Case Studies of the Cause and Origin of Fungal Growth in Residential and Commercial Structures

Stewart M. Verhulst, M.S., P.E.[1]
Erik L. Nelson, Ph.D., P.E., M.ASCE[2]
Deepak Ahuja, M.S., P.E.,M.ASCE[3]
Halet G. Poovey, Sc.D., C.I.H.[4]

Abstract

Fungal infestation of buildings has become a significant factor in how the integrity of structures is assessed. Fungal growth as a result of building envelope failures in structures is examined in four case studies. Two of the studies are in commercial buildings and two involve residential buildings. Illustrated are the effects of applying EIFS over a failed stucco finish, the lack of weep holes in a veneer cavity wall, lack of roof flashing, plumbing leaks, high maintenance details, lack of proper maintenance and poor scheduling during construction. Current industry standards were used in the determination of extent of fungal growth at the sites. Types of samples collected included surface, dust and air.

Background

Large water intrusions of the building envelope, such as roof leaks and pipe ruptures have traditionally been handled by drying out and removing significantly water damaged material in the affected areas, however, little attention has been given to the effects of fungal growth. Additionally, in the past, small leaks that led to localized fungal growth were not considered significant problems. While the actual health effects are still being debated, exposure to fungal spores and mycotoxins has become a significant issue in indoor air quality. As a result, the assessment of the amount and spread of fungal growth in buildings has become a significant factor in determining the overall condition of a building.

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[1] Project Director, Nelson Architectural Engineers, Inc., 3303 Lee Parkway, Dallas, TX 75219; phone 214-528-8765; sverhulst@architecturalengineers.com
[2] President, Nelson Architectural Engineers, Inc., 3303 Lee Parkway, Dallas, TX 75219; phone 214-528-8765; enelson@architecturalengineers.com
[3] Vice President, Nelson Architectural Engineers, Inc., 3303 Lee Parkway, Dallas, TX 75219; phone 214-528-8765; dahuja@architecturalengineers.com
[4] Director of Industrial Hygiene, Nelson Architectural Engineers,Inc., 3303 Lee Parkway, Dallas, TX 75219; phone 214-528-8765; hpoovey@architecturalengineers.com

Construction materials are not manufactured in sterile environments nor is the air brought into buildings sterile, thus fungal spores are readily available in most indoor environments. While fungal spores are ubiquitous, active fungal growth will not occur until moisture and a suitable source of nutrients are available. Nutrients are provided by the organic matter (i.e., gypsum board paper, ceiling tiles and wood framing) present in the building. Thus the only factor limiting fungal growth is moisture. Fungi can grow in the presence of high humidity (>70% relative) alone, but most fungal infestations can be related to water leaks or intrusions. Fungal growth starts about 24 to 48 hours after a water event. Once started, fungal growth in a building will progress as long as there is a source of moisture present.

Standard practice for determining indoor fungal contamination in air has been to compare outdoor and indoor samples. This determination is based on whether the mix of indoor fungi is typical or atypical of the outdoor fungal ecology and the relative levels inside are compared to the outside. The type and level of species and the presence of mycelial fragments are used as indicators of moisture damage and fungal growth in surface and dust samples. Species commonly associated with water damaged construction materials include *Aspergillus*, *Chaetomium, Penicillium* and *Stachybotrys*. Mycelial fragments in samples are used as an indication of active growth.

The following case studies illustrate the effects of various types of water intrusion and moisture problems in structures.

Case Studies

Case Study #1: Residential Structure

Foundation:	Conventionally reinforced concrete slab-on-grade
Framing:	Two-story steel framing with wood infill
Interior:	Gypsum board
Veneer:	EIFS over original stucco
Roof:	Composition shingles and built-up roofing (wood framing at roof)
Age:	Constructed in 1983
Location:	East Texas

Figure 1. View of Residence.

Case Study Background: The original complaint, filed in 2001, of water damage and fungal growth at this residence was related to the homeowners suspecting leakage at the balcony overlooking the pool deck at the back yard. Figure 1 is a view at the back yard and the balcony is visible. The homeowners reported that the water was entering the exterior wall below the balcony (1st floor wall) due to leakage at the wall-to-balcony interface.

