# Moisture Problems: Why HVAC Commissioning Procedures Don't Work in Humid Climates*

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Moisture-related damage in commercial buildings is a pervasive, costly problem in hot, humid climates. Excess moisture in buildings can stem from failure to control a number of climatic moisture sources, including rain, ground water, moisture diffusion, and air flows. A growing body of evidence indicates that the most problematic of these climatic moisture sources in hot, humid climates is the uncontrolled flow of outdoor air within building envelopes. Solving this problem is difficult for the following two reasons:

- Current commissioning techniques cannot accurately predict air flows because they do not measure their driving force. As a result, owners cannot identify potential moisture-control problems prior to acceptance of new buildings.

- Air-transported moisture is invisible and can travel long distances through interstitial cavities in buildings before accumulating and manifesting in such problems as mold, mildew, or corrosion. Thus, moisture-control problems are not easily diagnosed.

Forced-air heating, ventilating, and air conditioning (HVAC) system imbalances can easily induce the negative pressure that results in unwanted air flows through interstitial cavities in buildings. In hot, humid climates, these air flows carry large quantities of moisture into the building envelope from outdoors. If it accumulates, this moisture inevitably results in moisture damage to building materials and components.

The case studies cited in this paper illustrate the complexity of this problem and identify common sources of uncontrolled air flows in commercial buildings. In all of the cases cited, the forced-air HVAC systems were the primary cause of building depressurization and the resulting flow of outdoor air into interstitial building cavities. Examination of the case studies also revealed the following common characteristics:

- Measured building and interstitial cavity pressures and observed air flows contradicted both the design intent and the test and balance reports for the facilities.

- Building depressurization resulted in expensive moisture-related damage, with associated additional, uncontrolled outside air infiltration.

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*A great potential for moisture problems occurs at the start of a building's life.*

- The diagnostic procedures employed in the studies disclosed sources of moisture accumulation and damage that could not be determined by conventional HVAC commissioning procedures.

Perhaps most important, the diagnostic procedures used in the case studies could be adapted to serve as additional elements of the commissioning process. Employing these procedures would greatly assist architects, engineers, and building owners in ensuring that the design intent of a facility is achieved prior to final acceptance of the building.

## Background

While the relationship between HVAC system design and moisture problems in the exterior building envelope is well known, it has only recently been recognized that a great potential for moisture damage exists at the beginning of a building's life. In 1990, over a dozen hotels that had multi-million-dollar moisture-related problems that occurred in the final stages of construction or within the first year of building operation were identified.[1]

During the final stages of construction and during commissioning, conditions that promote severe moisture accumulation in the building envelope materials often exist. This damage can be greatly increased if the final stages of building construction occur during the humid summer months. Also, while many HVAC systems are intended to provide the proper pressure relationship between the building and outdoors, these systems often rely on distribution and air-control techniques, which may fail to achieve the stated design intent.

A growing body of field evidence indicates that standard HVAC commissioning practices are insufficient to identify system imbalances, which often result in the leakage of significant quantities of outside air into the exterior building envelope. In humid climates, this leakage almost invariably results in moisture accumulation and damage within the building envelope, plus adds a substantial energy load to the building.

In hot, humid climates, leakage of outside air into a building is the most pervasive cause of moisture damage (see Figure 1). In a survey of its over 10,000 members, the American Hotel and Motel Association (AH&MA) found that moisture-related problems are costing the industry over $68 million dollars annually.[2] The Design Professionals Insurance Company (DPIC) investigated 5,000 construction claims and determined that the most prevalent problems were moisture-related, such as corrosion, building material degradation, and mold and mildew.[3]

