

Two Studies of Mold and Mildew in Florida Buildings

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ABSTRACT

All across North America, the hotel industry has been plagued by moisture problems leading to odor, staining, and structural degradation. According to a 1990 survey by the Association of Hotels and Motels (AHM), mold and mildew cost the industry about 68 million dollars per year in lost revenues and repairs. The association suspects that these problems stem from faulty design of building envelope and HVAC systems. Indeed, this case study of two buildings supports AHM assumptions and illustrates how design faults may lead to excessive wetness and mold growth in hotels and motels in Florida.

The first case study, in Tampa, Florida, examines a hotel experiencing the infiltration of hot, humid air as a result of depressurization.

The second case study, in Lakeland, Florida, examines a nursing home experiencing rain wetting, infiltration of hot, humid air as a result of depressurization, vapor diffusion, and packaged terminal heat pump (PTHP) installation and operational problems.

INTRODUCTION

An investigative protocol was developed and included the following test procedures:

1. pressure field mapping,
2. fan/pressurization to determine airflow requirements to correct pressure imbalances,
3. spray rack testing to determine rain wetting,
4. field determination of wall assembly leakage characteristics,
5. tracer gas testing to establish communication pathways,
6. flow hood measurements to determine HVAC flow rates,
7. intrusive disassembly, and
8. infrared scans to quantify capillary effects and air leakage pathways.

A broad spectrum of measuring techniques was necessary to examine differences in air pressures as well as airflow paths. The search for the causes of the problem (i.e., identification of moisture sources and mechanisms of moisture transport) as presented in this paper may differ from a prevailing approach to remedy moisture damage by eliminating impermeable wall coverings and limiting the cooling effects coupled with application of anti-fungal agents.

CASE STUDY ONE

An investigation was conducted to determine the causes for the excessive moisture and mold growth on the interior surfaces of walls of a hotel in Tampa, Florida. The building was a six-story, rectangular structure containing about 25,000 square feet per floor. The building construction consisted of a concrete frame, floors of cast concrete, and internal walls of either masonry block or metal stud construction covered with gypsum board. All interior gypsum board surfaces were covered with impermeable vinyl wall coverings.

Roof construction consisted of a continuously adhered single-ply roof membrane over mechanically fastened rigid insulation.

The exterior walls were constructed of painted decorative masonry blocks with a metal stud backup filled with rigid foam insulation, gypsum board, and vinyl wall covering.

Space conditioning was facilitated by individual room HVAC units. Air was continuously exhausted from the bathrooms through stack ventilators. Make-up air was designed to be supplied through the corridors.

Construction of the hotel was completed in February 1989. The moisture problems appeared in the first summer. The symptoms were peeling interior vinyl wall coverings, wet interior gypsum wallboard, complaints of "musty" odors, and rampant mold and mildew growth at the vinyl/gypsum board interface of the interior and exterior walls. Damage at interior party walls occurred with both the masonry block and steel stud walls. Damage at the interior party walls was not localized at the point of intersection with exterior walls but appeared in various degrees of severity over the entire surface.

Repair done after the first summer included caulking at joints in the exterior masonry walls and replacing about 20% of the gypsum boards and wall coverings; however, the problems reappeared in the second summer season. New repairs, after the next summer, included a hydro-phobic coating over the exterior masonry and further replacement of damaged gypsum board.

Survey and Field Measurements

Excessive mold and mildew growth was observed on interior surfaces of both exterior and interior partition walls, particularly concentrated at the corners between interior and exterior walls, as well as between vinyl

covering and the surface of the gypsum board. Mold was also found at the back surfaces of the gypsum board.

The exterior masonry walls showed no indication of rain entry or water stains. Neither could we observe any deficiency of the roof, making assumptions of rain leakage improbable. We had to search for other reasons for the excessive wetness in the rooms.

Measurements of air pressure difference across windows of numerous rooms were taken during both calm and windy conditions. The differences in air pressure across the windows fluctuated between 2 and 3 pascals. Air pressure in the corridors was even lower, on average, about 3 pascals lower than the rooms. Covering the bathroom exhaust grilles in most rooms had no impact on the pressure reading.

