Preventing Defect Claims In Hot, Humid Climates

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Insurers paid approximately $200 million toward mold and moisture-related defect claims in 2000. That amount increased to $1 billion in 2001 and $3 billion in 2003. During this time, premiums increased more than 50%, forcing one-third of all contractors to abandon work in markets where they could not obtain or afford liability coverage.*

A confidential survey was administered in February 2007 to attendees of the annual Associated General Contractors of America (AGC) Surety Bonding and Risk Management Conference in Longboat Key, Fla., to determine which building elements they thought were at greatest risk of defect claims. Respondents represented six of the seven largest U.S. sureties, comprising 45.6% of the $58.7 billion commercial liability market.[1]

Findings from participants who were involved in more than 17,000 combined total construction defect claims indicate that 84% of claims are associated with moisture-related defects in building envelope systems (69%) and building mechanical systems (15%). More than half (53%) of all defects are caused by faulty installation. Other causes of construction defect claims cited by respondents include design errors and omissions (19%), improper sequencing and oversight of trades (15%), defective materials (8%), inspections (3%), and other causes (2%). More than 90% of respondents felt the number of defect claims had increased within the last 10 years, with nearly half (48%) indicating that defect claims had increased more than 25% during this period.

In response to the survey findings, this article provides best practices to avoid HVAC and HVAC-related envelope claims in moisture-vulnerable climates. Among the most vulnerable of these a- re hot,

*Krizan, W., et al. 2003. "Mold lawsuits have industry feeling vulnerable as larger projects are eyed." Engineering News Record (ENR), 250(12).

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humid climates, which according to ASHRAE are regions that maintain either a 19.5°C (67°F) or higher wet-bulb temperature for 3,000 or more hours during the warmest six consecutive months of the year, a 23°C (73°F) or higher wet-bulb temperature for 1,500 or more hours during the warmest six consecutive months of the year, or both. For the purposes of this discussion, a hot, humid climate encompasses all of Florida, the southern half of the Gulf-rim states between Florida and Texas, and southeast coastal Texas.

Mechanical Defects

Roughly 3.6 million (78.1%) of all U.S. commercial buildings in 2006 were air conditioned. Packaged units (36%), chilled water systems (21%), and heat pump systems (17%) are the predominant air-conditioning technologies used by U.S. commercial buildings in the South *(Figure 1*), although the use of these and other technologies varies by market. Construction defects commonly associated with these types of mechanical systems include condensation of outside or internally generated water vapor within ducts, plenums, walls, and ceiling cavities caused by inadequate dehumidification and exhaust ventilation.

Condensation control consists of lowering the dew point of the indoor air below the design indoor air temperature. This is achieved by dehumidifying return and ventilation air, exhausting significant sources of internally generated moisture and, controlling the infiltration of hot, humid outside air. Air that is at 90% relative humidity will condense on the first surface that is 2°C (3°F) cooler than the air. If the relative humidity is 40%, a surface must be 14°C (25°F) cooler.[2] Using the simplified method of proposed ASHRAE Standard 160P, Design Criteria for Moisture Control in Buildings, for buildings in hot, humid climates, users can maintain indoor RH of approximately 60% (and no greater than 70%) at 24°C (75°F) while maintaining effective condensation control, as long as the relative humidity remains within the limits of occupant comfort and other applicable standards (e.g., ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy).

To achieve effective dehumidification, HVAC systems are designed to provide a suitable fraction of sensible and latent capacity to maintain desirable indoor temperature and humidity levels based on the climate, building type, building use, and number of occupants. Moisture removed from the air must be removed from the building. Condensate that is not promptly drained out of the mechanical system may overflow drain pans, leak from condensate drain lines to surrounding moisture-vulnerable materials, or be entrained back into the supply air (*Photos 1a* and *1b*). Stagnant condensate also can provide a breeding ground for viruses, bacteria and fungi. ASHRAE prescribes a drain pan slope of 1 cm/m (0.125 in./ft) to an outlet at the lowest point and the use of P-traps on the negative (suction) side of draw-through systems to prevent hot, humid air from being drawn into the air handler through the condensate drain.