The homeowners reported that the residence was built in 1983, and that the balcony was originally a wood balcony. The original construction included a stucco finish at the exterior. In 1997, the exterior was re-finished with an Exterior Insulation and Finish System (EIFS) over the original stucco, and the balcony was also finished with EIFS. In 2000, the balcony needed to be re-finished due to an extensive leak at the balcony drain, which the homeowners suspected as contributing to the fungal growth.

Evaluation and Testing: Readings with a moisture meter indicated relatively high moisture contents (up to 100% relative) in the interior gypsum board finish at the 1st floor wall below the balcony intersection and in the wood flooring near this wall. However, some relatively high readings were also noted at other areas, especially below windows. Air samples had been conducted (by a third party) prior to the structure evaluation (results not available). A limited number of air samples collected during the investigation indicated elevated levels of *Aspergillus/Penicillium* spores.

Since fungal growth was detected in the wall below the balcony, the homeowners decided to begin the mold remediation process and to examine the structure for damage. The interior gypsum board was removed from the 1st and 2nd floor walls adjacent to the balcony. Staining was evident throughout the wall system. At the 2nd floor, staining was noted at the exterior gypsum sheathing at various areas, including at the staple penetrations for the metal lath (for the original stucco finish) and especially below the windows. It was clear that the water intrusion was not limited to the balcony and that the primary cause of water intrusion was related to the exterior wall system.

During the removal of the 1st floor wall interior, further staining and fungal growth were observed. Also, limited evidence of termites was observed at the wall. However, when the wood flooring adjacent to the 1st floor wall was removed, severe termite damage (and some live termites) was observed at the wood sub floor.

At this point, since the damage was obviously not limited to the balcony area, interior finish removal was continued at a 1st floor wall on the front side of the residence (opposite from the balcony) to help determine the extent of damages. At this wall, staining was observed throughout, especially below windows, and severe termite damage was evident. In fact, termites had completely destroyed several wood infill studs below and adjacent to the high windows. A view of the wall from the interior, with the missing infill studs, is presented in Figure 2. Note the steel framing around the wood infill.

Figure 2. Water and termite damage at interior wall.

Further investigation of various walls at the 1st story and 2nd story throughout the residence indicated widespread moisture intrusion, especially at wall discontinuities (such as windows) and at intersections of roof areas with the exterior walls. Termite damage and live termites were noted at several areas throughout the structure.

In general, termite damage to the wood infill was widespread, affecting the structural integrity of this framing. The steel framing was slightly corroded due to the moisture intrusion, however, the steel framing appeared adequate to carry the load..

Conclusions: The water intrusion at the structure was primarily caused by the exterior veneer systems, stucco originally and then EIFS on the original stucco. The original stucco system allowed water intrusion, but did not allow the water to properly escape. When the EIFS was installed on top the existing stucco, less water intrusion occurred through the wall system itself, however, water intrusion continued at windows and other discontinuities and less water was allowed to escape the wall system. The decision to apply EIFS over an exterior system which had previously allowed water penetration was improper, effectively sealing the already wet exterior walls.

The combination of a lack of proper waterproofing with the lack of weep drainage for the EIFS caused further water intrusion. In the relatively warm and humid climate of east Texas, the trapped water found conditions conducive to fungal growth.

Remediation required removal and replacement of the exterior walls (with the exception of the steel framing) and some interior walls, in addition to cleaning of localized interior areas and of the contents of the home. Due to termite damage, the wood flooring was not salvageable and required replacement. Structurally, shoring would be required for the areas where the 2nd floor and the roof relied on wood framing for support (wood framing was used to transfer the load from the roof and 2nd floor to the steel framing).

