Investigating and Resolving

# Moisture Problems

**The renovation of a Florida office building shows repairing and replacing envelope components and mechanical systems improves moisture conditions**

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A complete renovation of a 65,000-sq-ft Tampa, Fla., office building provided an example of proactive indoor-environmental-quality (IEQ) management. The 1991 building originally was a telecom office and call center. The complete interior build-out included the addition of five central fresh-air pre-conditioners that provide 29 cfm per person; the replacement or refurbishment of air handlers; the installation of new programmable thermostats, thermidistats, and humidistats; and the addition of occupancy sensors, HVAC-noise control, HVAC commissioning, building-envelope water/air-tightening and pressurization, and low-volatile-organic-compound (VOC) furnishings, carpeting, and interior finishes. The 30 direct-expansion (DX) split systems range in size from 2.5 to 10 tons, with a total nominal capacity of 208 tons. Total design supply airflow is 67,440 cfm, with 7,500 cfm of outside air. Bringing a 1991 building up to current standards requires attention to all systems and equipment.

Building IEQ improvements included corrective and preventive measures. Correcting a water-intrusion-vulnerable building envelope, upgrading HVAC controls and dehumidification capacity, correcting exiting microbial contamination, and providing an adequate outside-air supply were key. Although subject to Florida's torrential summer thunderstorms, with rainfall rates of inches per hour, the building has no roof overhangs, and windows are mounted flush with the exterior wall surface. This design relies solely on window caulking systems and adequate roof drainage for water tightness (Photo A and Figure 1).

Maximizing outside air for offices has been shown to reduce illness rates and improve productivity. However, with high latent loads, outside-air systems in humid climates must be designed

**PHOTO A. This Tampa, Fla., building had windows that were unprotected from the area's frequent downpours. The windows were caulked and sealed to fix the problem (Figure 1).**

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carefully to provide ample dehumidification capacity at an acceptable cost. Building pressurization is a key factor in maintaining building-moisture balance. Therefore, in a retrofit, envelope tightening is one way to reduce outdoor-air requirements while maintaining moisture control and increasing outside air.

The building is leased and will be occupied for 10 years by the Florida Department of Environmental Protection (FDEP), which has approximately 240 employees, microbiology and wet-chemistry laboratories, and several meeting/conference rooms. The building owner and the property management company implemented extraordinary measures to provide the best possible IEQ at the lowest possible cost.

The FDEP's Invitation to Negotiate (ITN) resulted in a lease agreement that stipulated various provisions for candidate rental properties. This written agreement was a key factor in implementing various features during a protracted retrofit period. While some of the features seemed burdensome to the lessor, various ITN features reduce maintenance and operating costs. Other features resulted in discovering and correcting unseen moisture intrusion that had damaged the building. The project was completed in June 2006.

Compared with typical buildings of similar age, size, and construction, IEQ features of this building are outstanding. With a comprehensive maintenance program, IEQ should remain excellent for many years, with relatively trouble-free operation, and provide a high-productivity work environment.

