Water Infiltration, Mold Colonization, and Construction Defects

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Mold growth can occur over time in buildings when water infiltrates or condenses, and then remains in place on porous, cellulose building materials. These materials are part of normal building construction. This paper will present an overview of mold growth in buildings, and an awareness of some of the construction defects that are sources of the water infiltration and condensation.

Mold Growth In Buildings

Molds (along with mushrooms and yeasts) are types of fungi. Molds (also referred to as mildew) are found all year, indoors and outdoors, in the air and settled out on surfaces. Outdoors, molds are part of nature; they break down organic matter and live in the soil, on plants, and on dead or decaying matter. Mold spores become airborne when air moves across vegetative matter, or when plants, soil or other decaying matter is disturbed.

There are thousands of species (often quantified as between 50,000 and 250,000) of mold, with more than 1,000 different kinds of molds found indoors in homes in the United States. Molds spread and reproduce over time when favorable growth conditions are present. These include a food source and sufficient moisture for growth. Indoors, paper facings on wallboard, wallpaper, ceiling tiles, wood, dust, and dead mold spores are just some of the materials found to be food sources for mold colonization. Sufficient moisture requirements will vary from mold species to species, but, generally, sustained relative humidity of greater than 70 percent, or wetted food source materials that remain at those conditions more than typically 48 – 72 hours will experience mold colonization, first on a microscopic level, then visible to the un-aided eye. Mold growth can be any color, including black, white, green, purple or orange. Once mold growth begins, depending on the conditions, and mold type, even in the absence of “visible water”, the moisture in ambient relative humidity may be sufficient to sustain and maintain mold growth.

The presence of mold indoors, in the form of airborne molds typically found in those types and concentrations outdoors are generally not considered atypical or problematic. However, mold growth (colonization) within buildings or interstitial wall cavities is not considered normal, and the aerosolization of these colonizing molds may be problematic to the occupants (i.e. potential for health problems) and will degrade the integrity of the structure if the growth remains unchecked.

The moisture source for mold growth in buildings or building envelopes is likely to be one of four general categories:

- Moisture becoming enclosed within the building due to materials used, or installation methods used during construction
- Moisture infiltration caused by defective construction methods, materials, system design or material compatibility selection
- An “incident” that subjects the building or envelope to water (i.e. plumbing leaks, spills, fire suppression, or natural disasters that alter the integrity of the building)

- Occupant usage or misusage (i.e. use of exhaust fans in kitchens and baths, water spills, housekeeping, uncontrolled humidity)

The focus of this paper is on the first two categories, collectively referred to as construction defects.

Moisture Entrapment During Construction

Moisture entrapment problems arise in buildings under construction when materials get wet during storage (at manufacturer, distributor, or at job sites) or during transport. Mold growth susceptibility can be increased if materials are stored on the ground as mold spores can be transferred to the building product, and moisture transfer potential is increased. To avoid these problems, materials should be sufficiently dried during manufacture (including wood) and stored, covered, and off the ground at all times. If any vulnerable materials are found to have gotten wetted (such as gypsum wallboard, medium density fiberboard (MDF), or wood polymer composite boards (such as Masonite®, particle board or chip board)), the material should be verified to be free of mold growth, or, if that is not possible, the wetted section(s) should be discarded.

Moisture problems also occur when buildings under construction are not made weather-tight prior to installing weather-sensitive materials. For example, if gypsum wallboard is installed while rain (or uncontrolled, elevated relative humidity) can enter the building through openings, sufficient moisture may be present to enable mold growth. This is also the case if wood polymer composite boards are used for wall or roof sheathing and left uncovered when moisture can condense, precipitate, or is present at elevated levels in the air. Moisture conditions ripe for mold growth can also occur if trim or wood finish materials are left unprotected in the building during high moisture time periods such as when wallboard joist compound and/or surfacing materials are drying. The previous examples are only a few of the many ways that moisture sensitive materials may become wetted and mold colonization enabled; an all-encompassing list is not easily compiled, as the construction sequence disorders are unlimited.

Buildings and building materials may also be subject to water “incidents” where water or water based products are spilled or leaked, and then soaked into porous building materials. The 48 – 72 hour time window of wetted or excessive relative humidity is significant to enable mold growth.