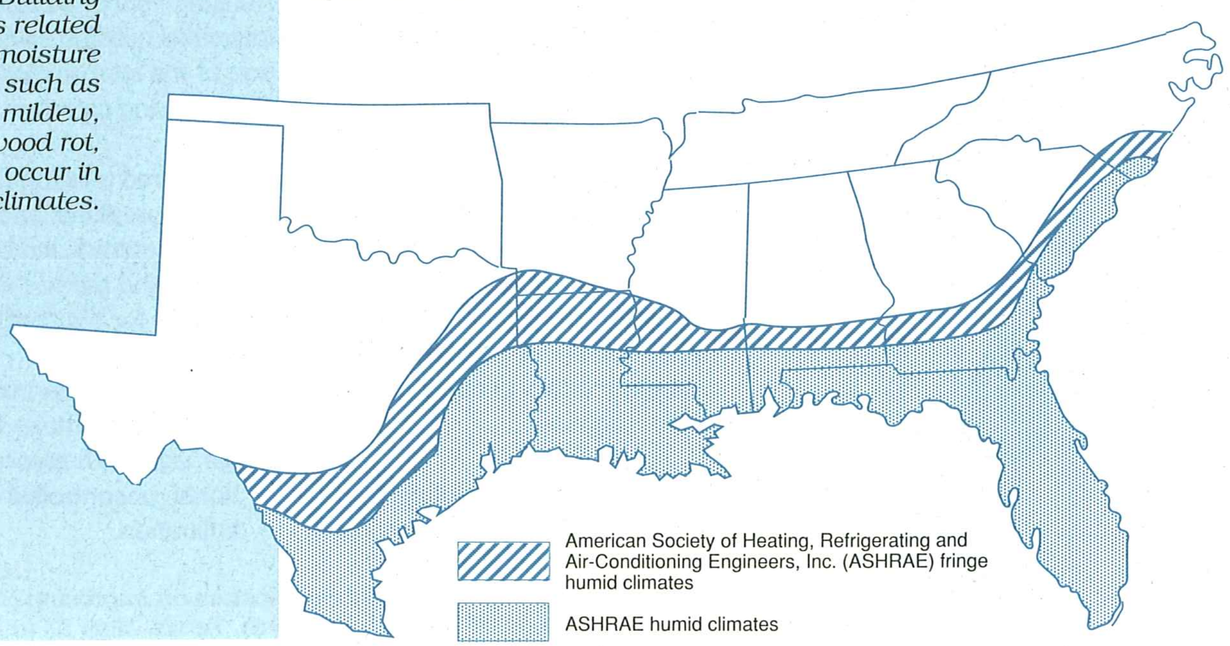



*Figure 1. Building problems related to moisture intrusion, such as corrosion, mildew, and wood rot, most often occur in humid climates.*



## Moisture Control Strategies

Understanding the patterns of moisture accumulation in buildings provides the basis for preventing moisture-related problems when commissioning a building or when analyzing the relationship between HVAC systems and the building envelope. Although mold and mildew growth, staining, and corrosion are the most visible signs of moisture-related damage in buildings, they are only symptoms of the fundamental problem of uncontrolled moisture flows. Thus, controlling the flow of moisture is key to preventing premature degradation of building components.

Moisture-related building damage can result from any of the following events:

- Intrusion of bulk moisture (i.e., rain water and ground water)
- Moisture generated internally by human or operational activity
- Moisture diffusion through building envelope materials
- Leakage of moisture-laden air into a building (i.e., outside air infiltration)
- Moisture in ventilation airstream
- Capillary flows

The architectural and mechanical engineering disciplines are responsible for controlling moisture in buildings. Architects are primarily responsible for controlling the intrusion of rain and ground water through the design of the water-shedding qualities of the building envelope. While the mechanism of vapor diffusion is based on the engineering principles related to temperature and vapor pressure differences between conditioned and unconditioned spaces, specification and placement of the moisture vapor retarder for the exterior building envelope is normally the architect's responsibility.

Mechanical engineers are responsible for controlling internally generated moisture and moisture in the ventilation air stream through designing, sizing, and specifying air conditioning equipment. Air flows induced by the mechanical systems must be controlled so that the potential for air flow across the building envelope is from the cool-dry environment toward the warm-hot environment. Unfortunately, the level of coordination required between the architectural and engineering disciplines to prevent moisture control problems rarely exists.

*Moisture control in buildings requires a high degree of coordination between architectural and engineering disciplines.*

### Air Leakage in Hot, Humid Climates

In hot, humid climates, outside air contains a large quantity of moisture. If outside air is drawn into a building by negative pressures, it travels through the wall system and into the interior space. As the air flows through the wall system and moves past cool, interior surfaces, the moisture in the air condenses and accumulates in the wall cavity. While it is unrealistic to hermetically seal a building envelope, the magnitude and direction of air flows across the envelope can be controlled by the construction "tightness" of and the pressure gradients across the building envelope. The interrelationship between the forced air systems and the building construction dictates the pressure characteristic of a building. Any feature that decreases the air barrier characteristics of the building envelope will increase the likelihood that the HVAC system will be unable to adequately pressurize the building.

Because air flow follows the path of least resistance, air can be carried down demising walls of an interior space if they are connected to the exterior envelope. Also, because leaking air can travel long distances through wall cavities, it must be determined whether the HVAC forced-air systems are pressurizing not only the interior of the building spaces, but also the interstitial spaces connected to them. Case studies have shown that building spaces can be adequately pressurized, while adjacent envelope cavities are depressurized with respect to the outside.

*Current commissioning techniques can't accurately assess air flows in buildings because they don't measure critical pressures.*

## Commissioning

The common practice for commissioning HVAC systems in new commercial buildings consists of verifying the following aspects of the system:

- The thermodynamic performance characteristics of individual heating and cooling components.
- Air flows in the conditioned air distribution system and in the ventilation air system.
- The operating characteristics of the system management and control components.

Inherent in this process is the assumption that commissioning procedures will detect differences between the design intent and operating characteristics of the building HVAC system.

A primary cause of air leakage is depressurization of the building by the HVAC system, although most HVAC designs for hot, humid climates have the opposite intent—to pressurize the building. Unfortunately, current HVAC commissioning procedures are unable to accurately determine if the HVAC design intent has been accomplished. This is because these techniques are based on measurement of air flows at delivery and extraction points, such as supply registers and exhaust grills. Air flow measurements at these points, alone, cannot properly assess the performance of the HVAC system or its impact on the pressure characteristics of a building because they fail to fully consider air distribution.

