USING FORCED VENTILATION TO MITIGATE MOLD GROWTH IN EXISTING MULTI-FAMILY HOUSING

Christopher Decareau AIA, HVAC-R[1]

[1] *Senior Project Manager, Simpson Gumpertz & Heger Inc., The Landmark @ One Market #600, San Francisco, California, 94105 USA*

ABSTRACT

Increasing emphasis on energy-efficiency has many jurisdictions enacting stricter energy codes. Yet, these same "green building" codes typically do not adequately address ventilation when a building envelope is designed to both minimize infiltration/exfiltration and maximize thermal efficiency.

Our company investigated an apartment complex in Southern California, U.S.A. that was designed 25% more thermally efficient than required by State Code. Within months of occupancy, the first complaints of biological growth at windows and closets occurred. It appeared that the combination of occupancy and the tight building envelope does not permit dilution of interior humidity.

We conducted multi-unit blower door tests to find the infiltration rate. We used EnergyPlus by US Department of Energy to simulate the interior environment and to model different forced ventilation scenarios to determine the effects on reduction of humidity levels. The simulations predicted optimal forced ventilation of 15 to 20 CFM per person. We installed computer-controlled, sensible and latent heat generating devices in two mockup units. The result showed marked differences between the repaired and unrepaired units. This paper will focus on the computer modeling, in-situ testing, and recommendations for practitioners regarding humidity control in multi-family housing.

KEYWORDS

Mold, ventilation, humidity, infiltration, thermal efficiency, blower door

BACKGROUND

The subject property[2], built in 2001, is a 7 story, 350 unit complex located in coastal Southern California, U.S.A. The buildings are constructed with a concrete structural frame. There are 7 different unit plan types that range from around 600 to 1500 square feet. All unit types have common walls constructed of poured-in-place concrete with interior metal stud walls. The exterior-facing walls are typically metal stud framed walls with cement plaster on the outside and paper-faced gypsum wallboard (GWB) on the interior. The sliding glass doors (SGDs) and windows are dual-glazed in aluminum frames; the entry doors are made of hollow steel. According to the drawings, the windows are flashed with self-adhering membrane. The corridor is open to the exterior.

---

[2] In respect to developer and property owner, the building's name and unique identifying characteristics are kept confidential.

The units are heated and cooled by a plenum mounted fan-coil unit with a remote condenser unit located on the balcony decks. The air path runs in this order: fan, heating coil, cooling coil, and insulated ducts. Heating capacity ranges from 18,400 to 31,600 Btuh, while cooling capacity is from 1.5 to 2.5 tons. Other conditions noted are that there is no provision for independent dehumidification in the equipment or controls, the bathroom fans are connected ("slaved") to the bathroom lights, and the kitchen stove hood has a recirculating fan.

PROBLEM

Excessive biological growth, fungi such as mold and mildew, was reported in two of the unit types. We observed its presence in closets, at windows and around SGDs. Both occupant lifestyle and the building construction contributed to excessive interior humidity conditions. We observed visible biological growth in over 14 units during our intitial investigation. However, there were no visual indications of water leakage through walls, windows, or SGDs. Approximately 50% of occupants kept windows closed most of the time, of which about 33% had biological growth. About 33% of the units had disabled bathroom exhaust fans, of which about 20% had biological growth.

TESTING

Simpson Gumpertz & Heger Inc. (SGH) conducted a series of fan pressurization tests on some units in general accordance with ASHRAE Standard 119 (1988). The data allowed us to characterize the tightness of the building envelope. Additional information in the standard also allows evaluation of natural ventilation through infiltration.

However, the ASHRAE standard is written for testing single-family, detached structures. We modified the standard procedures for our tests because there is currently no standard for testing multi-family, attached structures. The modified test allows us to differentiate infiltration air coming from adjacent units versus the exterior envelope. Our tests balanced the pressurization of all units adjacent to the test unit. For example, we balanced the 3 units on the floor above, the units to each side, and the 3 units on the floor below the target unit. Consequently, little or no differential pressure existed between the test unit and these adjacent units. We therefore recorded the air infiltration through the outside walls and not the inter-unit air leakage. We also operated both the bathroom fan and the clothes dryer during pressurization tests and recorded the pressure differentials.

The exterior envelope is rated ASHRAE's Leakage Class C and D. Test results show that at a standard pressure difference of 4 Pascals (Pa), the units have approximately 18 in^2 to 37 in^2 of leakage area. This leakage area consists of small holes, like window weeps, and cracks at windows and doors.