Construction Defects Associated With Water Infiltration

Construction defects are generalized to include defective design, material selection, preparation or installation, or compatibility of construction materials or methods. This paper will address only those construction defects associated with water infiltration into the interstitial wall cavities and the interior of the building, and will present a brief overview of the potential areas of concern. The paper is not meant to be a comprehensive list; instead the paper is intended to describe some commonly identified construction defects. The types of construction defects addressed in this paper, and associated with water infiltration may be grouped into the following categories:

- Design aspects
- Structural/rough carpentry
- Roofing
- Exterior cladding
- Windows and doors

- Ventilation Systems
- Plumbing
- Interior finish surfaces

Design Aspects – These are related to the plan design (or plan selection), the building site, specifications for materials and material installation, and a system approach (or lack of) for coordination with mechanical, electrical, heating, etc. The design aspects may be part of a builder's purview (as may well be the case for non-custom residences), or may be designated by engineers and architects. Depending on the building process, subcontractors or site superintendents may also control certain aspects of design.

Plan design (and the associated construction "details") should take into consideration prevailing wind patterns, ambient weather conditions (including usual conditions such as temperature and relative humidity, and precipitation conditions; and infrequent weather conditions such as hurricanes, earthquakes, and 50 or 100 year floods). Stock plans that may be used for more than one building site need to be evaluated for suitability to the geographic and climatic conditions found at each construction location, and consider the direction the building will face, and surface and subsurface water patterns and conditions. For example, placement of the vapor diffusion retarder just under the exterior cladding may be suitable in Georgia, but a similar placement in Montana would be improper and lead to moisture condensing in the wall cavities. The west-facing walls of buildings on the west coast where morning fog is prevalent may need to be designed differently than those on the opposite face of the building. The location of the building should be done so that surface and ground water are drawn away from the building, not towards it. The same consideration needs to be given to each element of the house where precipitation, ground water or condensation could have an affect, based on geography, climate or site conditions.

The design of a building, including selection of the building materials needs to be done using a systems approach, and there should be coordination between architectural and engineering disciplines. For minimization of water condensation within walls, materials should be selected based on the total heat and moisture transfer. Software programs have been developed to assist the designer in these analyses, a few of which include:

- WUFI-ORNL/IBP (A joint development between the Oak Ridge National Laboratory (ORNL) and the Fraunhofer Institute in Building Physics (IBP)) is an advanced hygrothermal tool to assess drying time of masonry, danger of interstitial condensation, the influence of driving rain, etc
- Dew-Point (as detailed in ASHRAE) to assess the moisture balance
- Window 5 – to model windows, an interactive tool for solving moisture problems

Designers often do not place sufficient emphasis on moisture infiltration avoidance through the exterior building envelope. If stock plans are intended for use, the plan details should be custom analyzed relative to site conditions and locale specific climatic conditions. Design elements often become integrated with installation elements when contractors have latitude to select building component materials.

Structural/Rough Carpentry – Structural/rough carpentry includes the general framing of the building, application of exterior sheathing, and installation of insulation. The framing of the building should be adequately connected to the foundation, and, where surface or ground water is a concern, a waterproofing seal should be applied at the connection. The exterior building frame should also be adequately connected to the roofing system. The framing members should be installed straight and plumb, especially at penetrations such as doors and windows, and should be flush with the exterior sheathing. Wall framing (where either wood or gypsum wallboard will be present) should not have the potential to contact soil or surface or ground water.

The design, selection and installation of the building paper, insulation, sheathing and any other barrier type component (air or water vapor) should be done with consideration of the interactions between these elements, the climate, and exterior cladding. Each component may deter the transfer of airborne moisture within a building envelope system. An appropriate combination may facilitate moisture not being retained in wall cavities; an inappropriate combination may trap moisture in the wall cavity and facilitate mold growth.