For example, the delivery of make-up air for a hotel corridor does not necessarily compensate for the extraction of air from guest rooms by bathroom vent fans. Furthermore, relatively large quantities of air often either leak from or are drawn into the air distribution ducting. Since this portion of the HVAC system is usually hidden from view and is difficult to access, its contribution to the air flows within a building is not accounted for by the standard commissioning process.

In most cases, pressure gradients develop in building interiors, chases, wall systems, and other cavities within the building. If uncontrolled, these pressures will induce infiltration of outside air. Present commissioning protocols do not provide for measurement of these pressures. More important, they also do not provide for direct measurement of building pressures that are induced by operation of the building HVAC components.

The startup and shutdown sequence of a complex HVAC system is closely related to the management and control components of the HVAC system. Improper startup sequencing of HVAC forced-air systems can result in severe moisture problems. Generally, startup of forced-air HVAC systems in humid climates should consist of the following sequence of activities:

- Operation of conditioned make-up air systems, if applicable
- Operation of all main conditioning units
- Operation of exhaust air systems

Experience has shown that this startup sequence often is reversed and exhaust systems become operational first. This occurs because the exhaust system is the easiest system to make functional and because of the belief that drawing air through the building will help "dry out" the structure. This assumption is untrue in humid climates because outside moisture levels typically exceed inside moisture levels. In humid climates this scenario often results in severe moisture accumulation problems from depressurization of the building. This is especially destructive if the main conditioning units become operational before the make-up air units.

Two techniques, pressure differential measurement and flow visualization, are valuable additions to the commissioning process. These methods are helpful because the measurement of air flows at the termination points of forced air systems is insufficient for determining the overall pressure relationship between a building's interior and exterior. The pressure differential measurement is a direct measure of the driving force for air flows, while flow visualization confirms and verifies the pressure differential measurement.

### *Pressure Differential Measurements*

*In humid climates, using an exhaust system to dry out a building can create moisture problems.*

Maintaining proper building pressurization is critical in preventing the leakage of outside air into the building envelope. Pressure differential measurements are used to identify the potential for air flows between spaces. Even a very large opening will have no air flow across it unless a pressure gradient (driving force) exists. Conversely, a number of small holes and cracks with large pressure gradients across them can exhibit surprisingly large air flows.

The static pressure difference between a room and its surroundings is determined by comparing time-averaged pressure differential measurements between the room and outside, the room and other interior building spaces (e.g., the hall corridor or adjacent rooms), and the room and envelope cavities that bound the room (e.g., wall cavities, ceiling or floor plenums, and plumbing chases). These measurements are necessary to determine the driving forces for air flow between the room and its surroundings and the direction of air flows in building cavities.

### *Air Flow Visualization*

Air flow visualization (i.e., smoke testing) qualitatively verifies air flow direction with devices that inject a visible gas across an orifice, making air flow visible. Air flow visualization can also be used to determine flow directions when pressure measurements are difficult or impossible to take, such as at junctions between wall and ceiling and floor planes.

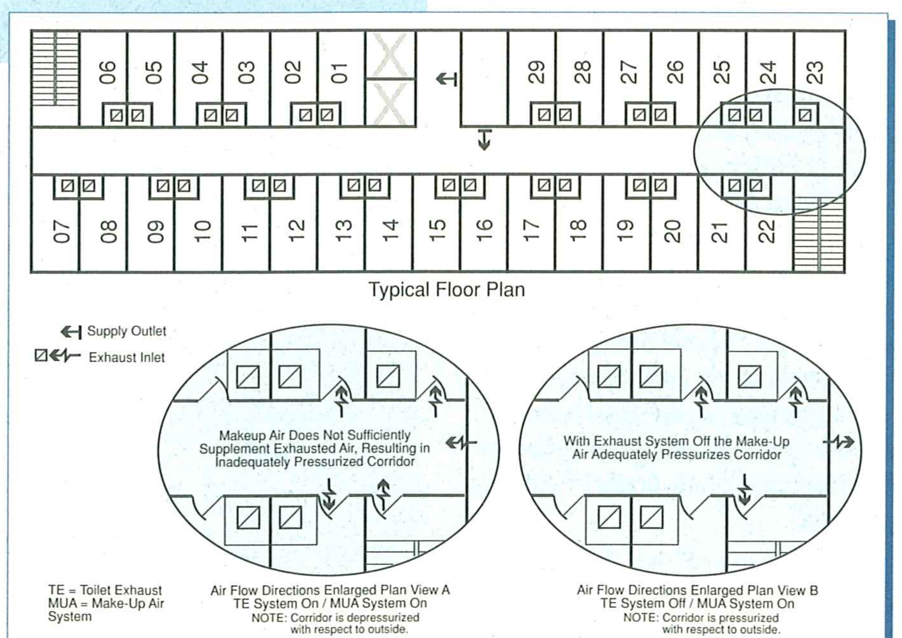
## *Case Studies*

The following case studies demonstrate the various ways that forced air systems can significantly affect building pressures. In each case, the authors were contracted to determine the cause of mold growth on interior drywall. Also in each case, mold growth was determined to be caused by moisture accumulation in the drywall, primarily from the uncontrolled flow of outside air into the building envelope.

