 75 °F (plus or minus 2 °F) (24 °C [plus or minus 1 °C]) and a constant humidity level of less than 60% can be demonstrated to the owner.
- Throughout the installation of finishes and until the owner's final acceptance, the HVAC system will operate 24 hours a day.
- If mechanical systems are not performing at optimal levels when interior finishes are installed, the HVAC contractor will provide additional temporary dehumidifiers (portable units) and heating or cooling units to meet required conditions. Instead of temporary dehumidifiers, an increased monitoring program may be acceptable.

If the project permits or requires the contractor to operate the permanent HVAC system during construction, it must be specified that the equipment be turned over upon project completion in a clean condition.

During construction, there can be increased pollutant load in a building because of heavy particulate load and off-gassing of formaldehyde and VOCs from newly installed products. There are various methods of controlling this additional pollutant load, such as additional air filtration, the use of temporary air handlers for heating and cooling, and flushing out the building with additional amounts of outside air.

Precast concrete has no outgassing that can cause deteriorated air quality. This has become a critical component in recent years as the need to enhance energy efficiency has tightened the "breathability" of buildings, preventing air from infiltrating and exfiltrating, which retains existing particulates in the air. Precast concrete will not add to outgassing that comes from VOCs and new materials brought into the structure. As proposed by USGBC LEED Credit 3.2, building flush-out can occur either late in the construction phase or after the building is occupied. While the use of outside air to flush out the building may reduce the concentration of off-gassed pollutants, it can also inadvertently cause moisture problems in buildings in many parts of the country during the summertime.

In a typical 100,000 ft^2 (9300 m^2) building, the amount of outdoor air rquired to meet the flush-out portion of this credit is 1,400,000,000 ft^3 (39,620,000 m^3). This amount of air volume in the eastern portion of the country during the humid summer months can be equivalent to over 200,000 gal. (757,000 L) of additional moisture introduced into the building. This moisture is in addition to the normal moisture load from construction activities, cleaning liquids, or construction-related moisture from curing concrete, paint drying, and similar activities.

One of the additional risks with conducting building flush-out (especially in an occupied building) is that it is usually done in the evening when the heat load (sensible) is the lowest and the moisture load (latent) is the highest. This can result in even greater RH levels in the building because the unfavorable ratio of sensible to latent load can cause overcooling of the building (resulting in flash condensation). This can cause moisture to accumulate in building materials such as gypsum wallboard, with subsequent material degradation and mold growth. The additional likelihood that the HVAC system might still be unbalanced at the time of the flush-out increases the potential for moisture problems as a result of this process. Infiltration of air with a high moisture load may also exceed the ability of the HVAC system to remove moisture from the supply air.

Moisture-related problems can be avoided if the building envelope adequately retards moisture, liquid, vapor, or air movement into the building and allows any accumulated moisture to either drain to the exterior or evaporate. Moisture comes from four sources, which have different impacts on a building depending on climate:

- ***Vapor diffusion through the building envelope.*** The vapor-diffusion mechanism does not typically induce significant moisture into a building and can generally be considered a negligible contributor to potential moisture problems. Nevertheless, it is a mechanism to consider in building design and construction, particularly in cold climates and in hot, humid climates, and especially as it relates to the construction of vapor retarders in walls.

  To control air and moisture flow through the wall, any air barrier or vapor retarder must have the proper air resistance or moisture permeability and must be installed at the correct location within the walls. The presence of multiple vapor retarders within a wall system is a common problem, and many architects do not recognize that common construction materials such as precast concrete act as effective barriers.

  Vapor diffusion is difficult to estimate because of microclimatic variables. The building envelope is subject to daily temperature extremes caused by shifting sunlight and shade on the walls or roof. However, using worst-case ambient temperatures in a steady-state analysis is usually sufficient for estimating vapor diffusion, especially if a vapor retarder is properly installed in the wall system.

  A vapor retarder is not required in all situations. Without one, the building envelope may still perform as an adequate barrier to vapor diffusion. Under many conditions, using an air barrier is more important than using a vapor retarder. However, if a vapor retarder is used, factors such as permeance, location, and use of multiple retarders become extremely important.

  The type and location of the vapor retarder can greatly affect moisture accumulation and mold formation. In hot, humid climates, for example, a vapor retarder located between a wall's thermal insulation and the building's interior could reach a temperature below the dew point (point of condensation) of the outside air. In cooler climates, an exterior vapor retarder could be located where the temperature is below the dew point. In both cases, condensation would form on interior surfaces or in interior cavities. To avoid such problems, the placement of vapor retarders is best determined early and with an understanding of the local climate.