A vapor diffusion retarder (referred to as a "vapor barrier" in the past) is a material which impedes the flow of airborne water vapor inside a wall cavity. In general, a vapor diffusion retarder is appropriate when installed on the side of the building envelope exposed to the highest vapor pressure. For hot, humid climates (cooling climates), the vapor diffusion retarder should generally be on the exterior side of the envelope, behind the exterior cladding. For cold climates (often categorized as above 4000 heating degree days), the vapor diffusion retarder should be on the occupied side of the envelope wall immediately behind the interior finish surface. For the Pacific Northwest, the climate is temperate and there is quite a variety of opinions for the appropriate use (if any) and general location of a vapor diffusion retarder in a building. If used, only <u>one</u> vapor diffusion retarder should be present in any exterior wall envelope. Oftentimes, more than one is installed. Materials which act as a vapor diffusion retarder include (but are not limited to) sheet plastic, kraft paper facing on insulation batts, closed-cell Styrofoam® sheathing, asphalt-impregnated building paper, and solid vinyl wall covering. Similar materials that are generally not considered vapor diffusion retarders include (but are not limited to) plywood sheathing, unfaced insulation batts, paper-type building paper, and Tyvek® housewrap (although it is considered an air impendence material which may affect the pressurization within the building, and impedes water droplets that may get behind the exterior cladding from being absorbed by other building envelope materials).

Moisture can also condense in wall cavities if the insulation or vapor diffusion retarder is incorrectly installed. The insulation should completely fill the voids in the wall cavity, including narrow voids and the space behind electrical boxes, and around pipes, ducts and vents. The vapor diffusion retarder should be contiguously installed, with joints properly seamed (according to the manufacturer's directions) and with no extra cuts or cut outs. Where there are window or door openings, the vapor diffusion retarder should be cut just to the extent necessary to expose the door or window opening. The material should be fastened to the building frame so that it is firmly fastened to the framing, and that the fasteners do not tear through the material, leaving holes where unanticipated water vapor may flow.

Cellulose (shredded) insulation is heralded as a green (environmentally-friendly) building material. However, if not installed according to manufacturer's recommendations, mold problems can ensue. For most installations, the dry cellulose insulation materials are combined with water (according to the Cellulose Insulation Manufacturer's Association (CIMA), typically 30%) as it is sprayed into wall and ceiling cavities. CIMA technical bulletins identify that vapor diffusion retarders are generally not used with cellulose insulation—or at least not until the insulation has had a chance to dry out, yet some buildings have been seen with newly installed cellulose insulation, newly installed vapor diffusion retarders or sheet rubber soundproofing, and elevated moisture levels (and mold growth) in the cellulose insulation due to the placement of vapor diffusion retarders or impermeable barriers, excessive water added during installation, or both.

Moisture infiltration is also a concern in wet areas of a building, such as where showers or tubs are located. The Ceramic Tile Council has expressed concerns about the use of "green" board (moisture resistant) gypsum wallboard as a tile substrate in wet areas. Instead, for installations intended to resist water infiltration, cementeous backer unit (also called backer board) should be utilized. Wonderboard® and Durock® are two brands of cementeous backer board.

Roof Systems – Roof systems consist of the underlayment, roofing finish surface, flashings, and treatment of roof penetrations. Problems can arise from water infiltration through roof systems, whether the roof is flat or sloped. In general, roofs are effective when they are installed watertight, and in such a manner that precipitation and water that may contact the roof cannot get into the building and have a means to get off the roof.

Insufficient flashing at roof penetrations (pipes, vents, etc) and at other changes in vertical planes is a primary source of roof leaks. Flashing often is not of a correct width or extended high enough on the penetration or vertical surface to keep water out of the roof and the building. Flashing may not have been properly installed, so that there are cuts or joints in areas where the flashing is the means of water diversion. Sometimes roofing mastic is utilized as the fastener for the flashing materials and it has been found that the mastic does not survive for long—certainly not for the life of the roof.

On sloped roofs, roof underlayment, often called roofing felt, is applied after the flashings are installed. If the felt is not installed with sufficient overlap between layers, weatherboard fashion, water can seep between the layers and enter the building. Water leakage may also occur where the felt is not extended enough over the base flashing. Tiles or shingles on roofs should be installed according to manufacturer's directions, with special attention to the spacing and location of mechanical fasteners.