Case Study #2: Commercial Structure

Foundation:	Hybrid reinforced concrete slab-on-grade with grade beams on piers
Framing:	One-story steel framing with metal stud walls
Interior:	Gypsum board
Veneer:	CMU with cast stone coping
Roof:	Single-ply adhered EPDM and berridge curved tee-panel standing seam metal roof systems
Age:	Constructed in 1999
Location:	Central Texas

Case Study Background: This structure was constructed in 1999. In August 2001, evaluation of the structure regarding the reported water intrusion began. The building owner reported that water was coming into the structure at some window locations and also that the carpet in at least one location was consistently wet after rainfall.

Weep holes: In the specifications, weep holes were specified to be spaced at 24" on-center. This differed with the Architectural Plans, which specified weep holes at 48" on-center. The actual number of weep holes at the structure perimeter was less than either of these requirements and was in fact only 29% of the weep holes required in the specifications. Also, of the weep holes that were present, approximately 63% were blocked with mortar from the wall cavity. Therefore, considering the unblocked weep holes only, the weep capacity of the wall system was about 11% of the amount specified.

Masonry veneers, such as the veneer in this case study, are not intended to be waterproof and require cavity drainage for moisture which penetrates to the back side of the veneer. Weep holes are therefore necessary in cavity wall construction to allow water to escape the cavity.

Figure 3. Front elevation of structure.

Mortar Blockage: The observation of blocked weep holes indicate a likelihood of mortar droppings in the wall cavity. The presence of mortar droppings and blockage of weep holes create a condition whereby the wall cavity cannot drain or ventilate properly. This condition is conducive to water damage at the interior building materials (Beall, 1993). For susceptible building materials, this condition is therefore conducive to fungal growth at the interior.

Test Blocks: A total of 4 Concrete Masonry Unit (CMU) veneer blocks were removed from the exterior veneer for observation of the conditions at the wall cavity. These are numbered B1 – B4. At location B1, when the block was removed, mortar was observed to be filling the cavity and was adhered to the back of the block. Mortar 7.6 cm to 10.2 cm (3" to 4") high in the cavity was visible at the adjacent blocks. Also, mortar protrusion and mortar bridging the wall tie anchors were observed in the upper areas of the cavity. The exterior gypsum board sheathing (which is at the inside face of the wall cavity) was moist and friable at the open area.

Block B2 was removed from another part of the structure perimeter. The wall cavity was blocked with mortar droppings and the gypsum board sheathing was stained. The stain locations on the sheathing were consistent with the mortar blockage. Figure 4 is a representative view of mortar droppings at the wall cavity.

The areas at removed blocks B3 and B4 also exhibited mortar blockage, mortar protrusions and corroded wall ties. Samples of the sheathing from test areas B1 - B4 were collected for testing.

During rainfall, the cavity at removed block B1 was observed for water penetration. Water entering though the opening seeped into the building interior in lieu of exiting the cavity through the weep holes. The result of this was a wet carpet in the corner (where the block was removed), which the building owner noted as a common occurrence during rain.

Figure 4. Typical mortar droppings at removed block B2.

A simple field water test was conducted at the area around test block B2. With the block in place, water was sprayed at the roof and allowed to shed down the exterior veneer. After 5 minutes of testing, the test block was removed and water staining was observed around the test block. Water drops were forming on a visible wall tie.

Coping: At the upper exterior coping (at the roof level), it was noted that there was sealant missing from some areas, allowing water intrusion into the wall cavity. There were also material failures and delamination at the coping, further allowing water penetration. It was also noted that the detail drawings for the project indicated that the flashing was discontinuous and therefore the coping alone separated the wall cavity from the elements.

Air Quality Testing: Five types of samples – air, swab, bulk, WallChek™, and CarpetChek™ were taken in the structure. The air samples were taken indoors and outdoors for comparison.

The swab and bulk samples were collected from the gypsum board sheathing at areas B1, B2, B3 and B4 and yielded high levels of *Stachybotrys* spores and varying levels of mycelial fragments, indicating active fungal growth. A bulk sample of insulation from area B1 also yielded high levels of *Stachybotrys* spores.

WallChek™ samples from the stud cavity of the walls contained Amerospores and *Stachybotrys* spores, indicating the spread of contamination from the exterior sheathing to the insulation and metal stud wall.