In addition to effective dehumidification, design consideration must be given to exhausting internal sources of humidity. Many internal sources of moisture, such as indoor swimming pools, spas, kitchens, and bathrooms, require exhaust ventilation.

Building occupants are another significant source of internally generated moisture. Humans are approximately 60% water by weight and consume roughly 2 L (0.5 gallon) of water per day. Exhaled breath and perspiration release roughly 1.4 kg (3 lb) of water vapor per person per day to the indoor air.

In addition to water vapor, chemical and biological contaminates in the indoor air also must be removed. The requirements for outside air ventilation for commercial buildings in the U.S. are provided by ANSI/ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality, and are defined by building use. The quantity of outside air can vary from 15 cfm (7 L/s) per person in a typical office environment, to as much as 100% fresh air ventilation in specialized health-care units. In hot, humid climates, the quantity of outside ventilation air should, at a minimum, exceed the quantity of exhaust air to maintain positive building pressurization. Without positive pressurization, humid air will readily enter through door and window openings or infiltrate through the envelope. Although the building may be designed with positive pressurization, an unbalanced HVAC system may induce negative air pressure in parts of the building. Subsequently, supply and return air in each room of the building must be balanced to minimize the infiltration of hot, humid air.

However, ventilation air in hot, humid climates is another potential source of moisture in buildings. Depending on the quantity of outside air ventilation, dedicated dehumidification systems (e.g., energy recovery ventilators, desiccants, or enthalpy wheels) may be necessary. In cases where the air-conditioning system alone can be used for effective dehumidification, energy-efficient reheat strategies (e.g., energy recovery exchangers, hot-gas-bypass, runaround coils, or heat pipes) may be considered to maintain adequate dehumidification when time-of-day or seasonal sensible loads are low, and, to avoid providing supply air that is lower than the dew point of the indoor air. In addition, CO_2 sensors can be used to match fresh air ventilation to actual building occupancy instead of maximum design occupancy in buildings where humans are the dominant source of internally generated moisture and indoor air pollution.

Common defects related to HVAC design in hot, humid

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climates include inadequate dehumidification caused by oversized sensible capacity and reduced airflow (especially during seasonal or time-of-day part-load conditions), inadequate exhaust for internal sources of moisture, and insufficient ventilation air to maintain positive building air pressure. Common construction (e.g., installation) defects include duct leaks, poor balancing on multiple inlet exhaust systems, closed or malfunctioning exhaust dampers, and exhaust air vented to an unconditioned space within the building instead of outdoors (e.g., via a ceiling cavity). Methods to promote and maintain effective building dehumidification in hot, humid climates include:

- Sizing the cooling system to meet, but not exceed, the sensible design load;
- Providing staged cooling capacity so that a fraction of the capacity can be operated when sensible loads are too low for effective dehumidification;
- Maintaining positive internal air pressure;
- Providing added dehumidification using energy-efficient reheat strategies;
- Providing dedicated dehumidification for ventilation air;
- Using CO_2 sensors to match Standard 62.1-2004 outdoor ventilation requirements to actual occupancy instead of maximum design occupancy; and
- Using enthalpy sensors if conditioning or precooling with outside air.

Condensation control also includes insulating equipment surfaces and materials that will unavoidably condense water vapor, such as chilled water pipes, valves and fittings, air-handling cabinets and supply ducts passing through unconditioned spaces (*Photo 2*). Closed-cell insulation should be used where practical to provide a thermal buffer and an air infiltration barrier. Exposed interior HVAC surfaces that will unavoidably come in contact with condensate must be fabricated from hard-surfaced materials such as galvanized metal, and in certain applications, stainless steel. These materials must be resistant to corrosion and mold growth and easily cleaned.