In the next stage of the examination, holes were drilled through the gypsum boards to measure pressure in wall cavities. When the air-handling unit (AHU) was operating, pressure in the cavity could be as much as 10 to 15 pascals lower than the external air pressure. With the AHU shut down in the individual room, these pressure differences were reduced to 3 to 4 pascals, i.e., the same difference as measured between rooms and the corridor. Even these pressure differences (between corridor and rooms) became negligible when the corridor's air-handling system was cycled.

Discussion and Conclusions

We may assume that wall moisture problems are caused by the infiltration of hot, humid air as a result of air pressure differences induced by the individual HVAC units and the corridor's air-handling system. When this hot and humid air comes in contact with much cooler (cooled by room air conditioning) gypsum board surfaces, condensation takes place. Gypsum, being strongly hygroscopic, absorbs all the condensed moisture. Then, the thermal gradient pushes all condensed moisture toward the cold side of the gypsum board. Drying toward the interior is prevented by the interior wall coverings, and moisture accumulates at the vinyl covering and gypsum interface. This is the location where mold and mildew are likely to occur.

For hot and humid external air to infiltrate the building envelope and cause mold and mildew damage on internal surfaces, there must be a sufficient amount of moisture in the exterior air and sufficient air leakage through the wall. In turn, the air leakage is governed by the area of openings (holes) in the wall and the pressure difference between the outdoor and indoor air, the latter driving the external air inward.

All these conditions are believed to exist. Local climatic conditions provide for significant quantities of moisture in the exterior air during the summer season. Holes in the exterior wall system were present as a result of a visible examination of the building envelope. (No detailing for air retarder continuity was provided in the construction drawings.)

HVAC unit housings and duct connections were not tight, leaking air inward. As a result of this leakage, the gypsum board enclosures surrounding these units were significantly depressurized. These gypsum board HVAC enclosures (built into the exterior corners of each room) were connected to both the interior and exterior wall interstitial spaces. These walls were built with perforated studs and therefore facilitated air pressure equalization. Even when masonry blocks were used, the gypsum board was installed over treated wood furring strips, creating a cavity between the gypsum board and the masonry. These cavities were also interconnected, since the furring strips did not extend continuously from floor to ceiling. In effect, the zones of negative pressure, although created locally, were extended laterally and down the masonry interior partition walls in a manner similar to that occurring at metal stud walls.

Thus, we may conclude that the air leakage pathways allow the migration of humidified air from the exterior through the exterior masonry walls into the interstitial spaces of both the interior and exterior walls. Our hypothesis is also supported by the fact that the moisture problems at the hotel appeared only during the summer cooling periods. Lack of cooling during the winter months in Florida eliminated thermal drive of moisture through the gypsum board, and the differences in temperature and vapor pressure act mainly in the opposite direction.

CASE STUDY TWO

Introduction

The building under investigation was a two-story nursing home, consisting of two wings intersecting in a common area, which was constructed in 1990-1991 in Lakeland, Florida. The building construction consists of a post-tensioned concrete floor slab supported by concrete grade beams and piles at grade and precast concrete slabs at the second floor (and at some roof locations) supported by interior and exterior load-bearing masonry block walls.

Roof construction consists of pitched, vented wood trusses covered with wood sheathing and fiberglass shingles and sloped and horizontal precast concrete roof slabs covered with rigid insulation, plywood sheathing, and fiberglass shingles.

The exterior walls are of two construction types. In both cases, however, gypsum board is placed on 7/8-inch metal furring strips.

Space conditioning in the majority of the facility is facilitated by individual room through-wall electric packaged terminal heat pump (PTHP) units. Air is designed to be continuously exhausted from the bathrooms through six central exhaust systems. Make-up air is designed to be supplied through the PTHP units. Separate air-handling and space-conditioning systems are provided for the corridors. Communication between the corridors and the individual rooms and apartment units, according to the mechanical system design, should not occur.

Space conditioning in the Alzheimer's wing of the facility is facilitated by a central system. As in the rest of the facility, air is designed to be continuously exhausted from the bathrooms through a central exhaust system. Make-up air to each room is designed to be continuously supplied through the space-conditioning central system that services the rooms.