Flat roofs present their own challenges, as the underlying surface (which may be a concrete slab) generally has cracks or other openings that water may use as a pathway into the building. Built-up roofs (layers of roofing felt and hot-mopped asphalt) may become blistered and crack, exposing a pathway from the outside to within the building. Membrane roofs may allow water to infiltrate the building if the joints are not properly sealed, if moisture had been present in whatever materials remained on the building during re-roofing (such as an old roof), or if the membrane is not sufficiently extended up any penetrations or vertical surfaces that intersect.

Exterior Cladding – This is the surface material on the exterior wall face. Building exteriors may be clad with wood or engineered wood siding, cementeous board, masonry, stucco, exterior insulation finishing system (EIFS), architectural glass panels, concrete panels, or stone panels. The intent of the exterior cladding is to provide primary protection from the elements and prevent water from entering the wall cavities. Most of these cladding systems also are intended to have a secondary system of water deflection where any water that enters the wall cavity through (or behind) the exterior cladding system can drain out of the cavity before wetting down porous building envelope materials. Problems arise when the secondary system is not installed correctly (such as weep holes being filled with mortar, weep screens being installed below the intended finish grade of the soil, or intended gaps behind cladding being filled with other materials such as closed-cell foam sheathing).

Improper materials or construction methods used in stucco cladding can be the source of defects. One type of stucco, often called traditional or conventional stucco, consists of metal lath, and three coats of a Portland cement plaster. Another variation is called one-coat stucco, which combines two of the coats of stucco of the traditional stucco method, and utilizes a slightly different plaster mixture. Both are called “hard-coat” stucco, and both may be sources of construction defects if the lath is incorrectly integrated into the window flashing, or if there are improperly flashed penetrations and intersecting building sections. Cracking of the stucco may also be a construction defect associated with water infiltration where the crack is structural; that is, typically larger than ¼” in width, and where the crack penetrates the full depth of the stucco, allowing moisture to enter. Moisture infiltration may also be prevalent when the weep screed (also called weep screen) may be improperly located, blocked by stucco, buried below slabs, or below finished grade. Moisture that condenses or infiltrates behind the stucco cladding may be retained behind the stucco if the joint between the stucco and the weep screed becomes blocked, or filled in (with a sealant).

Exterior Insulation Finishing System (EIFS), often called synthetic stucco, is exterior cladding consisting of expanded polystyrene foam insulation, glued or mechanically fastened to the exterior sheathing, and finished with two coats of polymer (non-cementitious) stucco material, with a fiber reinforcing mesh sandwiched in between. The thickness of base coat, mesh and finishing coat is approximately ⅛ to ¼ inches thick. It typically is intended to be moisture impenetrable, and historically installations did not incorporate a means for water to drain or ventilate moisture. A fair amount of litigation and media coverage addressed un-vented EIFS systems on buildings. Moisture issues can arise when moisture gets behind the EIFS system, and the cladding has an insufficient or blocked drainage system to not allow drainage of moisture behind the EIFS cladding to drain out.

Masonry (i.e. brick) veneer buildings can also have moisture retention problems. Masonry is a porous material and can absorb and retain large amounts of water. Problems arise when weep holes are blocked, or covered on the back with mortar. Problems also arise if the entire wall system has not been designed to address the water absorption and retention abilities of the masonry veneer.

Fiber-cement siding is a manufactured siding product composed of cement, sand, and cellulose (wood) fiber that has been autoclaved (cured with pressurized steam) to increase its strength and dimensional stability. Fiber-cement siding is installed over studs or exterior wall sheathing with an appropriate water-resistant barrier, using galvanized steel nails or screws that penetrate into wall studs. Defective construction, leading to water infiltration can be caused by improper installation methods, including not following manufacturer’s instructions, improper flashing around openings and when the vertical plane of the siding changes directions, and improper means of allowing moisture to drain, if it gets behind the siding. The new fiber-cement boards may be factory primed, or be on site in a raw state (un-primed); moisture may infiltrate the siding if it is not properly primed on all faces prior to installation. Moisture can also infiltrate through joints and edges, if these are not properly caulked or flashed. Testing performed for the US Department of Housing and Urban Development has shown that for buildings clad with fiber-cement siding, the most effective means to keep water from impacting the building framing is to construct the siding over a drainage plane (space between the building frame and back of the siding), with a weatherproof membrane installed over the building frame.