Methods to promote and maintain effective building condensation control in hot, humid climates include:

• Sealing and testing all ductwork, plenums, and air handlers;[4,5]

• Avoiding use of rooms, crawl spaces, stud wall cavities, or other unsealed building cavities as return air plenums (*Photo 3*);

• Insulating all chilled water piping, ductwork, and air-handling equipment (especially in unconditioned spaces);

• Installing air handlers, chilled water piping and ductwork inside the building insulation and air barrier; and

• Installing water piping in interior walls and chases to avoid condensation.

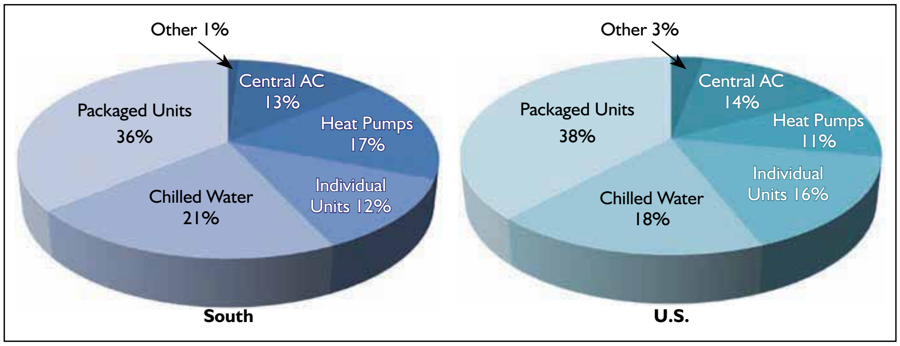

Figure 1: Predominant cooling equipment in U.S. commercial buildings by percentage of total floor area.[3]

Care should be taken to ensure the mechanical system is not a source of unwanted moisture or water penetration into the building. Likely sources of rainwater penetration include rooftop penetrations (e.g., curbing around packaged units and exhaust fans) and wall penetrations (e.g., ventilation intake and exhaust air louvers). To prevent moisture problems caused by blown rain entering outdoor air intakes, consider using louvers that meet AMCA 500-L-99, Laboratory Methods of Testing Louvers for

Photos 1a and 1b: Condensate pan overflow into return air plenum caused by blockage of condensate drain line.

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Photo 2: Condensation on an uninsulated chilled water line in an unconditioned space.[2]

Photo 3: Mold growth in a wall cavity depressurized by a return plenum.[2]

Rating, for intake air velocities less than 500 fpm (2.5 m/s).

The permanent HVAC system may be used for interior space conditioning and dehumidification during construction[2] only if operating the system does not void the manufacturer's warranty and, if all return air locations are protected from contamination by providing adequate filtration at each return air location in addition to filtration at the return air side of the coils. Air handlers, coils, drain pans, filters, humidifiers, heat exchangers, and mixed air plenums should be designed and installed according to Standard 62.1-2004 to be easily inspected, maintained, and cleaned. Specific attention should be given to the inspection of the following mechanical components during installation:

- Drain pans, drain pan outlets, traps, and disposal.
- Insulation and vapor retarders on exposed surfaces expected to fall below the dew point of ambient air (e.g., chilled water lines, refrigerant lines, air conditioning air handlers, and chillers) particularly at transitions (e.g., penetrations through walls, floors and ceilings, support clamps, valves, dampers, pumps, blowers, and gages).
- Access panels (e.g., air handlers, filters, coils, drain pans, and supply ducts near air handlers) to ensure that they allow inspection and maintenance of HVAC components.
- Exhaust ventilation systems, for duct sealing, insulation, and vapor control.

During building start-up, an independent, certified commissioning agent should ensure enclosure airtightness according to ASTM E779-03, Standard Test Method for Determining Air Leakage Rate by Fan Pressurization (blower door test), and duct seal tightness according to ASTM E 1554-03, Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization (low-rise residential and small low-rise commercial buildings). Diagrams labeling key components and operating instructions should be affixed to the mechanical system to aid others in accessing and repairing the HVAC system. This may include diagrams of flow directions and valve locations and functions in the commissioning documents (e.g., as-built drawings), as well as information on HVAC operations and maintenance activities, personnel, and contractors.