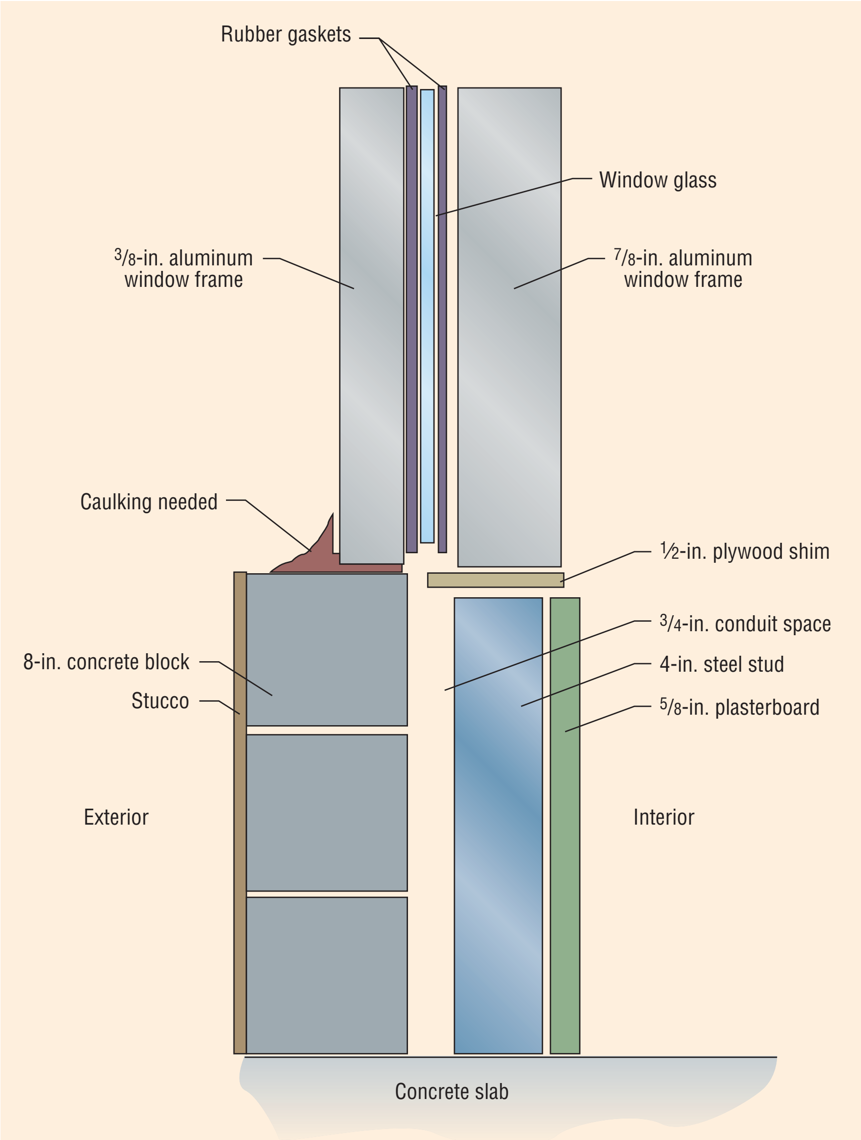


***FIGURE 1. Windows were caulked and sealed to stop leakage.***

**ENVELOPE TIGHTENING**

One of the most recent authoritative reports of damp buildings and health outcomes was published in 2004 by the National Academy of Sciences.[1] It found that damp indoor environments are associated with upper-respiratory-tract symptoms, cough and wheeze, and asthma symptoms in sensitized asthmatics. In addition, there was limited evidence for dyspnea (shortness of breath) and asthma development. While many other symptoms have been claimed to be caused by damp-building exposure, the report indicated that by 2004, there was inadequate evidence of an association between damp buildings and other such symptoms.

Mold contamination in buildings indicates a moisture-control failure. Many of the observed and claimed health effects in damp buildings are thought to be caused by mold. The 2004 National Academy of Sciences report revealed no evidence that mold causes adverse health outcomes but did find evidence of an association between the presence of mold and other allergens and upper-respiratory-tract symptoms, cough and wheeze, asthma symptoms, and hypersensitivity pneumonitis. A similar 2000 National Academy of Sciences report[2] presented evidence that dust-mite exposure causes asthma development, indicating that this moisture-requiring pest deserves consideration in building health studies. Clearly, these health outcomes support the claim that visible mold growth inside buildings can impact human health as well as affect moisture-related degradation of buildings.

Visible mold growth inside buildings is inappropriate and produces indoor allergens. Because 20 percent of the population at large exhibits allergic responses to one or more allergens, indoor mold growth poses a potential health risk to a significant fraction of employees.