Vapor-diffusion problems are accentuated by cold walls or building spaces, permeable exterior surfaces, and impermeable interior surfaces. For example, in hot, humid climates, if the exterior portion of the building envelope is porous—moisture absorbing and permeable—and the interior portion is porous as well as impermeable, the effect of vapor diffusion can be more significant. In cold climates, the opposite condition can cause problems (that is, when the exterior portion of the building envelope is porous and impermeable and the interior portion is porous and permeable). Vapor diffusion is discussed in chapter 25 of the *ASHRAE Handbook—Fundamentals* (ASHRAE 2001).

One advantage of insulation is that it keeps the primary vapor retarder (if one exists and is correctly located) from reaching the temperature at which condensation may occur. In a precast concrete wall system, a closed-cell nonhygroscopic insulation is recommended.

To avoid moisture problems, the design team must consider how direct contact with moisture-laden air affects wall structures. Thermal bridges that allow the structures to cool below the dew point of the ambient air may cause local condensation on the structural materials. For example, metal studs can act as a thermal short circuit or bridge, allowing condensation to occur on interior or exterior portions of the stud even though the wall may be well insulated.

Selecting an interior surface finish with the proper permeance is one of the most critical aspects of an exterior-wall-system design in any climate. Typically, the interior finish is selected for aesthetic appeal or ease of maintenance, with little regard for wall-system performance. An interior finish should have a high permeance rating in hot, humid climates to allow moisture vapor that enters the wall to migrate into the conditioned space, where the vapor will eventually be removed by the AC system. The opposite is true in cold climates. The mechanical engineer will use interior-finish-permeance ratings in performing the dew-point analysis on the wall system.

- ***Rainwater intrusion.*** Moisture can be present in building materials and on the site during construction, causing moisture problems in a building. Significant amounts of moisture can also result from water leaks within building systems or through the building envelope. In both hot, humid climates and temperate climates, rainwater leaks are a major source of building moisture and microbial growth problems.

Because of its panelized construction, fewer points of potential moisture penetration exist with precast concrete. This helps control moisture and eliminate the possibility for mold growth from water that penetrates the walls. Maintenance needs for precast concrete panels also are minimal, with panels requiring caulking only every 15 to 20 years to maintain their reliability. This limits the need to budget for repairs in annual maintenance budgets and reduces the potential for lapses to allow a problem to develop.

Rainwater can be drawn into a building by gravity, capillary action, surface tension, air-pressure differentials, or wind loads. The building envelope (exterior walls and roofing) should control water from all of these sources.

Weather-related moisture includes rainwater and groundwater, which can severely affect the building envelope. Rainwater rarely causes widespread problems in HVAC systems or building interiors; instead, it concentrates around window penetrations, roof lines, joints, and the base of exterior walls. It is important to understand performance criteria as they relate to moisture intrusion for fenestration components such as windows.

HVAC-induced moisture can equal or sometimes far exceed the amount of moisture attributable to rainwater leaks. Additionally, HVAC-induced moisture can mask or obscure rainwater leakage because it is often an envelope-wide problem. This misunderstanding can lead to misdiagnosis, which often results in expensive, unnecessary repairs to the building envelope when simply modifying the HVAC system would have been less expensive and more effective.

In all climates, the building skin must be the primary defense against rainwater and be designed to shed water quickly away from the building. The building envelope plays a vital role in minimizing uncontrolled moisture and air movement into a building and in preventing moisture entrapment within the wall.

Although the building envelope contributes to moisture-related problems in hot, humid climates, infiltration of humid outside air and vapor diffusion through the envelope is not usually as great a factor in more temperate climates. However, in temperate climates, the building envelope plays an important role in minimizing rainwater intrusion into the building, and in avoiding the subsequent mold growth that can result from such intrusion. In cold climates, vapor diffusion or exfiltration of humid indoor air during colder months can also be a problem in wall cavities.

- ***Internally generated moisture.*** After construction, occupant activities and routine housekeeping procedures can generate additional moisture, which can contribute to mold. Normally, if no other significant sources exist, well-designed and properly operating AC systems can adequately remove this moisture. Internally generated moisture is more likely to cause moisture damage inside a wall system in northern climates than in hot, humid climates.