Envelope Defects

As shown in *Figure 2*, exterior insulation and finish system (EIFS), stucco and brick veneer are the predominant wall systems used by U.S. commercial buildings in the South (50%) followed by concrete panels and masonry units (29%) and integrated metal glazing (15%). Construction defects commonly associated with these types of wall systems include rain and groundwater penetration, capillary action (e.g., wicking), water vapor infiltration, and subsequent condensation. In hot, humid climates, air infiltration may be the dominant source of moisture in air-conditioned buildings. Methods to prevent water vapor migration and subsequent condensation inside wall cavities and building interiors include:

- Installing materials with low vapor permeability to the warm side of the thermal layer;
- Selecting wall insulation that meets ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings
- Except Low-Rise Residential Buildings, for the climate; and
- Designing walls to dry to the interior, exterior, or both.

The wall assembly illustrated in *Figure 3* shows an EIFS on metal framing with a properly designed drainage plane, vapor retarder, air barrier, and thermal envelope appropriate for hot, humid climates. The assembly has a continuous drainage plane provided by building wrap installed on the inside of the stucco rendering that is drained to the exterior. An air gap between the exterior rigid insulation and the drainage plane provided by a spacer mat, channels, or textured building wrap provides a capillary break and allows liquid water to drain. In addition, the drainage space provides a vented or flow-through assembly that allows drying to the outside.

Latex paint on the interior gypsum board provides a semipermeable, Class III vapor retarder (= 10 perms) that resists the exfiltration of inside air into the wall cavity while allowing the wall to dry to the interior if wetted. An air barrier is provided

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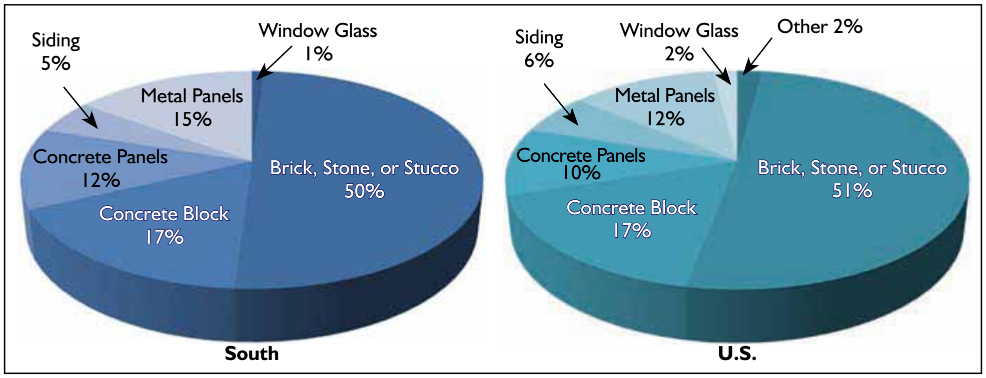

Figure 2: Predominant exterior wall systems in U.S. commercial buildings by percentage of total floor area.[3]

by the interior gypsum board, the exterior stucco rendering, the exterior sheathing or the exterior building wrap.[6] Materials with low vapor permeability, in this case the rigid polystyrene, are installed on the outside of the primary (batt) insulation layer to avoid condensation within the wall cavity. Together, these elements resist the entry of water vapor into the wall cavity and ensure the temperature of condensing or moisture-accumulating surfaces remain above the dew point of the infiltrating or exfiltrating air.