In the Tampa building, pre-construction moisture surveys showed numerous damp areas under windows around the building perimeter. Lawn sprinklers misaimed at walls and landscape levels rising above slab levels played significant roles in persistent wetting. Some damp areas under windows that extended down to floor had visible mold growth behind the windows' vinyl trim. In especially damp areas, mold was visible on the back of gypsum board, with water leaking down the concrete-block knee-walls below the windows. Glass-fiber-batt insulation was visibly wet, and the concrete blocks were wet to the touch. Although leaks were not visible to the eye, radio-frequency (RF) and infrared-(IR-) thermography surveys revealed leaks beneath windows around much of the building perimeter. Sixty-eight moist wall areas of varying size were marked for repair on perimeter walls. While wall construction allowed water in at the top, it also allowed water to exit the building at the bottom, so occupants could not visibly detect serious, persistent water intrusion that could thoroughly wet the wall cavity. Wall depressurization (either wind or HVAC-driven) then could bring mold spores into occupied spaces. Some moist areas were small, while others extended for several feet and caused light-gauge steel framing studs to rust through. Floor dampness in a few areas extended 1 to 2 ft from the walls, indicating a perimeter water source persistent enough to soak into the concrete floors.

A critical task is to identify and correct all sources of moisture intrusion. In the Tampa building's areas that showed evidence of high moisture levels, interior walls were opened, dried, and replaced with new gypsum board and interior finish. The insulation was replaced with a non-absorbing polyisocyanurate insulation board instead of glass fiber or polystyrene to reduce wall moisture capacity. The facility manager tracked areas drying under the action of the air-conditioning system using an RF probe over a period of months. Because of the absence of protective window overhangs, annual maintenance of the building's caulking at windows and exterior walls is essential to preventing water intrusion. This and the following listed measures successfully dried out the walls. Moisture-intrusion control included:

- Repair and caulking/sealing of roof parapet caps.
- Replacement of exterior caulking at all windows and wall penetrations (Photo A and Figure 1).
- Elastomeric coating of building exterior.
- Exterior caulking beneath all window frames and undercuts.
- Repeated adjustment of sprinkler-head aim.
- The lowering of the landscape grade below building-slab level, the sloping away of the landscape from the building, and the installation of drains.
- The extension of roof flashing over exterior doors and the installation of wide rain gutters and downspouts over door-top catch basins at the ends of the four building wings.
- The addition of catch pans and drains to direct roof runoff and condensate away from building walls.

**FRESH-AIR PRE-CONDITIONERS**

In the 1991 design, approximately 4,000 cfm of raw outside air was drawn into the existing air-handling units in which, if the condensing unit was energized by a thermostat call, the outside air was dehumidified and cooled. When those units cycled off, moisture on the cooling coil evaporated back into the space, and little net dehumidification was realized. Analysis of Tampa weather data shows there are about 1,430 hr per year when dehumidification is required, but there is little or no sensible-cooling load.

During the pre-construction survey, several of the 30 DX air-conditioning split systems were not performing well. The mostly single-stage units were oversized by approximately 15 to 30 percent. Conditions indicated that part-load dehumidification performance was inadequate because of frequent on-off cycling. The units were not running long enough to dehumidify because the controls were based on temperature only. Excessive indoor humidity occurred during the unoccupied night hours and during relatively cool (74 to 84 F) and humid (over 65-percent relative humidity) daytime hours. The units were serviced with refrigerant-charge and evaporator-airflow adjustments to improve dehumidification capacity. Reduction to 300-cfm-per-ton airflow and field adjustment for a coil leaving temperature of 52 to 56 F increased the length of the on cycles.

To fully address these problems, five dedicated outside-air package units also were added to provide continual fully conditioned airflow for humidity control and pressurization. Each of these 6-ton DX pre-conditioners is equipped with wrap-around heat-pipe coils, ultraviolet (UV) emitters, and hot-gas reheat. Total fresh-air intake of 7,500 cfm is through minimum-efficiency-reporting-value-(MERV-) 6 pleated pre-filters and MERV-11 final filters, which provide 29 cfm of fresh air per person at full occupancy. Overall occupant density of 3.7 people per square foot is lower than the ASHRAE Standard 62.1-2004, *Ventilation for Acceptable Indoor Air Quality,* default value of five people per square foot. The ASHRAE 62.1 requirement for office space (5 cfm per person plus 0.06 cfm per square foot , including corridors) gives a minimum fresh-air requirement of 21.3 cfm per person for this building. Approximately one-third more fresh air was provided to optimize IEQ.