Wood or engineered wood siding is prone to the same problems with water infiltration to the building frame as the fiber-cement siding. Additionally, the material may warp or absorb water. One source of construction defects is when installation methods prescribed by the manufacturer are not followed. The failure of certain types of engineered wood sidings has gotten a fair amount of notoriety in the media. Solid wood siding, such as cedar, can also absorb moisture and warp if not properly installed, including priming on all sides. Often the failure of the siding is coupled with (or compounded by) problems with window and door installations, improper flashing, or incorrect abutment to trim or corner boards.

Window and Door Systems – Construction defects of window and door systems can involve the selection of the specific windows and doors, problems with handling and transport, and installation methods. Depending on the region where the building is located, the usage of the building (relative to moisture generation/retention), and the exterior cladding on the building; the selection of the brand and type of windows and doors may contribute to moisture infiltration and retention. Factors such as the type of cladding (i.e. wood, aluminum, vinyl, or composite material) on the window, the type of glass system (single or thermal pane), and the thermal bridging factor of the windows and doors are also elements in appropriate window and door systems, relative to moisture condensation. Certain window and door units have self-flashing attached, and often construction defects are identified where the window self-flashing is designed for a different exterior cladding system, cladding thickness, or installation method than that found employed on the building in question.

Even if the proper window and door system was selected, they will not function as intended (relative to moisture (and air) infiltration) if the window or door was racked or torqued during handling and transport so that it cannot be installed square or uniformly flush with the structure.

As far as installation construction defects, many installers do not understand how to install flashings around windows and doors so that when water runs downhill (as it surely will). The moisture should be guided down and out, instead of into the wall cavity. When installers install flashing by “reverse lapping” at the sill flashing paper (which is often done) water is drawn into the walls instead of out of walls. Installers also often rely on caulking to create a weather-resistant joint, instead of proper flashing. Caulking will deteriorate with age and weather, and is subject to proper installation to provide the water resistance; proper flashing can last considerably longer and is not subject to deterioration from most climatic stressors (wind and rain).

Installation construction defects also relate to the interconnection of windows and doors to the building structure relative to the vapor retention barrier and wall insulation. The vapor retention barrier is typically initially installed in continuous sheets, and then cut out for window and door openings. Construction defects occur when the “X” cut typically made at these openings extend beyond the opening size required for the windows and doors, thus creating locations where water will pass through the envelope, unimpeded; moisture will condense in this area. Moisture also infiltrates the wall cavity if insulation is not uniformly installed in all areas around windows and doors.

Ventilation Systems – Heating, ventilating and air conditioning (HVAC) systems and local ventilation exhaust systems (collectively referred to as ventilation systems) affect moisture infiltration, condensation and retention relative to the system design and installation. Construction defects occur when the installation is not done correctly or the system is not appropriately designed for geographic, climatic, or operational parameters.

Ventilation systems may be appropriately designed to pressurize buildings, depending on the geographic location of the building. However, defects occur when inappropriate pressurization occurs, or the pressurization design is inconsistent with the location and type of vapor diffusion retarder. Buildings in hot, humid climates should typically be pressurized net-positive. That is, the pressure in the building should be greater than that outdoors so that when doors are opened, air from inside the building will move outside the building to attempt to equalize the pressure. The intent is that when moisture will condense on the cool surface of the building from the hot/humid outdoor air, it condenses on the exterior of the vapor diffusion retarder (and not inside the wall cavity where wood, insulation, and porous gypsum wallboard are present). For cold climates, buildings should not be positive; that is, the pressurization may be neutral (pressure inside equivalent to that outside) or negative where, when doors are opened, air moves from outside to inside the building. When designed effectively in conjunction with the vapor diffusion retarder, moisture will not become entrapped in the wall cavity. Even with an appropriate initial design of the ventilation system and appropriate coordination with the placement of the vapor diffusion retarder, a number of installation problems can create defective pressurization. One example is over-sizing or under-sizing exhaust fan ducting. In addition, if the building has multiple floors or is exposed to strong winds, pressure may be uneven in the building to the extent that lower floors may be positively pressured while upper floors may be negatively pressured, or a building may be positively pressured on the side exposed to the wind while negatively pressured on the opposite side of the building. These conditions may enable moisture to enter and become entrapped in porous materials of walls and wall cavities.