The air sampling indicated a change in the fungal ecology profile at the interior with respect to the exterior. However, no airborne *Stachybotrys* spores were detected and the change in the ecology profile was related to contamination of the HVAC system and was unrelated to the contamination at the wall cavity.

Conclusions: Water intrusion was reported by the building owner about 2 years after the structure was constructed. Water intrusion to the exterior sheathing was observed at removed CMU veneer blocks at the base of the exterior wall. Mortar droppings and blocked weep holes were observed along the bottom of the cavity wall and mortar bridging wall ties was also observed at the wall. A lack of flashing and improper detailing at the exterior coping allowed water intrusion into the cavity. However, the primary areas of water intrusion to the interior of the building occurred where the drainage system was rendered ineffective by mortar blocking the weep holes and bridging the cavity.

Therefore, the combination of design and construction defects at the perimeter cavity wall has caused widespread moisture intrusion and the formation and spread of *Stachybotrys sp.* at the interior of the structure.

Case Study #3: Residential Structure

Foundation:	True pier and beam system with auger-excavated piers
Framing:	Two-story conventional wood framing
Interior:	Gypsum board and wood paneling
Veneer:	Brick and limestone
Roof:	Slate shakes with copper flashing
Age:	Constructed in 1987
Location:	North Texas

Figure 5. Front view of residence.

Case Study Background: The homeowners reported visible mold at various locations throughout the residence. During a visual assessment, possible fungal growth was observed in the wine cellar, at the kitchen ceiling, in a bedroom, the game room, the family room, the garage, at several supply air vents and at the crawl space. No direct crawl space ventilation was provided for this structure.

Water Intrusion: Several areas of water intrusion into the structure were identified. Additionally, the exterior brick veneer had no visible weep hole locations. As noted in the previous case study, a lack of weep holes does not allow for adequate drainage of the wall cavity, causing water to be trapped in the cavity and to possibly penetrate the building materials at the inside cavity surface. In general, it is recommended that weep holes be spaced at 24" on-center (Beall, 1993).

Many of the doors and windows show evidence of water penetration and damage. The flashing and sealing at doors and windows was generally poor. Several roof leaks were also apparent. Leaks at the roof were caused by missing and displaced slate tile (roof tile) and high-maintenance details at the roof, causing trapped water and flashing joint separations. Leakage through the roof eave vents was also evident.

Plumbing Leaks: Testing on the domestic (pressure) plumbing system indicated two pressure leaks in the crawl space. Testing of the wastewater plumbing system indicated a minor leak at the master bathroom shower pan that only occurred under conditions of standing water. Although less common, pressure leaks are typically more severe than wastewater leaks, considering fungal growth. Pressure leaks can yield a large volume of water over a short period of time, creating situations where drying building materials is difficult and water damage is widespread. In this case study, the pressure leaks caused limited damage to the crawl space framing, however, these leaks did significantly contribute to the overall moisture in the crawl space.

In addition to the pressure leaks and the wastewater leak noted above, the homeowner reported leakage at the Heating Ventilation and Air Conditioning (HVAC) water pipe system. Several areas of condensation, saturation and dripping were visible at the HVAC cold water lines and fungal growth was evident at the insulation surrounding these lines. Additionally, 5 leaks at the HVAC drip pans had been recently repaired.

Crawl Space and Wine Cellar: In general, the damp and/or water damaged areas at the crawl space were located either near the perimeter of the structure or near water sources.

The perimeter soils in the crawlspace were generally more damp than the soils near the center of the structure, with the exception of the areas around the two pressure line plumbing leaks. This indicates that the crawl space was effectively acting as a sump, attracting moisture from the soils near the foundation perimeter. Also, the excessive water penetration at the perimeter walls caused leakage into the crawl space area, contributing to the moisture at the crawl space perimeter.

The moisture contribution of the two pressure leaks was significant. Based on the general dispersion of soil moisture in the crawlspace, it was estimated that the two pressure leaks contributed 10% to 20% of the total volume of moisture present. The wastewater leak had a negligible effect on crawlspace moisture on an overall basis.