Pre-conditioned air is ducted to each air-handler intake, where it is mixed with return air from ceiling return grilles and supplied to the space via existing ductwork. The lay-in ceiling return grilles—

## Detecting Moisture Intrusion

Building-moisture-control failures through building envelopes may be difficult to detect if HVAC systems are controlling indoor humidity adequately. Interior finishes could be nearly dry at the inside surface, even while significant water volumes move through the wall and drain to the exterior. In such cases, conductivity probes may fail to identify a wall system as wet. A good RF probe often can penetrate gypsum board and detect cavity moisture. IR imaging also can detect tiny temperature differences that can be created by variations in moisture content (figures 2 to 4). The cavity dampness may cause mold growth and contribute to interior allergens if a building-pressure imbalance causes unwanted flows to the interior from the cavity. Correct pressurization may keep air (with spores and mold odor) moving outward through wall cavities, but wall water still can cause structural damage, such as metal-stud corrosion inside the cavity, as found in the Tampa building.

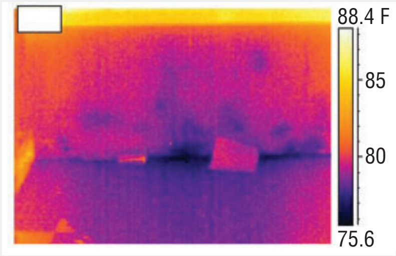


***FIGURE 2. Wet fiberglass in a wall cavity caused by water entering a building exterior can produce a mottled pattern in an IR image where unevenly wetted fiberglass contacts gypsum board. Such patterns may be revealed by RF moisture probes, but only after many measurements.***

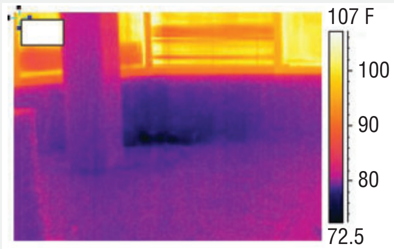


***FIGURE 3. Moisture enters a wall and slab at a slab-wall joint because of an elevated landscape-soil level.***

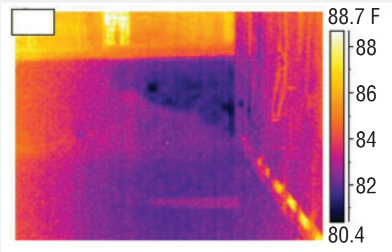


***FIGURE 4. Moisture intrusion from above may be revealed by obvious seepage patterns where water enters from failed window caulk above a kneewall.***

one 20-by-20-in. return grille per 2 tons of nominal rating for noise control—also are fitted with MERV-11 filters. The installation of UV lights was specified separately to maintain coil cleanness and airflow (leveling and reducing operating costs). The selected UV fixtures are made expressly for rooftop-package-unit applications. These measures should reduce asthma symptoms in building occupants, reducing health-care and absenteeism costs.[3] The increased outside air also should increase productivity.

### HVAC CONTROLS

With glass-curtain walls facing all compass directions, solar loads varied dramatically across the single-story building during the day. Achieving thermal comfort required careful zoning and HVAC control. The original HVAC control included 30 stand-alone thermostats that independently controlled each of the 30 DX split systems. Although these thermostats were capable of two-stage operation, dual compressor units were wired for tandem single-stage control. All were replaced with networked programmable controllers, which were calibrated to ±1 F. Each fresh-air pre-conditioner has a two-stage temperature control and a humidistat set to 55-percent relative humidity. New thermostats were programmed for a 1-F deadband constant fan during occupied hours and fan cycle with compressor during unoccupied hours with a 1-hr pre-occupancy purge to reduce night moisture accumulation. The calibration and programming of every thermostat was checked carefully by an independent third-party commissioning agent. Some thermostats had to be relocated away from supply-air diffusers.