Special design consideration must also be given to brick and masonry-clad walls to prevent the rain-sun-driven water vapor dynamic. If the cladding is brick or concrete masonry and the wall is insulated with high permeability (>10 perm) porous insulation, the cladding should be back-vented, and low permeability (<1 perm) insulating sheathing or vapor retarder should be placed between the veneer and porous materials.[7]

For obvious reasons, roofing systems are the most vulnerable building element to water penetration and subsequent moisture-related construction defect claims. Built-up bituminous roofing (32%), heat-welded polymeric and synthetic rubber (19%), and metal roofing systems (17%) are the predominant roofing materials used by U.S. commercial buildings in the South (*Figure 4*). A significant number of smaller commercial buildings (less than 5,000 ft^2 [465 m^2)]), use shingle and tile roofing materials. Construction defects commonly associated with these types of roofing systems include progressive membrane failures from roof penetrations, weather exposure and ponding water. In addition to providing effective drainage, roof and ceiling assemblies must also be designed to prevent water vapor migration and condensation. Methods to prevent water vapor migration and condensation underneath roofing membranes, roof decking and ceiling cavities include:

- Using a layer of material in the roof and ceiling assembly as an air barrier such as interior gypsum board, foam board or spray foam insulation, concrete, oriented strand board (OSB) or plywood decking, and fully adhered roofing membranes (fluted, corrugated or standing seam metal decking, or suspended ceilings should not be used as air barriers);
- Selecting roofing or ceiling insulation that meets or exceeds Standard 90.1-2004 for climate;
- Installing the air barrier, the insulation layer, and materials with the lowest water vapor permeability (<2 perms) into an assembly of consecutive touching layers;
- Installing materials with low water vapor permeability (<2 perms) together on one side of the insulation layer or the other. For vented roofs, use a vented space to separate low permeability materials in the roofing and ceiling;8 and

Determining the rate of air infiltration through the building envelope using ASTM E779-03, Test Method for Determining Air Leakage Rate by Fan Pressurization.

Material Defects

Finally, the mechanical and envelope systems design should incorporate materials that minimize the use of moisture-vulnerable materials. Some materials can be safely exposed to moisture while others are so easily damaged by water that they must never become wet. Moisture-vulnerable materials:

- Contain nutrients that are a food source for molds, bacteria, or wood-decaying fungi;
- Are porous and easily absorb water;
- Have no antimicrobial characteristics; and
- May delaminate, crumble, or deform when exposed to moisture.[2]

Examples of moisture-vulnerable materials commonly used in both mechanical and envelope systems include gypsum board plenums and open-cell duct insulation. Paper-faced gypsum board contains organic starches and sugars. Fiberglass duct insulation, while not organic, can trap organic debris (e.g., sawdust). Both materials readily absorb and retain moisture,

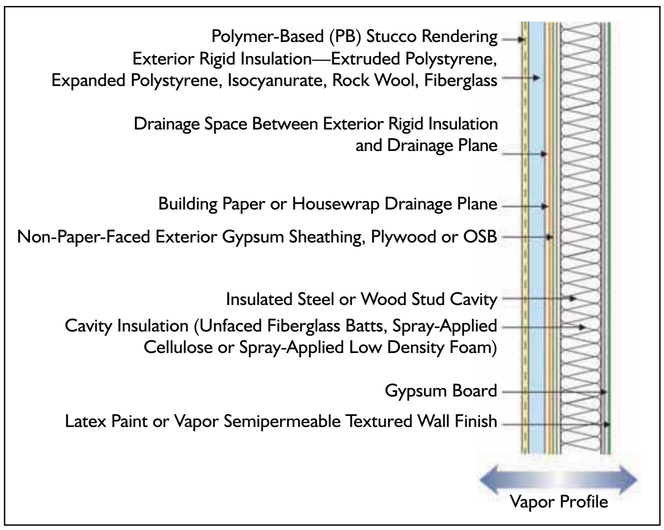

Figure 3: Frame wall with exterior insulation and finish system.