Construction of the nursing home was substantially complete when the moisture problems first became noticeable (August 1991). The initial symptoms were wood base moldings separating from exterior walls and condensation at the bottom surfaces of wood window sills. Subsequently, mold was observed to be growing through interior vinyl wall coverings, followed by the appearance of wet interior gypsum wallboard and complaints of "musty" odors within the conditioned spaces. Surface mold also soon became evident on the exterior surfaces of painted gypsum board and within cabinets.

During September 1991, some interior vinyl wall covering and gypsum board were removed, indicating rampant mold growth between the vinyl wall covering and the gypsum board and at numerous locations in the interstitial spaces.

Survey and Field Measurements

Exterior Wall Type A In several rooms, baseboard trim and gypsum board were removed from the exterior wall. In addition, the PTHP units and their sleeves were removed in several rooms to facilitate the visual observation of the brick veneer cavity (airspace). A hole was knocked through the concrete block from the interior in one of the rooms for the same reason. The window sills in several rooms were also removed to allow visual observation of the concrete block construction. A substantial portion of the brick veneer was also removed. Wall coverings at several locations were peeled back to allow observation of the rear surface of the wall covering and the interior face of the gypsum board.

The back side of the removed trim was visibly water stained and wet. Water droplets were present on the underside of the removed window sills. The removed gypsum board from the exterior wall was soft and water-logged at the bottom edges. The exposed metal furring installed on the interior of the concrete block wall showed evidence of corrosion. Water was observed at the bottom of the interior of the concrete block wall. A damp, musty odor was noticeable throughout the facility. The concrete block wall was visibly damp in several locations.

Where visual observations were possible, specifically at the PTHP openings and the opening in the concrete block wall where the brick veneer was removed, the brick veneer cavity (airspace) was substantially filled with mortar droppings. The rigid foam insulation visible in the PTHP openings appeared separated from the front face of the concrete block wall or loose in the cavity. Closer inspection

revealed mortar droppings between the rigid foam and the concrete block wall.

Review of the drawings indicated that weep holes were to be installed at grade at 24-inch o/c. Inspection of the exterior face of the brick veneer walls revealed that many of the weepholes were covered by planting and backfill material. Approximately 50% of the weep openings on the south exposure of the building were completely covered. Of the remaining ones, many were partially covered. Approximately 25% of the weep openings on the north exposure of the building were covered. The grade appeared higher than in the drawings, and site drainage appeared to be poor. Observations indicated that irrigation water tended to collect in pools of water adjacent to the building on the south exposure.

In many rooms, the vinyl wall covering was peeling and pink blotches were showing through it in many locations. Where the wall covering was pulled back, mold growth was evident on the back of the wall covering and on the interior surface of the gypsum board. In many locations, the gypsum board was saturated with water and soft to the touch. The gypsum board was deformed easily when pushed by the hand. Many rooms had of a foul odor.

Exterior Wall Type B It happened to rain for approximately one hour during the investigation. Within one hour, water spots appeared at the ceilings of several rooms where the ceiling intersected the exterior wall. The water spots were localized at precast joints on the underside of the second-floor concrete floor slab panels. After the rain, the exterior vinyl siding and rigid insulation were removed exterior to the rooms with water spots, along with the PTHP units and sleeves, in an attempt to trace the water leakage paths.

As the vinyl siding was removed, numerous gaps in the rigid insulation were observed along with sections of the exterior wall where no rigid insulation was present at all. The rigid insulation appeared to be ill fitting, loose, and held in place only by the attachment of the vinyl siding. Water stains and water marks on the exterior of the concrete block wall indicated that the rain was penetrating through the siding and rigid insulation adjacent to the window opening at the second floor and running down the exterior surface of the concrete block wall below and beside the second floor window opening. The rainwater appeared to be absorbed by the concrete block and subsequently to enter the block cavities above the cast concrete ledger at the perimeter of the precast concrete second floor.