The two laboratories (microbiology and wet chemistry) are separated from the office spaces by slab-to-deck partition walls that had to be resealed at the roof deck joints after significant air gaps were discovered during commissioning. Each lab has a 4-ft fume hood and a general ceiling exhaust with rooftop fans. Two dedicated DX rooftop units for heating, ventilation, and cooling are controlled by a combination thermostat-humidistat. The fan and outside-air damper controls are interlocked with the fume hoods and general exhaust fans for pressure control. The exhaust fans have variable speed control, and there are barometric dampers to maintain proper makeup-airflow rates under all conditions, such as when a door is opened to enter/leave a lab or the fume-hood sash is repositioned.

### PRESSURIZATION

Positive pressurization is used to keep out humid unfiltered outdoor air and to help contain chemical odors and contaminants in the laboratories. The original airflow schedule showed a total of 5,950 cfm of outside air and 4,870 cfm of exhaust. The schedule showed seven exhaust fans totaling 1,870 cfm and six gravity-relief vents totaling 3,000 cfm for a total exhaust air of 4,870 cfm. This design differential of 1,080 cfm was insufficient to pressurize the leaky building. Modeling predicted a positive pressure of only 0.005 in. wg with respect to the outdoors, and actual measurements showed nearly neutral conditions, which was unacceptable.

Work included taking out all relief vents and minimizing powered exhaust based on a 2-cfm-per-square-foot lavatory-code requirement. Air tightening of the building envelope was achieved in the following manner:

- Exterior-door weather stripping and threshold seals were upgraded and replaced.
- All wall and roof gaps/penetrations for electrical, refrigerant, communications, and other pipes and lines were sealed and caulked.
- Laboratory isolation walls above the suspended ceiling required careful and repeated sealing along the bottom of the roof deck because of the greater differential pressures created by the lab exhausts.
- Occupancy sensors and barometric dampers were installed on lavatory exhaust fans.
- Total outside air was increased to 9,400 cfm: 7,500 cfm via the pre-conditioners, 1,000-cfm makeup air for janitor closets and restrooms, and 900-cfm makeup air via the laboratory package units.

Computer modeling predicted a positive pressure of 0.025 in. wg, and actual tested pressure after the retrofits averaged 0.031 in. wg. This was sufficient to match the site's average annual wind velocity of 8 mph, which represents a windward-side pressure of about 0.03 in. wg. The laboratories are maintained at 0.022 in. wg negative with respect to the office spaces and 0.01 in. wg positive with respect to the outdoors.