- ***Infiltration of outside moisture-laden air.*** Whether introduced by wind or negative pressurization caused by the HVAC system, air infiltration can cause condensation on interior surfaces, including inside building cavities. Condensation and high RH are important factors in creating an environment conducive to mold growth and are primarily a problem in hot, humid climates.

  No building is hermetically sealed. That is, all buildings have some degree of air leakage (openings inherent in the envelope construction) and this leakage carries a certain amount of moisture with it into, or out of, the building. Precast concrete construction allows minimal air infiltration or exfiltration, reducing the potential for moisture problems due to moist air migrating into a wall and building. The most critical areas of envelope air leakage are gaps around windows and doors; joint openings at roof, ceiling, or floor lines; and the intentional installation of soffit or wall vent systems. These areas provide the most likely openings in a building envelope and are convenient pathways for air leakage and moisture intrusion into the building. Although this air leakage can typically be overcome with positive building pressurization, a tightly sealed building envelope will minimize air leakage and reduce the amount of air required to achieve good pressurization with the HVAC system. Moisture contributed by air leakage is significant and should be a serious concern in the design of the wall system. In fact, the design of the building envelope for minimizing air leakage is more critical than the design of the vapor barrier.

The potential for infiltrated moisture to be deposited in the building envelope is directly related to the interior temperature of the building, the moisture content of the outside air, and the amount of outdoor air infiltrating the building wall systems.

An advantage to precast concrete construction is that an air barrier is inherent in its construction. Unlike a framed wall, a precast concrete wall usually provides a solid air barrier that is free from penetrations. This does not release the design team from designing a properly pressurized building envelope. A depressurized interior space will induce the intrusion of outside air, even through a precast concrete wall. And most wall systems will have openings for fenestration where possible air-infiltration pathways exist.

Nonconditioned air rarely should be the source of makeup air for a building. To preclude its introduction, the system should be designed and installed to eliminate negatively pressurized spaces (with respect to outside conditions) in the rooms, walls, or ceiling cavities. An exception to this recommendation applies to facilities that have higher internal moisture conditions than outdoors; forcing the moisture through the exterior envelope may allow moisture accumulation in the cavity. For example, natatoriums try to maintain indoor conditions of 82°F (28°C) and 60% RH to minimize pool surface water evaporation. In cold climates, forcing this moisture through the exterior envelope can cause condensation on cooled surfaces, ice formation, microbial growth, and degradation of wall or roof materials.

- ***Ventilation.*** Most buildings will bring in conditioned outside air to replace exhausted air, maintain indoor air quality (IAQ), and provide building pressurization (see ASHRAE 62.1). Providing enough ventilation to positively pressurize the building will reduce uncontrolled air leakage into the building. Ventilation moisture loads tend to be one of the highest moisture loads that need to be mitigated.
- If the HVAC system introduces moist outside air into the space for ventilation, the system must continuously dehumidify the air. *Under no circumstances should adequate dehumidification be sacrificed for ventilation.*

In regions with high ambient dew-point conditions and elevated RH levels (which include much of the eastern half of the country during portions of the year), there is a direct correlation between the number of moisture problems (mold) and increased rates of mechanical building ventilation. This can occur for obvious reasons, such as the additional moisture load that is introduced into the building along with outside air. It is important to bring in the minimum amount of outdoor air possible (while meeting ASHRAE 62.1 and pressurization requirements) and dehumidify it directly and constantly.

In ASHRAE 62.1-2004, a number of revisions were made that, on average, reduced the outdoor ventilation rate by about 15 to 20% when compared with the 2001 version. For designs in humid climates, this is a good design practice. Less air means less moisture. But some don't like the cut in the rate, which in an office environment reduces the rate from 20 cfm/person to an average of about 17 cfm/person.

The LEED rating system awards an additional credit (Increased Ventilation – Eqc2) for an increase in the rate of at least 30% over the 2004 calculated values. LEED went with 30% because the USGBC would actually prefer a number 50% higher than the 2004 rate (about 25 cfm/person), but a 30% bump was seen as a compromise between indoor air quality and energy efficiency.

This is a catch-22. If designing in a humid climate, you could actually be rewarded for increasing the potential for mold and moisture problems by bringing too much moisture inside. If the warm, moist air hits a cooler surface, such as the interior gypsum board of an air-conditioned room or the cold-water supply pipe in a ceiling plenum, the vapor from the moist air will condense and mold will form on the wallboard or on the ceiling tiles below the pipe.