It should be noted that the lack of ventilation in the crawlspace allowed the moisture levels to remain high. The levels of fungal contamination in the crawlspace would likely be significantly lower if adequate crawl space ventilation was provided.

Water staining was observed at the wine cellar and the sump pump in the utility space in the corner of the wine cellar showed evidence of rusting at the base, indicating the presence of intermittent water in this location.

Air Quality Testing: Four types of samples – air, swab, bulk and tape, were taken in the structure. The air samples were taken indoors and outdoors for comparison.

Air samples at the interior contained elevated levels of *Aspergillus/Penicillium* spores, Amerospores and Basidiospores. A low level of *Stachybotrys* spores was detected in one sample.

Swab samples taken in the crawl space area contained *Aspergillus/Penicillium* and *Cladosporium* spores, among others. High levels of *Stachybotrys* spores were measured near the crawl space entry.

Tape samples at the supply air vents primarily contained *Aspergillus/Penicillium* spores and *Cladosporium* spores.

Conclusions: The individual causes of water intrusion at the superstructure were numerous and were primarily related to the architectural details at the roof, improper construction and a lack of proper maintenance. Based on observations and testing, the cause of moisture, water damage and fungal growth at the exterior walls was related to the numerous individual water intrusion points at the superstructure. The lack of weep hole drainage of the cavity exacerbated the damage at the perimeter walls.

The primary water sources to the crawl space were surface water from the structure perimeter and water leaking from the perimeter walls above. The pressure line plumbing leaks were a secondary moisture source at the crawl space. This excessive moisture, along with a lack of crawl space ventilation created conditions favorable to fungal growth in the crawl space. It should be noted that, due to the lack of crawl space ventilation, the wine cellar effectively acted as a ventilation point for the crawl space and the fungal growth at the wine cellar was determined to have originated in the crawl space.

Case Study #4: Commercial Structure (School)

Foundation:	Conventionally reinforced concrete slabs-on-grade with piers
Framing:	One-story steel framing with metal stud partition walls
Interior:	Gypsum board
Veneer:	Brick
Roof:	Metal roof and built-up-roof
Age:	Constructed in 2001
Location:	North Texas

Figure 6. School structure. Note metal roofing.

Case Study Background: The structures (the school actually comprised three connected structures) discussed in this case study were an elementary school, and was still under construction when observations were made. There had been several delays in the construction, especially with regards to the roofing. The roofs for the school were a combination of built-up roofing and standing seam metal roofing. A representation of the standing seam metal roof is included in Figure 6.

It was reported that, during the course of construction, several roofing contractors had performed work but had left the project before finishing. This caused significant delays in the roof installation (more than 6 months delay). Meanwhile, no similar delays were experienced by contractors working on the interior of the building. Consequently, much of the interior drywall and many of the ceiling tiles were installed before the structure was "dried-in", i.e. before the roofing was completed and the interior was protected from the elements. After several rains, significant water damage was done to the interior finishes and there was widespread fungal growth on gypsum board and ceiling tiles.

The gypsum board sheathing at the interior face of the brick veneer wall cavity was also installed before dry-in was complete. Due to the incomplete roofing, excessive amounts of water entered the perimeter wall cavity, causing damage to the sheathing and efflorescence staining at the brick veneer. Efflorescence is a white crystalline deposit that forms at the surface of the brick due to the evaporation of water containing dissolved salts (Day, 1999).

Interior: At the interior, there were several indications of previous water intrusion. Streaking stains were observed on the sheathing and on the metal studs at the perimeter walls. As indicated in Figure 7, fungal growth was observed at the sheathing. The specifications for the project indicated that the gypsum board sheathing was to be protected from the environment.