***PHOTO B. Granular particulates shed from an air-handler coil.***

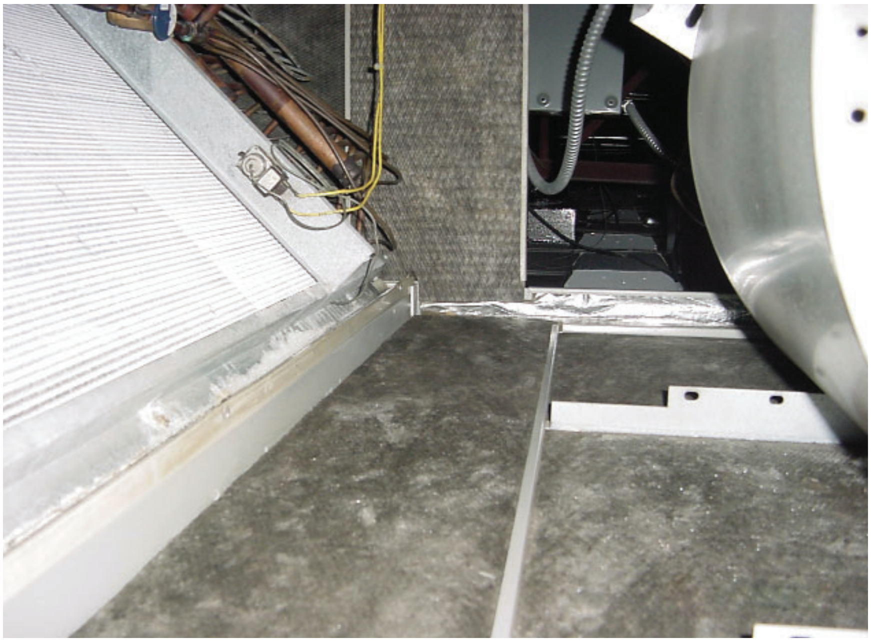

***PHOTO C. Air handler disinfected and cleaned with a HEPA vacuum.***

**AIR-HANDLER REMEDIATION**

During the initial survey, amplified fungal growth was observed within and downstream of several cooling coils. Mold growth in cabinet fiber-glass linings was identified in several air handlers. Fungal-culture results from six units indicated contamination, with counts ranging from 5,000 to 996,000 colony-forming units (cfu) per square inch. These six air handlers were discarded and replaced with new units. Moderate contamination was found in 12 units with counts ranging from 100 to 500 cfu per square inch. These air handlers were cleaned and disinfected carefully. Heavily deteriorated cabinet-liner sections were replaced with foil-faced liner. Confirmation testing showed acceptable counts from 80 to fewer than 10 cfu per square inch after all work was completed. Limited confirmatory airborne fungal-spore sampling levels ranged from 36 to 424 cfu per cubic meter indoors, compared with 2,200 cfu per cubic meter outdoors at the time of the sampling.

Outdoor mold spores can be present all year long in Florida because high ambient-humidity levels and warmer temperatures allow mold fruiting in all seasons. This particular location also borders a river flood plain and wet woodlands. Outside-air supplies carry spores into building ventilation systems as soon as HVAC units are installed. Even with MERV-10 filters, an outdoor spore load