### *Case Study 1. Central Exhaust System*

A multi-story hotel in Florida experienced moisture damage during the final stages of construction. As shown in Figure 2, the toilet area of each room is exhausted by a roof-mounted ventilator. The corridors on each floor are fed by a conditioned, continuous make-up air system. Cooling and heating is provided by a self-contained, fan-coil, air-handling unit (FCU) (an air-handling unit with a cooling and heating coil) in each guest room. The design intent of the system was equal balance between the exhaust system and make-up air system. Conventional testing and balancing of the HVAC forced-air systems showed that the conditioned make-up air system was supplying slightly more air than was being exhausted by the toilet exhaust system (exhaust air, 1,472 cubic feet per minute [cfm]; make-up air, 1,560 cfm).

*Figure 2. Despite air balance measurements to the contrary, the HVAC system was not properly pressurizing a multi-story hotel in Florida.*




### *Commissioning Technique*

While the commissioning requirements were satisfied as the forced-air systems were tested and balanced and all air-flow delivery requirements had been met, severe moisture problems developed shortly after construction was complete. As the moisture patterns were symptomatic of outside air leakage, pressure measurements were taken between the corridor, the room, the room wall cavities, and outside (see Figure 3). The measurements showed that the building was being depressurized, despite air balance measurements indicating that more make-up air was being supplied than was being exhausted.

The pressure relationship between the interior and exterior of the building was reversed when the toilet exhaust systems were turned off. For example, in Room 606, differential room pressures were reversed from -6 Pascals (Pa) to +5 Pa (see Figure 4).



### *Air Flow Visualization*

As shown in Figure 2, the air flow directions were consistent with the pressure measurements. Under normal operating conditions, air flow was from the exterior wall into the corridor and from the stairwell into the corridor. When the toilet exhaust system was turned off, air flow reversed, indicating that the make-up air system was pressurizing with respect to the outdoors and the stairwell.

### *Conclusion*

This building satisfied typical HVAC commissioning requirements. Air flow volume measurements indicated that the HVAC systems were performing according to their design intent. In fact, according to the commissioning procedure, the forced air systems should have slightly pressurized the building as more air was being supplied than was being removed. However, pressure measurements indicated that the forced-air systems were directly affecting all the building cavities and depressurizing the entire building with respect to outside.

### *Case Study 2. Building Chases Used as Air Distribution Systems*

In a central Florida hotel, a medium-rise, twin-tower building connected by a common atrium-style public area, air pressure differential measurements were taken between the rooms and outside, the corridors and outside, and the wall cavities and outside. These measurements were taken to determine if air leakage was causing moisture-related problems in the wall systems. HVAC air balance testing indicated that proper air flows were being delivered to the interior building spaces.

*Figure 3. In Case Study 1, the average room boundary component pressures were negative with respect to outside under normal operating conditions, causing air to be drawn into the wall system.*

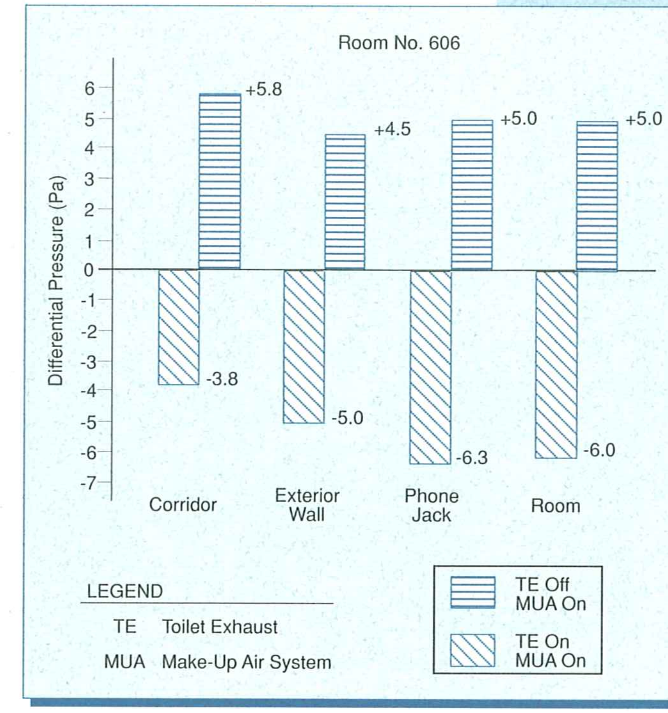



*Figure 4. Another cause of air leakage into the rooms in Case Study 1 was that room pressures were negative with respect to outside.*