In buildings where air conditioning will be installed, the design aspect is critical to the system's capability to maintain an optimal 20% - 60% relative humidity, relative to minimizing mold colonization. When the relative humidity is 70% or greater for in excess of 48 – 72 hours, mold may grow on susceptible materials, without other sources of moisture. For large buildings, the air conditioning capacity is typically designed by a mechanical engineer. For smaller buildings, the air conditioning may be sized by the mechanical contractor who will install the system. If the air conditioning system is under-sized, the units will run nearly continuously on very hot days and all areas of the building may not be sufficiently cooled (and dehumidified). If the air conditioning system is over-sized, then the units may short-circuit; that is, they may run only briefly to drive down the ambient indoor temperature; however the units may not run long enough to dehumidify the space. It is essential that the correct size of the unit be selected for proper dehumidification. In some geographic areas, the air conditioning controls based on temperature may need to be supplemented with others based on relative humidity.

The uniform distribution of heated air is also a concern for water vapor condensation on interior surfaces. If heated air is not uniformly distributed when the temperature is cold outdoors, water vapor can condense in cold air pockets. The cold air pockets may be in corners at the ceiling, behind furniture, or other "dead" air spaces. The cold air pockets can be minimized through appropriate placement of ductwork and outlet grills.

Adequately sized and exhausted local exhaust fans (and ductwork) in the kitchen and bathrooms are critical to adequately removing moisture produced by occupant activities. The same applies to clothes dryer exhausts. Construction defects occur when the ductwork is undersized, the exhaust piping kinked or otherwise distorted, or when additional elbows or turns are utilized during the installation. Defects associated with exhaust ductwork also occur when the location of the exhaust from the building is too close to fresh air vents or other building openings and the exhausted moisture-laden air is re-entrained back into the building.

Plumbing – Construction defects from plumbing are a source of water being introduced into a building where it can be absorbed by porous building materials. The defects may include leaks in pipes, nails or screws protruding into piping, or toilets not properly seated (not level). If plastic plumbing fittings are threaded onto metal pipes, the plastic piping can become over-stressed and fracture. Installation defects for plastic piping also include over-tightening the fittings (they are designed to be hand tightened only). Faucets and mixing valves can also be installed in a manner that they leak water into the wall cavity, or into finished cabinetry; this can occur if not anchored or installed properly.

Interior Finishes – Defects in interior finishes can contribute to moisture condensation or water retention. One example is vinyl wall covering. The wall covering acts as a vapor diffusion retarder and may retain moisture in wall cavities and the gypsum wallboard, elevating the relative humidity of the wall cavity.

Ceramic tile tub and shower enclosures are another source of water infiltration or retention. Grout between the individual tiles and between the tile and fixture (tub or shower pan) is often the source of a construction defect. The type and application of the grout and mortar (adhering the tile to the wall) must be consistent with the application methods for tile in wet areas, such as bathrooms. Installations are found defective when the tiles are installed with "thin-set" methods used only for dry applications such as wall wainscoting. The material installed behind ceramic tile in tub and shower areas is also a concern, as stated in the rough carpentry/structural section.

Summary – Construction defects can have many faces and can include design, material selection, transportation and installation issues. The defect may be relatively simplistic, involving only one material, or may involve complex compatibility problems between many systems or products. Potential defects may involve any combination or permutation of the list of possible defects included in this paper, and an array of others not mentioned. Defects in construction involving water and moisture can range from the framing to the exterior cladding to ventilation systems to plumbing and interior finishes. What can be stated is that often something goes wrong in construction of a building, and moisture infiltrates, condenses, or is retained in porous materials. Undetected and uncorrected, this moisture can facilitate mold growth, which compounds the other construction problems with the building, and complicates any needed repairs.

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