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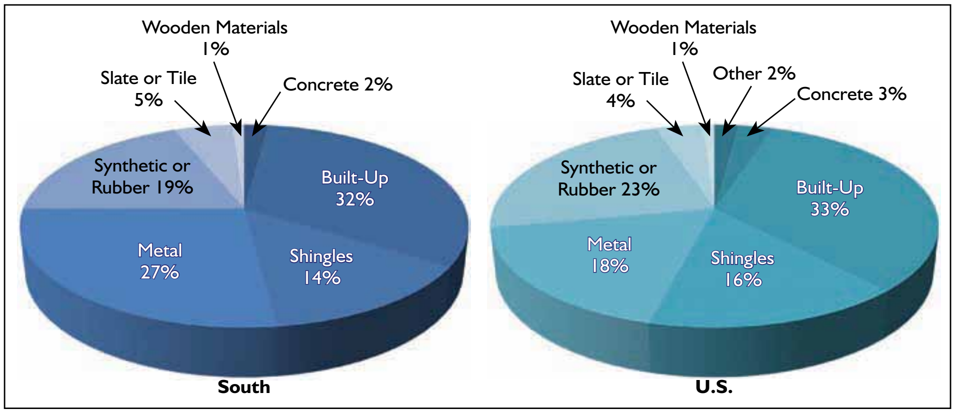

Figure 4: Predominant roofing systems in U.S. commercial buildings by percentage of total floor area.[3]

providing an ideal environment for molds and bacteria. Gypsum board should not be installed in duct chases or plenums, especially those using evaporative coolers.[2]

Contractors should carefully consider just-in-time delivery of at-risk materials to coincide with installation to reduce weather exposure during storage as well as unnecessary material handling, theft and damage.[9] The building enclosure, or portions of the enclosure, should be made weathertight before delivery or installation of moisture-sensitive materials. Materials should be inspected when delivered to the job site for evidence of moisture damage or mold growth. Shrink-wrapping should be removed and replaced with a ventilated cover to allow trapped moisture and condensation to dry to the open air. Materials should be raised at least 4 in. (100 mm) by placing spacers (e.g., dunnage) between the ground or concrete floor and moisture vulnerable materials. "First in, first out" inventory rotation should be implemented to ensure new shipments of materials are placed behind materials already in stock. Avoid using hydrocarbon fuels such as propane for heating in enclosed spaces. In addition to noxious fumes, hydrocarbons produce water vapor as part of the combustion reaction.[2]

In addition to keeping building materials dry during transport and on-site storage, moisture-vulnerable materials and materials in contact with them should be dried before being enclosed. Gypsum board, including moisture resistant (MR) board, should not be installed in duct chases, plenums, fire-rated walls or above suspended ceiling spaces (e.g., pre-rock) until the building or building zone is weatherproof. Throughout construction, third-party forensic inspections can be used to target areas of the building where moisture-related defects are most likely to occur. Commissioning specialists independent of the design professional and contractor can ensure proper operation of building systems in accordance with the contract documents during project closeout and handover. All jobsite tests and inspections should be documented in field logs with photographic entries where appropriate.[9]

Conclusions

Moisture-related construction defects are of greatest concern in educational, health-care and multifamily markets, where molds and other indoor air pathogens can cause serious secondary infections in the elderly, the young, and those with compromised immune systems.

In buildings, the only mold-causing condition that can be reliably controlled is moisture. Moisture control is a two-fold process of preventing liquid water intrusion and water vapor condensation in areas of a building that must remain dry and, managing water in areas of a building that are regularly wet because of their use. In hot, humid climates, air infiltration may be the dominant source of moisture in air-conditioned buildings. Failure to provide adequate dehumidification, exhaust ventilation, infiltration control, and thermal insulation will likely result in condensation within wall and ceiling cavities, on the surfaces of mechanical equipment, and on moisture-vulnerable interior finishes, causing damage and mold growth.

Acknowledgments

This research was made possible by grants provided by the Associated General Contractors of America (AGC), the U.S. Environmental Protection Agency (EPA), the Florida Roofing and Sheet Metal Association (FRSA), and the M.E. Rinker Sr. Foundation.

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