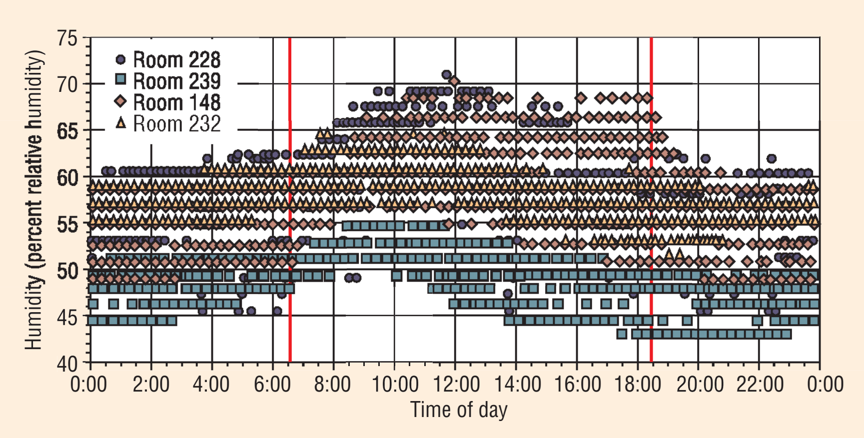


***FIGURE 5. Humidity by time of day. This trend data shows humidity and comfort conditions from May 25-31, 2006.***

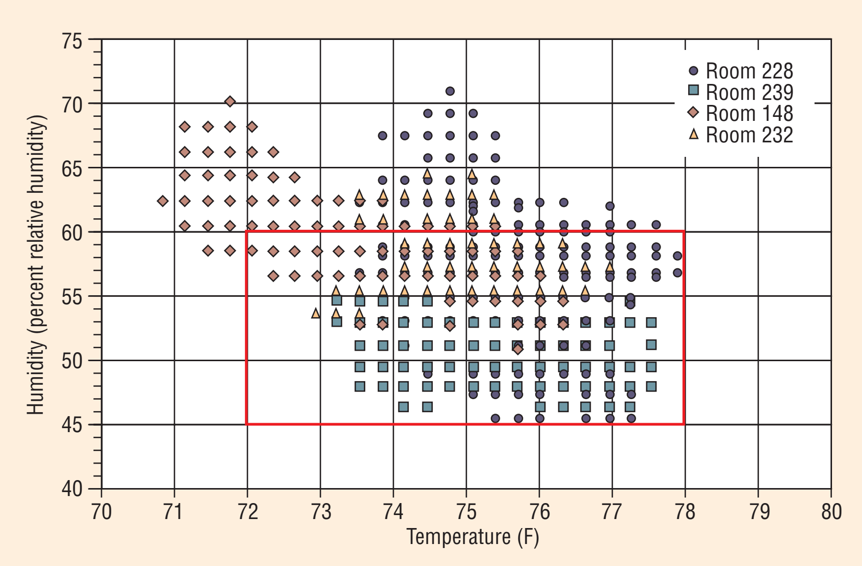


***FIGURE 6. This trend data shows space conditions from May 25-31, 2006.***

of 20,000 cfu per cubic meter still would introduce thousands of spores into the ventilation system. Filtration certainly is required, but careful moisture management is even more essential to mold control because mold spores should be expected even in "new" air-conditioning systems with "good" filtration.

A coarse-particulate problem developed after the original contractor completed initial coil cleaning. Large amounts of material remained lodged deep in the coil fins after they were cleaned with a foaming agent. After the air-conditioning demand dropped and the coils dried thoroughly, the film of loosened debris contracted, gradually blew through the coils, and was ejected into the supply ducts. It eventually fell into the occupied space as brittle black flakes and granules. These conspicuous particles were a nuisance and concerned some occupants. This shedding condition is a common outcome of the use of light-duty "no-rinse" coil-cleaning products on heavily soiled cooling coils. No-rinse coil cleaners often are used when an air handler is within a finished space (carpeting, drywall, etc. are installed) or a contractor cannot or does not remove an air-handler coil to the outdoors so it can be rinsed with water thoroughly or cleaned with a pressure washer. After the particulates were discovered, the offending units were dry cleaned with a high-pressure air jet and high-efficiency-particulate-arrestor (HEPA) vacuumed to reduce particulate shedding (photos B and C).

Shallow condensate P-traps were at an inadequate depth, not vented, and not insulated, which resulted in dripping and frequent overflows. Traps were replaced with 4-in. U-traps, and each overflow switch was tested during commissioning. A few switches failed the test because they were wired in parallel with the control circuit instead of in series.

## CONCLUSION

Lessons learned during this retrofit can benefit future projects.

- Lawn sprinklers, which incorrectly were aimed at walls, and the landscape level, which rose above slab level, played a significant role in persistent wetting.
- Although not visible to the eye, RF and IR thermography surveys revealed extensive water leakage associated with failed window caulking.
- The use of a non-absorbing polyisocyanurate insulation board, rather than glass fiber or polystyrene, reduced wall moisture capacity and dry time.
- The field adjustment for a coil leaving temperature of 52 to 56 F and an airflow reduction to 300 cfm per ton improved dehumidification.
- Positive pressurization to match the average wind pressure kept out humid, unfiltered outdoor air and helped contain chemical odors in the laboratories.
- Shallow condensate P-traps are inadequate for systems with large pressure differentials.

This was a difficult retrofit because numerous general conditions established in the FDEP's ITN continually had to be negotiated to the exact detail and then verified for completion after installation. This drove first costs up, and it is not clear whether the savings from the expected benefits will be tracked to determine whether long-term costs are lower.