Numerous mold spots were observed throughout the building in similar locations to the rain spots, namely, at the precast joints on the underside of the second floor concrete floor slab panels where these panels intersected the exterior wall. Mold was also evident in the bathrooms of rooms where the bathroom's dropped ceiling intersected the interior wall gypsum board. Similar mold spots were observed at the underside of the sloped precast concrete

roof panels in rooms where these roof panels intersected the exterior wall. These interior spots were located directly opposite to the exterior exposed V-joints in the sloped roof panels at the exterior soffit.

Interior Partition Walls Interior partition walls, either with vinyl covering or paint, appeared affected by mold. The vinyl-covered wall had numerous pink blotches. When the vinyl wall covering was peeled back, mold growth was observed on both the back of the wall covering and on the surface of the gypsum board.

Numerous electrical and service outlet boxes and penetrations on interior partition walls appeared to be surrounded by "puffs" of mold, indicative of air movement through the outlet boxes.

One interior partition was disassembled. The gypsum board did not extend all the way to the surface of the exterior concrete block wall but stopped at the plane formed by the interior surface of the metal furring installed on the interior surface of the exterior concrete block wall. Since the metal furring on the exterior concrete block wall is leaky and discontinuous and the steel studs are perforated, the cavities along the interior and exterior walls were interconnected. Discussions with nursing home staff present during construction confirmed that this was a typical detail.

Roof Assembly A close examination of the connections between roof panels and the tops of exterior walls revealed air leakage paths, specifically where a change in roof elevation occurs. This opening was more than 1 inch in width and ran the entire length of the roof/wall intersection.

Ceiling Diffusers In the Alzheimer's wing, where space conditioning was facilitated by a central system instead of PTHP units, approximately one-fourth of the ceiling diffusers showed evidence of mold growth around the adjacent ceiling gypsum board.

Measurements of Air Pressure

The difference in air pressure between the exterior and indoor or interstitial (wall and other building assembly cavity) spaces was determined using smoke pencils and digital micro-manometers. A detailed mapping of air pressure fields was conducted for the entire facility.

The entire facility was found to be operating under a negative pressure. Depending on operating conditions, door openings and closures, location, and ambient climatic conditions, the difference between outdoor and indoor pressures varied from 4 to 11 pascals. Smoke pencil testing indicated that the majority of the interstitial spaces were leaking air into the conditioned spaces. This was the case for the interstitial spaces of both interior and exterior walls.

Seven different airflow paths, traced by smoke pencil and measurements of air pressure are listed in Table 1. These paths show how the exterior air would find its way to the central exhaust system. Only the first two flow paths occurred by design.

Flow paths and air pressure fields were mapped under various conditions, e.g., with bathroom doors open and closed. Except for the plumbing wall, differences in air pressure were not much affected by opening and closing bathroom doors. Closing doors increased the pressure drop from external to the interstitial space in the plumbing wall.

Air Pressurization

Portable fan pressurization equipment was utilized to determine the total airflows required to bring the pressure level inside the facility to the ambient level. The facility was compartmentalized by closing fire doors, and different sections were tested individually. The assisted-living section was further compartmentalized into two areas, namely, the first and second floors. The portable fan pressurization system was typically installed in a corridor/stairwell door

TABLE 1
Seven Patterns of the External Air Flowing
Through the Building into the Central Exhaust System

Code	Flow Path
1.	Exterior air flows through PTHP into the room, then to the bathroom and out through the central exhaust system.
2.	Exterior air flows through the AHU into the corridor, then to the room, later to the bathroom and out.
3.	Exterior air leaks into the porous exterior wall, then to the room through outlets and under baseboards, later to the bathroom and out.
4.	Exterior air leaks into the exterior wall, then via interstitial cavities to the internal wall, later to the room through outlets and under baseboards, then to the bathroom.
5.	Exterior air leaks into the exterior wall, then to the precast concrete floor and roof panel V-joint voids, later to the bathroom's dropped-ceiling cavity and to the bathroom.
6.	Exterior air is vented into the roof space or attic, then via interstitial cavities and service openings to the partition wall and through the outlets and under baseboards to the room, later to the bathroom and out.
7.	Exterior air is vented into the roof space or attic, then via interstitial cavities and service openings to the plumbing wall and through service openings, dropped ceiling, outlets, and under baseboards to the bathroom and out.
NOTE:	In the Alzheimer's wing of the facility, no PTHPs were installed. Flow #1 was altered: Exterior air flows through the central supply AHU to the room, then to the bathroom and out of the facility via the central exhaust system. Neither were flow paths #6 and #7 present in this wing of the facility, since this wing is located at grade level and has no attic or roof space. However, flow paths #2, #3, #4, and #5 were present.