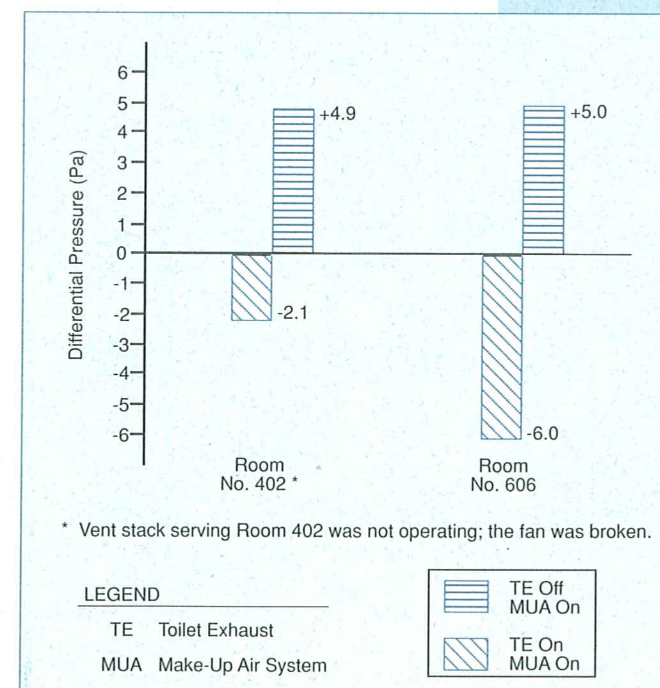


*Figure 5. In Case Study 2, the average room pressure was negative with respect to outside under normal operating conditions, drawing air into the room.*

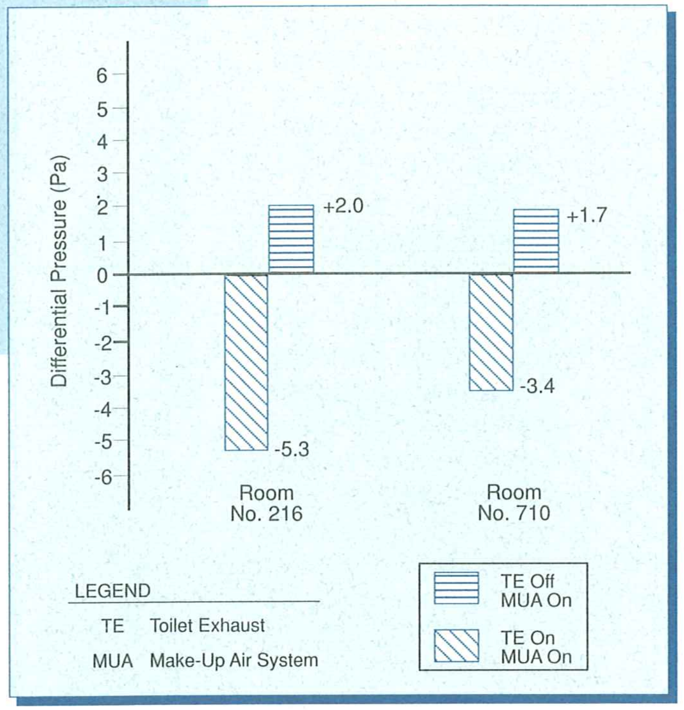
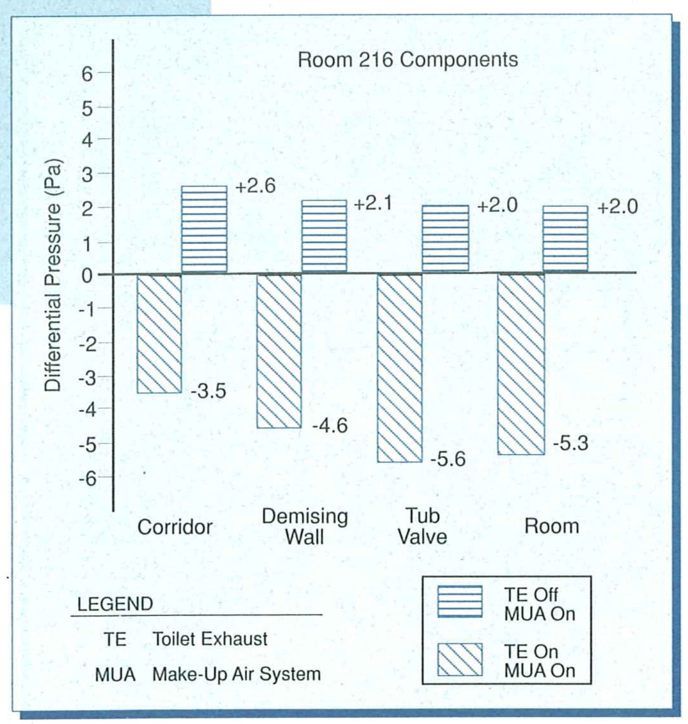