A more progressive and safer approach would be to skip the LEED point and bring in the code minimum. Then, on projects that merit the added control complexity, apply a demand-control ventilation strategy to actually cut that quantity down further whenever possible. This might even earn a LEED point under the Optimize Energy Performance Credit (EAc1).

Considering both energy conservation and moisture-management goals in the design, construction, operation, and maintenance of HVAC systems can minimize the required energy use and resulting cost. However, the impact of mold proliferation suggests that energy-cost savings should not be achieved at the expense of sound moisture management in a building.

It is more difficult to maintain a specific RH than a specific temperature, which means it is easier to lose humidity control. To fully dehumidify the air flow, the HVAC cooling coils must be sized properly to meet the sensible and latent load. (Latent load is the moisture in outside air that is brought into the building and requires removal via dehumidification. Sensible load is the air temperature that is sensed and addressed by the HVAC system, either by heating or cooling the air, to reach the established set point.) This air flow, the combination of outside air and return air, must be brought to a temperature that causes the moisture in the air to condense. This is known as latent heat removal **(or latent energy removal)**. Simultaneously, the cooling coil is reducing the sensible temperature of the air to offset the sensible energy generated in the space by lights, solar radiation, people, equipment, and so on.

AC units are typically sized according to the peak design cooling load. The cooling load is often standardized for a number of areas and sensed by a room thermostat. AC unit run time is typically controlled by temperature, instead of by humidity (humidistat). Run time is a critical variable in the ability of the unit to dehumidify the space. If the unit is sized properly to match the room sensible load and to maximize unit run time, the room will be dehumidified adequately. If the unit is improperly sized, however, when the room sensible load falls below the peak design load, the AC unit will run for a shorter period and could fail to dehumidify the room properly. The system should have control overrides to monitor air quality and force operation of the system independent of temperature conditions to achieve a balance of thermal comfort and RH in the building. Dehumidification needs to operate efficiently at peak and off-peak loads, and regardless of whether the building is occupied or unoccupied.

Chapter 26 of the *ASHRAE Handbook—Fundamentals* (ASHRAE 2001) contains a complete description of methods of calculating cooling loads from ventilation and infiltration. The outside humidity during a typical year may be quantified to determine annual moisture load before designing and sizing the mechanical system. Annual humidity information can be obtained from weather data that report mean frequency of occurrence of dry bulb temperatures with mean coincident wet bulb temperatures for temperature ranges and corresponding hours of occurrence per year. One such source is AFM 88 29 (U.S. Air Force [USAF] 1978).

The data as presented by ASHRAE work best for sensible load calculations but do not always apply for latent calculations. In humid regions, designers should know the highest vapor pressure likely to occur during the year. In most climates, the highest RHs are found during the morning and evening hours and occur at high values even during the winter. Also, the highest latent loads are usually found at lower dry bulb temperatures than the ASHRAE design data reflect.

ASHRAE outlines good practices for ductwork design, cooling for dehumidification, and proper installation of humidification systems to reduce moisture in ductwork and the likelihood of mold growth (see the 2001 ASHRAE publication *Humidity Control Design Guide for Commercial and Industrial Buildings*). In many cases the level of moisture control required to control mold is no more stringent than that required to ensure good performance and durability.

In any climate, the normal functioning of standard AC units can result in microbial growth. Just downstream of the cooling coils, the air is at or near 100% RH during the cooling season. The interior surfaces of the AC unit and ductwork immediately downstream of the cooling coils are often lined with insulation, generally for acoustical purposes. Dirt and fungal spores are often trapped in the lining. This environment is conducive to microbial growth and can lead to IAQ complaints because the conditioned air (and any microorganisms it carries) is distributed inside the building.

Building Layout Considerations for Proper Building Pressurization

Uncontrolled movement of nonconditioned moist air into a structure is an important source of unwanted moisture. Moist-air infiltration is often a bigger problem than rainwater leaks because water generally obeys the laws of gravity. By contrast, air movement can enter a building from any direction. While making a building watertight is a formidable task, making it airtight is an impossible one.

Maintaining proper pressurization in a building is the best way to prevent uncontrolled airflow, but this depends on a building layout that promotes interior air distribution. The uniformity of the layout from floor to floor, space usage, and construction style (atrium lobby areas or continuous slabs between all floors) affect air distribution and the degree of pressurization required. Atriums and a lack of between-floor air barriers provide portals for airflow that affect multiple levels, making pressure relationships more difficult to control. The building layout should be analyzed both vertically and horizontally for its effects on the pressurization.