with the exterior doors opened to allow the exterior air flowing through the test equipment into the corridor. The rate of airflow was monitored along with the air pressure differences. During the course of the test, the facility's air-handling equipment was set to function as specified by design. The air pressurization testing indicated that it was necessary to introduce approximately 4,500 cfm of outside air to pressurize the nursing section of the facility to the level of 1 pascal and approximately 9,000 cfm to achieve the same in the assisted-living section.

Tracer Gas

The facility was being operated under standard conditions, and the PTHP unit in the room was not operating during the period of this test. A portion of the exterior wall was compartmentalized with sheet polyethylene. A tracer gas, SF₆, was injected into this exterior air compartment and a recording device was positioned in the room. In approximately 34 seconds, the test device indicated that the tracer gas had migrated into the room from the compartmentalized portion of the exterior wall.

Tracer gas was also injected into the vented attic located above the second floor of the assisted-living section, and the measuring device showed the transfer to room space occurred in one minute. Tracer gas concentrations were higher in the demising and plumbing walls than in the room. This indicated different resistance to flow path 6 and 7, as listed in Table 1.

Infrared Mapping

An infrared camera was utilized to map infiltration pathways. Hot spots were identified at the precast joints on the underside of the sloped precast concrete roof panels and where the interior partition wall (demising wall) intersected the exterior wall. The hot spots corresponded to mold spot locations.

Measurements of Rain Penetration

A portable water spray rack was assembled and hung from scaffolding exterior to the facility. The water spray rack is designed to uniformly deposit a film of water over a surface to simulate the effect of rain. Water pressures within the spray rack are limited to 30 psi following ASTM standards, which apply to window, curtain wall, and precast assemblies. Nozzle design and placement are similarly constrained.

The combination of a water spray rack and a controlled air pressure difference was designed to simulate the effect of wind-driven rain on the exterior wall assemblies. After one hour of wetting under controlled conditions, the exterior cladding was stripped away. Numerous gaps in the rigid insulation were observed. Water was seen to have wetted the exterior surface of the concrete block wall beside window openings and over a large expanse of wall area below windows. Windows did not appear to be leaking.

Water appeared to be penetrating the vinyl siding at the J-molding/trim. No evidence of water was found inside the rooms at this time.

The spray rack was repositioned so that the lower portion of the exterior wall was now wetted. Weep openings in the brick veneer over the portion of the wall under test were open and above grade. The test was repeated, and after one hour the cladding was stripped away. The pattern of wetting was similar to the wetting observed previously, when the observations were made immediately after a rain storm. Water stains were observed at the bottom, where the vinyl siding met the top of the brick veneer. When the brick veneer was stripped away, a substantial rain wetting of the concrete block wall was revealed. The carpet was found wet in the location adjacent to the removed brick veneer.

Upon removing carpet and the interior gypsum board, substantial quantities of standing water were found on the surface of the concrete slab at the intersection with the concrete block wall. Water marks were also observed at the concrete block joints, indicating that a rain penetration occurs at the mortar joints.

Discussion

Air will move moisture from the exterior to the interior if three conditions prevail: (1) moisture is present in the external air; (2) openings, holes, and pathways through the building envelope exist; and (3) interior air pressure is lower than that of the exterior air.

All three conditions exist in the nursing home at Lakeland, Florida. During the summer season, quantities of moisture in the exterior air are significant. Furthermore, rain penetrating into the exterior wall provides additional humidification.

Holes in the exterior wall system and attic/roof assembly were shown by measurements with the tracer gas and by on-site inspection. Numerous gaps and openings were also observed when access to wall cavities from the interior was provided. Both the interior and exterior walls are built principally with leaky metal furring and perforated metal studs that facilitate airflows.