*Figure 6. Negatively pressurized wall cavities also caused air to be drawn into the rooms in Case Study 2.*




### *Normal Operating Conditions*

Normal operating conditions consisted of continuous operation of the toilet exhaust fans; the use of thermostatically controlled guest room air conditioners; a continuously operated, corridor-fed, make-up air system; and a continuously operated atrium exhaust fan. The design intent of the guest room HVAC system had the following features:

- Removal of air in the toilet area through the central, continuous, toilet exhaust system
- A corridor-fed make-up air system to replace the removed air (make-up air was intended to enter the guest rooms through guest room door undercut)
- An air conditioner designed for thermostatic control to cool or heat the guest room

### *Commissioning Techniques*

Pressure measurements revealed the following conditions under normal operating conditions:

- The guest room interiors were negatively pressurized compared with the building exterior (see Figure 5).
- The guest room wall cavities were negatively pressurized compared with the building exterior (see Figure 6).
- The corridors were negatively pressurized compared with the building exterior (see Figure 6).

### *Air Flow Visualization*

Air flow visualization of the tested rooms supported the pressure measurements (see Figure 7). Furthermore, air flow direction indicated that the toilet exhaust system was directly affecting the demising wall cavity pressures and that air flow direction was from the rooms to the plumbing chase. Even in the toilet area where the exhaust inlet is located, air flow direction was predominantly from the toilet area to the wall cavity. The pressures also indicate that air entering the exterior building envelope is likely to travel down the demising wall, toward the plumbing chase where pressures are lowest (see Figure 7).

### *Conclusion*

The use of building chases as exhaust ducts can produce negative pressures within the building envelope. As a result, design air flows can be satisfied in all the building spaces, yet the system can create negative pressures within other connected cavities and chases. Under these conditions, the toilet exhaust system not only depressurizes the rooms, but also directly depressurizes the plumbing chase and adjacent wall cavities because of ductwork leakage (see Figure 8).

Pressure measurements were also taken with all the guest room toilet exhaust fans off. Under this condition, all areas were pressurized with respect to the outside.

## *Case Study 3. Leakage at Guest Room Fan-Coil Units*

Individual space FCUs can also directly affect the pressures of the building interior and building envelope cavities. If the FCU has return-side air leaks, depressurization of the adjacent wall cavities can occur. Pressure differential measurements in this case study identified the potential for individual-space FCU fans to

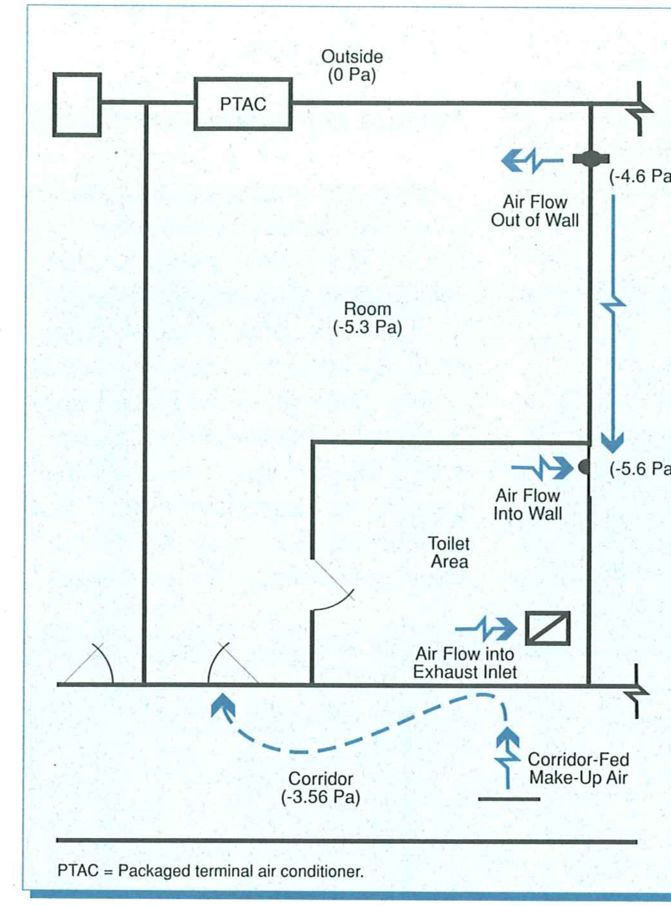



*Figure 7. In Case Study 2, air flow visualization showed that air was entering the exterior building envelope and traveling down the demising wall.*