HVAC systems that positively pressurize a building space by supplying unconditioned or only partially conditioned outside air will avoid infiltration of outside air through the building envelope. A positive pressure will cause air to generally flow out of the building through joints and cracks such as those found at windows and closed doors. However, even a well-pressurized building cannot prevent infiltration through large openings like door entrances. Unless a rate of air flow of at least 150 feet per minute (fpm) [0.8 meters/second (m/s)] can be achieved through these large openings, wind-induced air leakage into the building must be expected.

Mechanical Considerations

If improperly designed, constructed, and operated, building mechanical systems are likely to create moisture and mold problems. Therefore, particular attention must be paid to their design, equipment selection, installation, and start-up. The key factors to consider are pressurization and dehumidification.

Pressurization

Pressurization of buildings can work in all climates to eliminate uncontrolled air flows. In cold climates, pressurization during the winter forces moisture out through the building envelope and may allow moisture to accumulate if it does not have a pathway out, or if it reaches a vapor retarder that is below dew point. In hot, humid climates, outside air can contribute a large moisture load to the wall cavity and conditioned space. If outside air is drawn into the building envelope by negative pressure inside the building, it will travel through the wall and into the interior space, making it very difficult to maintain a set RH. Because airflow will always follow the path of least resistance, outside air can even get into any interior walls that intersect with an exterior wall. The potential for moisture accumulation increases with lower interior temperatures and with higher negative pressures. Proper building pressurization depends on control of mechanically induced depressurization and the proper distribution of makeup air within the building spaces. Even a properly designed and installed building envelope cannot compensate for a building under negative pressure. Achieving proper building pressurization is sometimes difficult because it must overcome any depressurization from stack, wind, and fan effects.

Building Operation and Maintenance

Operation and maintenance are no less important than design and construction to avoid moisture problems in a building. If the HVAC system is not properly operated, the relative humidity in the building may increase, or condensation may accumulate to the point where mold will begin to grow. For the most part, the HVAC system should be kept turned on. Among other things, the costs and benefits of humidistats should be considered.

Once construction is complete, designers should encourage the development of a detailed set of written procedures for scheduled maintenance and inspection programs for the prevention and early detection of mold. The first step in achieving timely and appropriate maintenance is to make sure visual inspections and component service-life monitoring are conducted regularly of the building envelope, windows, roofing system, HVAC, and drainage systems. Particular attention should be paid to flashings, counter flashings, and sealants. Attention should be paid to all plumbing and piping systems and to any water used to clean or otherwise maintain the interior of the building. Below grade, water infiltration through foundation walls should be avoided.

Sources of dampness, high humidity, and moisture should be eliminated and any conditions that could be causes of mold growth should be corrected to prevent future mold formation. Wet or damp spots and wet, non-moldy materials should be cleaned and dried as soon as possible (preferably within 24 to 48 hours of discovery).

Commissioning

A comprehensive continuous commissioning program should ensure that the building's energy-related systems provide optimal design performance at all times and produce expected comfort, reliability, and savings, and should analyze the building envelope's performance. It should also find and correct any equipment-installation mistakes. The HVAC designer should provide input on the operation and maintenance guidelines for the specified systems and equipment, and should actively participate in the commissioning process to ensure that building operators understand their role and responsibility in mold prevention.

To reduce the possibility of moisture and mold problems, the following should be included in building commissioning:

- During the design phase, a technical peer review of the contract documents should identify issues that will likely be a major cause of moisture and mold problems in the operating building. This review may need to be accomplished by someone other than the traditional commissioning agent because they may not have the requisite skill set to conduct this type of analysis. This review needs to specifically identify which building components and systems have a high potential for moisture problems and offer alternative solutions to the design team.
- The commissioning process needs to consider the interrelationship of the building envelope and the HVAC system. This area is often overlooked because it involves the dynamic interaction between two separate technology areas. The building should be properly pressurized and the HVAC system dehumidifying properly.
- The building envelope needs to be commissioned to ensure avoidance of rainwater leaks, excessive air leakage, and condensation problems. In cases where the envelope is commissioned, both individual envelope components (like windows) should be tested as well as assemblies of multiple adjacent components. Testing individual components does not address the connection points and intersections between various envelope components where most failures occur.