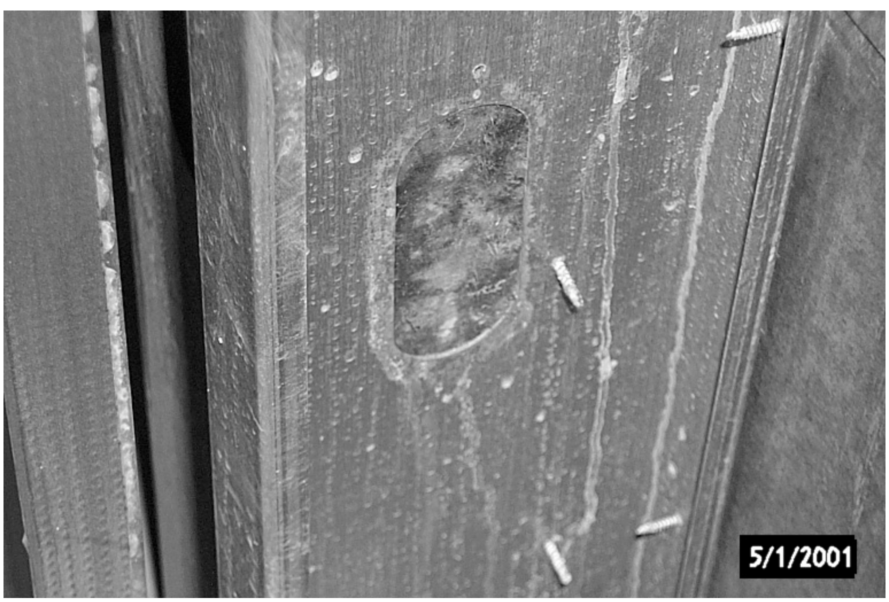

Figure 7. Streaking at metal studs and fungal growth at sheathing.

There were several water damaged ceiling tiles throughout the interior, indicating roof leakage. Water damage was especially significant below roof valleys. Also, there were several portions of the roof where daylight was visible. The roofing was still incomplete when these observations were made.

At some locations, portions of the sheathing had been removed, making the wall cavity visible. Mortar droppings were present at the cavity, creating bridges from the backside of the veneer to the sheathing. These bridges allow moisture to flow from the veneer to the wall sheathing. The bridges can trap or pool moisture against the sheathing that would normally run down the wall and out of the cavity through the weep holes.

Roof: The water leakage was primarily evident at areas roofed with standing seam metal roofing. Some unfinished areas were observed at the perimeter of the flat roofs, however, a majority of the unfinished areas and installation defects were at the metal roof areas. Incomplete items and defects at the metal roofing included a missing ridge cap, incomplete dormers, flashing missing at dormers, flashing missing at metal roof/flat roof intersections, gaps at installed flashing, a gap and exposed insulation at the exterior wall, missing sealant and separations at lap joints. In summary, there were several installation defects and incomplete items at the metal roofing; and the roof was not sufficient to consider the school as "dried-in".

A tape sample was taken from the gypsum board sheathing. Analysis of the sample indicated that *Cladosporium* and *Alternaria* spores were present.

Conclusion: The scheduling for the roof installation on the project was substantially delayed. However, the installation of gypsum board sheathing at the exterior walls and at the plenum area was not delayed sufficiently for the conditions at the roof. Consequently, the unfinished roof leaked rain water into the building, causing water to intrude into the wall cavities and onto the plenum gypsum board (in addition to other building materials).

The roof leaks were primarily the result of incomplete installation, with a secondary cause being incorrect installation of some roof elements. This shows how a lack of proper project management and scheduling can lead to extensive repairs and remediation due to water damage and fungal growth. This case study also highlights the importance of ensuring that the roof is 100% dried-in before the installation of finishes susceptible to water damage.

Summary

Each of these case studies illustrates the need to be aware of potential sources of water intrusion into structures from design, through construction and during the on-going maintenance of the structure. The architect must ensure that the design directs water away from the interior of the building and has provided adequate means of egress for the moisture that penetrates the building envelope. The architect should also avoid high maintenance details and any “water tight” envelope designs. The builder (or contractor(s), such as in commercial construction) needs to be aware of how the building envelope is designed to both prevent excessive water penetration and to eliminate water which does penetrate the building envelope. The builder/contractor should ensure that all the features are properly installed. Finally, the owner/occupant of the structure needs to be aware of how the building is designed to handle the moisture load and should ensure proper maintenance of the critical aspects (such as weep holes and roof gutter systems) of the building envelope.

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