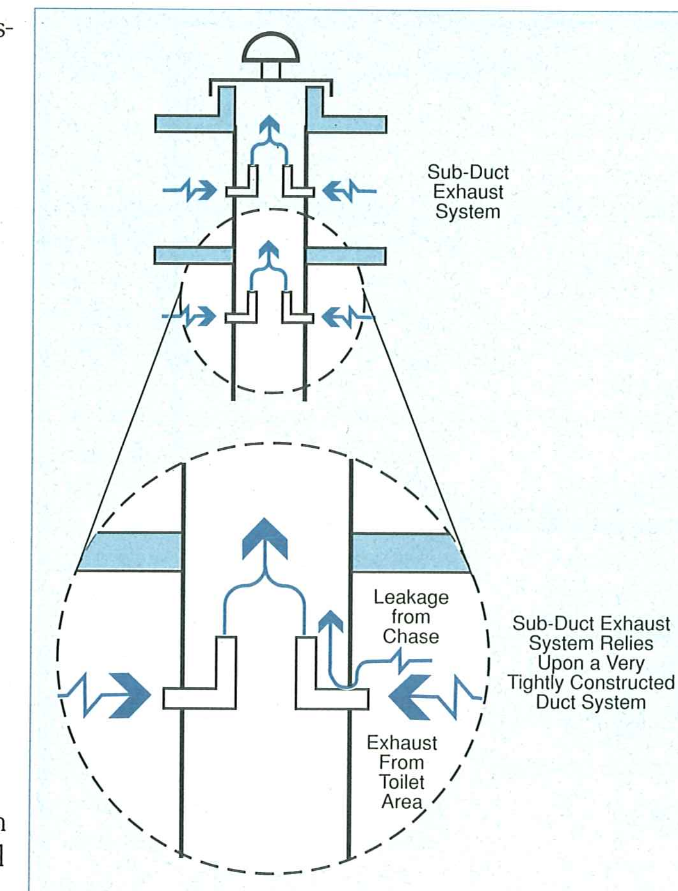


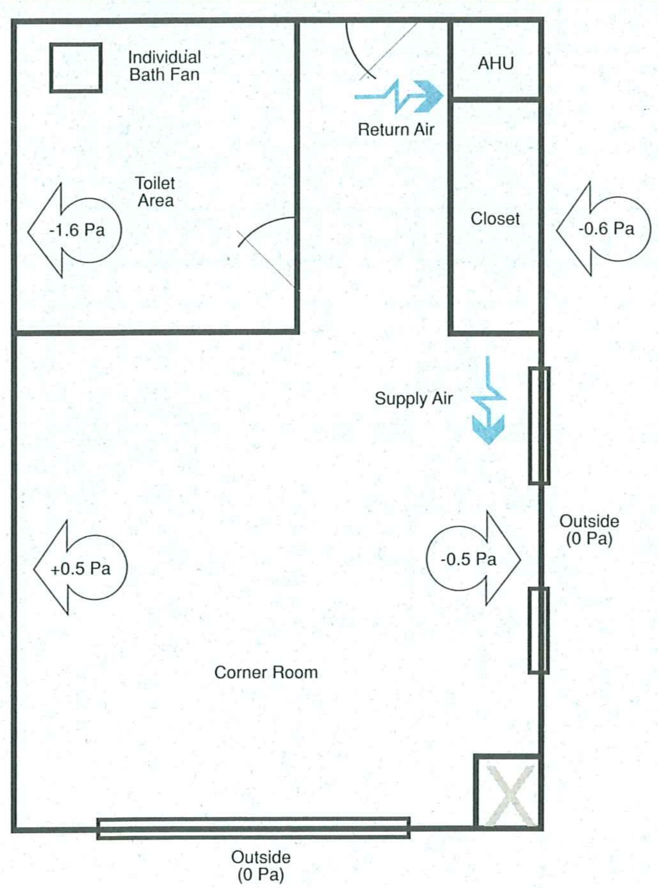

*Figure 8. Air leakage from the plumbing chase to the central exhaust duct caused the entire chase to depressurize and draw air through the demising walls from outside.*

induce outside air into the exterior and demising walls.

### Normal Operating Conditions

Cooling and heating building interior rooms is provided by individual FCUs. The FCU is installed vertically in a small mechanical closet near the entry of each room. The FCU discharge is ducted to a supply outlet. The inlet of the FCU is open to the mechanical closet enclosure, with a return grill mounted at the guest room wall to allow return air to enter the closet from the room. Visual inspection of the enclosure showed that it was open to the drop ceiling and adjacent wall. The corridors are fed by a 100-percent outside air make-up air system. Make-up air is intended to enter the room through the entrance door undercut. The building toilet areas are exhausted through individual, occupant-controlled fans, which were intermittently operated.