The sequence of commissioning is critical to avoid problems that may occur even with a properly designed and constructed building. For example, during the final stages of construction, a combination of events may occur that results in depressurization of the building despite the fact that the building will eventually operate as a fully pressurized building.

Remediation of Mold

Reliable sampling for mold can be expensive, and standards for judging what is and what is not an acceptable or tolerable quantity of mold have not been established. If visible mold is present, then it should be remediated by removing standing water and drying affected areas within 24 to 48 hours regardless of what species are present and whether samples are taken. In specific instances, such as cases where health concerns are an issue, litigation is involved, or the source(s) of contamination is unclear, sampling may be considered as part of a building evaluation, or to document that remediation efforts were successful at removing contamination.

Repair of the defects that led to moisture accumulation (or elevated humidity) should be conducted in conjunction with or prior to mold remediation. Specific methods of assessing and remediating mold contamination should be based on the extent of visible contamination and underlying damage. The simplest and most expedient remediation that is reasonable and properly and safely removes mold contamination should be used.

Nonporous (for example, metals, glass, and hard plastics) and semi-porous (for example, precast concrete) materials can be cleaned and reused. Cleaning should be done with a water extraction vacuum and using a damp wipe with water and a high-quality detergent solution, scrubbing as needed until all visible signs of mold are removed. The process is completed by rinsing the area with clean water, but in some circumstances, a disinfectant such as bleach may be used to complete the rinsing process. If a disinfectant is used, allow the area to dry overnight; otherwise, dry the area immediately. It is suggested that water not remain on the treated surface more than 24 to 48 hours to prevent the conditions necessary for mold to redevelop.

Porous materials, such as ceiling tiles and insulation, and wallboards with more than a small area of contamination (obvious swelling and seams not intact), should be removed and discarded. All materials to be reused should be dry and visibly free from mold. Routine inspections should be conducted to confirm the effectiveness of remediation work.

Precast concrete construction supports the scientific community's maxim to prevent or inhibit mold formation rather than attempt remediation of fungi in indoor environments. This, coupled with durability, fire safety, and all of the other outstanding attributes of concrete make it an excellent choice as not only an ideal mold-resistant material, but also one that mold simply won't consume.

— J. David Odom
Vice President, Senior Building Forensics Consultant
Liberty Building Forensics Group LLC
Orlando, Florida (d.odom@libertybuilding.com)

References:

1. Mold Litigation Task Force. 2003. Managing the Risk of Mold in the Construction of Buildings: Guidance for Building Owners, Construction Contractors, and Other Parties to the Construction Process. *Constructor,* May.

2. Odom, J. David, and George H. DuBose. 1996. *Preventing Indoor Air Quality Problems in Hot, Humid Climates: Problem Avoidance Guidelines.* CH2M HILL and the Disney Development Company.Odom, J. David, and George H. DuBose. 1999. *Commissioning Buildings in Hot, Humid Climates.* Lilburn, GA: Fairmont Press.

3. Odom, J. David, George H. DuBose, Richard Scott, and Norman Nelson. 2005. *Mold and Moisture Prevention.* Washington, DC: National Council of Architectural Registration Boards.

4. Odom, J. David, Richard Scott, and George H. DuBose. 2007. The Hidden Risks of Green Buildings: Avoiding Moisture and Mold Problems. *Direct Connection,* V. 10, No. 2.

5. Ontario Association of Architects (OAA). 2003. *OAA Mould Control Practice Guide.* Toronto, Canada: OAA.

6. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 2001. *ASHRAE Handbook—Fundamentals*. Atlanta, GA: ASHRAE.

7. ANSI/ASHRAE TC 4.3. 2004. *Ventilation for Acceptable Indoor Air Quality*. (Standard 62.1-2004). Atlanta, GA: ASHRAE.

8. ANSI/ASHRAE TC 7.6. 2004. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. (Standard 90.1-2004). Atlanta, GA: ASHRAE.

9. Harriman, L.; G. Brundrett; and R. Kittler. 2001. *Humidity Control Design Guide for Commercial and Institutional Buildings*. Atlanta, GA: ASHRAE.

10. U.S. Green Building Council (USGBC). 2006. *New Construction & Major Renovation version 2.2 Reference Guide*. 2nd ed. Washington, DC: USGBC.

designer'snotebook

PCI Precast/Prestressed Concrete Institute
200 West Adams Street | Suite 2100 | Chicago, IL 60606-5230
Phone: 312-786-0300 | Fax: 312-621-1114 | www.pci.org