It is not clear how to verify lower expected life-cycle costs to justify higher

## Taking a Second Look at IEQ Improvements

The IEQ improvement measures described in this article were completed from March to June 2006 at a cost of $160,000 ($2.46 per square foot). At final punchout, IEQ was deemed "excellent," based on fresh airflow rates, filtration efficiency, VOC reductions, and humidity control. A followup site visit was made in November 2006. Upon entering the building and talking with occupants, the subjective assessment was one of good air quality in the building. Measurement of carbon dioxide and pressurization indicated fresh-air and exhaust-flow rates still were in balance.

Even so, it appeared that the recommended maintenance plan was not being followed rigorously. MERV-8 filters were found installed in place of the specified MERV-11 filters, allowing an increase in airborne allergen levels. Some of the filters were undersized and were sucked into the return plenum. Several water-stained ceiling tiles, some still wet to the touch, were noticed. They apparently were caused by persistent roof leaks and air-handler-condensate backups. Also, a rooftop fresh-air unit had experienced an overflow of condensate onto the ceiling. Spot occurrences of mold growth on wetted tiles were likely, but not confirmed with sampling.

A couple of these findings prompted further investigation. Two types of filter-back return-air grilles that take slightly different filter sizes were found, even though a uniform-sized filter housing had been specified throughout. The output of the UV lamps in the fresh-air units was found to be partially covering coils. All were quite low on energy, at 10 to 20 mw per square centimeter at 10 in. The lamps were not the long, high-output type specified to make certain the deep-cooling coils in the 100-percent outside-air units stayed clean.

The occupants reported poor housekeeping, which would increase the level of soiling and allergenic material in the carpeting. Fungal spores are expected to remain inactive as long as the humidity continues to be maintained below 60 to 70 percent relative humidity, with control via the fresh-air units. Nonetheless, airborne-allergen levels probably will increase from material raised by normal occupant activities, such as walking and moving files.

Fortunately, these problems were identified early enough for corrective action to be taken to avoid irreversible IEQ deterioration. To date, only four of the more than 200 occupants have complained of allergy symptoms. The project team will be discussing fixes for each problem, as well as changes in maintenance responsibility and replacement of the 15-year-old built-up roof. Because both tenant and landlord feel a budget for the roof replacement is not available, third-party financing of a polyurethane foam roof is being proposed. The roof would provide extreme wind resistance, leak protection, and sufficient energy conservation. Ultimately, the FDEP would like to seek Leadership in Energy and Environmental Design for Existing Buildings (LEED-EB) green certification for its office building.

first costs in a leasing arrangement because verification costs themselves generally are viewed as a burden.

The occupants have not been surveyed to judge their satisfaction with the new building, and systems verification beyond the initial commissioning has not been undertaken. Neither of these important provisions was included in the ITN.

Humidity and comfort conditions were measured shortly after the project was completed (figures 5 and 6). Although humidity sometimes drifted above the desired maximum, conditions remained in the comfort zone 81 percent of the time during the test period. Keeping peak humidity levels at no higher than 70-percent relative humidity and having no less than 80 percent of readings in the comfort zone was defined as minimally acceptable by the building owner.

Building-operation costs fall unevenly on tenants, managers, and owners, depending on lease agreements and motivation. On the other hand, environmental quality (EQ) powerfully affects tenant productivity, health costs, and absenteeism through thermal comfort, allergen control, moisture control, outside-air levels, lighting, etc. Building productivity often suffers as limited building-operation control allows EQ to deteriorate. No one makes the connection until a critical problem, such as visible mold growth coupled with severe illness, arises.

Tenants seldom have the ability to improve, track, or control EQ and largely are unaware of these connections or their controllable costs. The amazing fact is that with recent advances in HVAC, energy-efficiency, lighting, and design techniques, costs on both sides can be reduced while EQ is improved. Buildings in which EQ is improved, such as the one in this article, are pleasant, productive, and healthy workplaces with a significant long-term value proposition for tenants, managers, and owners.

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