*Figure 9. Case Study 3 demonstrates that it is possible to have pressurized rooms and depressurized wall systems.*




| Measurement Location | FCU | Room Pressure | Wall Pressure |
|---|---|---|---|
| Outlet at Exterior Wall | On | +3.5 | -0.5 |
| | Off | +0.5 | -0.5 |
| Outlet at Demising Wall | On | +2.5 | -0.5 |
| | Off | +1.7 | +1.7 |
| Penetration in Closet Wall | On | +4.0 | -0.6 |
| | Off | +2.5 | +2.5 |
| Vanity Outlet | On | +3.2 | -1.6 |
| | Off | +1.8 | +1.6 |

Pa = Pascals

### Commissioning Technique

Preliminary pressure differentials between the room and the corridor were measured. Pressure differences were measured across each room entrance door threshold with respect to the corridor. For each measurement, the FCU fan was on, which positively pressurized the rooms in relation to the corridor. Since the FCUs are intended only to recirculate room air, the corridor would be expected to always remain at a positive pressure with respect to the rooms. Initial results indicated that the rooms had a return-side FCU leak and were drawing air from outside the room, resulting in overpressurization of the room with respect to the corridor. Thus, air flow at the room door threshold was from the room to the corridor, rather than the design intent of from the corridor to the room. As a result, odors in the guest room were often detected in the corridor.

Detailed pressure measurements were taken in several rooms (see Figure 9). For each set of measurements, the outdoor air pressure was used as the reference and was taken with the FCU both on and off. The measurements indicated the room is always positively pressurized with respect to the outdoors; however, the wall cavities are positive only when the FCU is off and, with the exception of one interior wall, are all negative when the FCU fan is on.

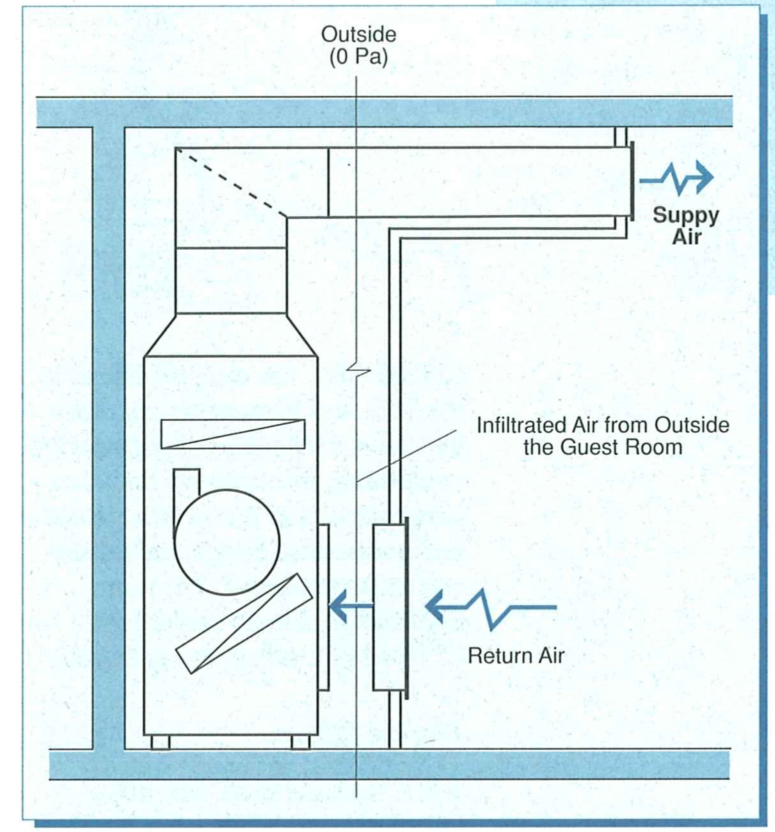


### Conclusion

Pressure measurements showed that the FCU was drawing air from outside the room because of the suction pressure at the return side of the FCU (see Figure 10). Pressure measurements also showed that many of the wall cavities and ceiling areas of the rooms were negatively pressurized with respect to the outside while the FCU was on. This was true despite the fact that the room was positively pressurized with respect to the outside.

Traditional HVAC commissioning techniques would not have measured the pressures that indicate a depressurized envelope wall cavity, which induces infiltration of outside air.

*Figure 10. As demonstrated in Case Study 3, the return-side leak in the FCU pressurized the guest room, but depressurized the wall systems.*




## Summary

Moisture-related damage in commercial buildings, which results in millions of dollars of damage annually, can be attributed to five possible sources of moisture: bulk moisture intrusion, internally generated moisture, vapor moisture diffusion, capillarity, and air leakage. Of these, leakage of outside air into buildings is the most common source of moisture damage in hot, humid climates.

A primary cause of air leakage is depressurization of the building by the HVAC system, although many HVAC designs have the opposite intent—to pressurize the building. Unfortunately, current HVAC commissioning procedures are unable to accurately determine if the HVAC design intent has been accomplished. This is because current commissioning techniques are based on measurement of air flows at delivery and extraction points, such as supply registers and exhaust grills. Air flow measurements at these points, alone, cannot properly assess the performance of the HVAC system or its impact on the pressure characteristics of a building because they fail to fully consider air distribution.

The startup sequence of HVAC forced-air systems is also a critical aspect of commissioning a building. The proper sequence consists of operation of first, all make-up air systems, then all air conditioning units, and last, all exhaust systems. An improper startup sequence will prevent a HVAC forced-air system from performing according to the design intent. If this condition occurs during hot, humid weather, moisture accumulation and mildew can occur within several weeks.

### References

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