Further examination of the construction drawings and field observations reveals numerous additional infiltration pathways. Exterior air migrates from the vented roof space or attic into the plumbing wall and into the demising walls and subsequently into the rooms. Exterior air migrates through the porous exterior masonry wall into the interior furring space created by the installation of the interior gypsum board on the exterior concrete block walls and from there migrates through the joints in the precast concrete roof and floor panels into the bathroom spaces, resulting in mold patterns on ceilings and mold in bathroom dropped-ceiling locations.

These flow paths, which can be traced by an understanding of the construction drawings and documents, are further substantiated by the air pressure field mapping, the infrared mapping, and the tracer gas testing conducted.

The question is why the operation of the central bathroom exhaust fans provided the negative air pressure, which, in turn, induced the infiltration of exterior hot, humid air via multiple pathways, as outlined in Table 1. One should note that the expected make-up air through the PTHP units was not delivered. The mechanical engineer relied on the outside air coming through the PTHP units to compensate for the airflow continuously exhausted by the bathroom exhaust without realizing that these units were operating only 20% of the time. The PTHP units were oversized for the service conditions and, accordingly, were unable to remove sufficient moisture from the room air without overcooling. This resulted in a duty cycle of approximately 20%, effectively causing an 80% reduction in design assumed make-up air.

Matters were not helped by the removal of the vent dampers that essentially reduced the make-up air contribution through the PTHP units to negligible values. This can be seen from the measured test results.

It took approximately 4,500 cfm to pressurize the nursing section of the facility and 9,000 cfm to pressurize the assisted-living section of the facility. The actual measured toilet exhausts were 3,749 cfm and 7,960 cfm, respectively. The PTHP units were expected to supply 3,740 cfm to the nursing section and 7,480 cfm to the assisted-living sections. When the toilet exhaust flows were shut down, the entire facility went to a slight positive air pressure relative to the exterior.

It is quite obvious that the designed exhaust airflows were obtained but the designed make-up air was not. The additional 751 cfm (4,500 - 3,749) of make-up air required in addition to the design expected make-up air to pressurize the nursing section and the additional 1,040 cfm (9,000 - 7,960) of make-up air required in addition to the design expected make-up air to pressurize the assisted-living section can be accounted for by duct leakage and the leakage characteristics of the building envelope. Furthermore, there were no provisions for the continuous dehumidification of ventilating or make-up air.

The influence of bathroom door closure and the continuous bathroom exhaust on the negative pressures measured in the plumbing walls becomes apparent in testing. With bathroom doors open, the exhaust air is drawn from the entire room and bathroom combined, whereas when the bathroom door is closed, the exhaust air is drawn from the bathroom only. This results in a greater negative pressure in the plumbing wall, which leaks to both the bathroom and to the attic (roof) space. Humid air from the attic readily infiltrates into the conditioned spaces along this pathway. This explains the presence of moisture damage on the interior plumbing walls. It is significant to note that these walls are also built with metal perforated studs, as are the demising walls, thereby also resulting in extensive distribution of negative pressure zones.

Rainwater is believed to be penetrating the exterior claddings, wetting the exterior concrete block walls, and ultimately leaking into the interior space. To some extent,

the condensate from PTHP units leaking into exterior wall cavities (poor installation) enhanced moisture loads. The moisture contained in the wet brick and concrete blocks helped to further humidify the exterior air on its way toward indoor space. Exterior air was drawn inward by air pressure differences induced by the operation of the central bathroom exhaust systems.

There is also another force driving moisture from wetted walls toward the indoors. This force is the temperature difference caused by air conditioning on one side and solar radiation on the other side. Moisture always moves toward the cold side, and when it reaches cold gypsum board covered with impermeable wall covering or paint, condensation occurs, resulting in mold growth. These two mechanisms are capable of transporting large quantities of moisture, and, because when wetted by rain exterior cladding and concrete blocks supply large amounts of moisture, the mold problem is significantly exacerbated. Even in the absence of the additional wetting by rain, hot and humid exterior air that is infiltrating through the leaky building envelope supplies enough moisture to cause problems when condensing on moisture sensitive materials.

Air pressure differences across exterior claddings can be controlled if the pressure equalization (rain-screen) principle is applied. This principle, however, requires clear air spaces, airtight construction of the back of the airspace, sufficient weep holes, and compartmentalization of the air spaces. Observe that none of these conditions was met in the brick veneer wall system examined (Exterior Wall Type A). The air space between the brick veneer and the exterior face of the rigid insulation was filled with mortar, and many of the weep holes were plugged or located below grade. No attempt of compartmentalization was made. No air barrier system was present or specified in the construction drawings and documents.

Rain-screen principles were not met in the vinyl wall system examined (Exterior Wall Type B). Vinyl siding should be installed over a tight building paper or sheathing, and wall should be provided with an air barrier system. Neither building paper nor air barrier systems was used.

Pressure equalization did not occur, and, accordingly, both wall systems allowed rain penetration to occur. This was observed immediately after a rain and demonstrated under both the rain penetration testing and the tracer gas testing, indicating leakiness to airflow. Additional faults, such as lack of a flashing at the intersection of the vinyl cladding and brick veneer, enhanced rain leaks into the wall assembly. Once in the wall, the rainwater leaks through mortar joints and is probably assisted by the flashing located at the bottom of the wall.

Once the moisture has entered the wall assembly (through the mechanisms of wind-driven rain and gravity flows), the air pressure difference caused by the air-handling systems moves this moisture to the interior conditioned space. Since the air infiltration is induced on a continuous basis and this infiltrating air is humidified by the rain-saturated brick and concrete block, it constitutes a powerful mechanism of moisture transport.

Moisture driven toward gypsum board and condensing on its surface has a number of negative effects, such as reduction of mechanical strength as well as mold and mildew growth. Molds are simple plants of the group known as fungi that grow on the surfaces of objects. Mold discolors surfaces, leads to odor problems, deteriorates building materials, and leads to allergic reactions in susceptible individuals as well as other potential health problems.

The following conditions are necessary and sufficient for mold and other biological growth to occur on surfaces:

1. mold spores must be present,
2. a nutrient base must be available (most surfaces contain nutrients),
3. temperature must range between 40 and 100 degrees, and
4. relative humidity adjacent to the surface must be above 80%.

Of these conditions, relative humidity near surfaces is the easiest to control. Spores are almost always present in outdoor and indoor air. Almost all of the commonly used construction materials can support mold growth; therefore, control of available nutrients is limited and human comfort constraints limit the use of temperature control.

Where relative humidity near the surface is below 80%, mold growth can be controlled. Since relative humidity is dependent on both temperature and vapor pressure, mold control is dependent on controlling both the temperature and vapor pressure near surfaces.

Where the cold air is supplied to a room, it may, due to poor diffuser design, diffuser location, or diffuser performance, create cold spots on the interior gypsum board surface. Although the cold air itself is dehumidified,

however, the cold spots may create a mold problem on board surfaces if the exterior humid air comes in contact these cold spots. Cooling exterior air will raise its relative humidity to above 80%. This is exacerbated with the use of impermeable wall coverings, such as vinyl wall paper, that may trap moisture between the interior finish and the gypsum board. When these interior finishes are coupled with cold spots and exterior moisture, mold and other growth is rampant.

CONCLUSIONS

One of the conclusions of the investigation is that there is an industry unwillingness to recognize the great differences in climate and its effect on building design and operation. Much of the building stock in the lodging industry is developed by the "formula" approach that tends to ignore regional variation. Standardized design and construction regardless of climate are typical. Hotels and motels designed in Memphis, Tennessee, are built the same way in Illinois, Massachusetts, and Florida. In both of the facilities investigated, the problems experienced either would not have appeared had they been built in a heating climate (hotel in Tampa) or would have been significantly less in scope (only rain penetration, no mold problems for the nursing home in Lakeland).

Another major conclusion is that the interrelationship between mechanical systems and the building envelope is typically ignored and/or not understood. In the two case studies presented, both facilities were experiencing excessive depressurization of either rooms, corridors, or interstitial spaces. The effect of climate, construction practice, conditions during construction, and operation all influenced the final outcome.