Airflow through the bathroom exhaust fans was inconsistent from unit to unit, though the fans are the same capacity. The exhaust is vented through a flexible metallic duct that has some elbows as well. During blower door testing, we also took measurements of interior versus exterior pressures while the bathroom fan operated. The calculated fan airflow from the tests indicated that the 70 cubic feet per minute (CFM)-rated bathroom fan draws 50 CFM.

COMPUTER ANALYSIS

SGH used an energy modeling software program called “EnergyPlus” (Version 1.0.1.042). The program can simulate the heat gains and losses of a single room or an entire building along with the performance of the mechanical systems that condition the spaces for an entire year. The program inputs include typical yearly outdoor weather reported on an hourly basis, interior temperature and humidity controls and set points, latent heat, air infiltration, solar heat gain, building construction and configuration, effects of fenestration, and operation of mechanical systems. We modeled only individual units for this study.

To model occupancy conditions that were reasonable, we assumed a few conditions. Occupants were either “always home” or “not home much”; shower(s) were taken every day and the bathroom exhaust fan was somewhat effective at containing and removing most of the shower moisture; conditioning set points for heating starts at 65 F at night and at 70 F during the day; cooling starts at 75 F; and any adjacent units are maintained at similar conditions (thus, common walls are adiabatic).

We did not include other specific heat and moisture generating activities such as cooking, but we included an estimate of sensible heating loads from electrical appliances and lighting. The models also assume that the occupants do not open windows on a regular basis and that units are ventilated through infiltration air.

SGH modeled all seven unit types. Each unit was modeled in at least two solar orientations. Each solar orientation was modeled at a low floor (2nd or 3rd) and at the top floor (7th). We also modeled some 5th floor units. Each model includes adjacent buildings as potential solar shading devices. In total, we modeled 38 different units. Each model was run through about 9 occupancy scenarios. In all, we modeled at least 336 simulations to determine the nature of each existing unit and potential repairs.

Additionally, we used a commercially available cooling and heating load estimate sheet to calculate the cooling equipment size for the smallest unit. We compared this calculation to the installed capacity and the EnergyPlus simulation. The design capacity for this air conditioning unit is 18,000 Btu (1.5 tons) with 600 CFM airflow. The original balancing report indicates that the fan airflow is 1.5 times that specification. The hand calculation indicates an equipment load of 14,246 Btu (1.2 tons) for peak cooling. Assuming a 55 degF discharge air temperature, which is typical for a DX cooling coil, the mechanical system needs to circulate 570 CFM of air. We scanned the EnergyPlus simulation data for the maximum cooling system heat transfer in a 20-minute calculation time step interval and calculated an hourly Btu rate. The maximum simulated load is 5,908 (0.5 tons) and the installed capacity operates a maximum of about 40% of the during the high load period.

DISCUSSION

Moisture generated by the occupants within the dwelling units caused high humidity conditions that foster excessive biological growth because the tight construction limited natural air ventilation and the DX air cooling systems were only effective at removing moisture when there was a concurrent thermal load. Essentially, occupant-generated moisture is stored within the units until removed by 1) cross-ventilation (open windows or natural infiltration), 2) mechanical ventilation (bathroom exhaust fan), 3) condensation onto the cold coil during air cooling operations, or 4) condensation onto cold surfaces, such as windows.

There is little natural outside air infiltration into the units when little differential pressure exists under existing wind and temperature differential conditions. While tight building construction helps with energy conservation, it counteracts humidity control when the outside air is able to dry the interior.

Where architects and mechanical engineers would once rely on occupants to open windows often to air out the living space, we must now assume that the convenience of air conditioning, issues of privacy, safety, and energy conservation will preclude such activity. The vent size used to calculate outdoor air is often not the same size as with safety locks engaged.

The bathroom fans are connected to long runs of high friction flexible duct and there are elbows in the duct runs that introduce additional static pressure. The bathroom fan is inadequate for effective exhaust of moisture, and it is also problematic because it is connected to the bathroom light. Many occupants disabled the fans, and others do not leave them running to purge moisture from the space because the fans are loud (3 sones).

The existing mechanical systems are only able to remove moisture when the cooling coil is active. Consequently, at critical high humidity periods during the cooling season, which typically peak during cool morning hours before sunrise, the system is unable to dehumidify. Also, this system does not have reheat capabilities. Our analysis also indicates that the cooling capacity of the DX system greatly exceeds the thermal load for most units. The effect of this over-capacity is that the cold coil operates for very short cycles.

Our analysis of potential repairs show that a minimum of 15 CFM forced ventilation per occupant, from ASHRAE 62 (2001), substantially reduces the levels of humidity within each unit type. Even with 15 CFM forced ventilation, there are brief periods over 70% relative humidity because the outdoor ventilation air is not dry enough to dilute the air. Increasing airflow per occupant over 20 CFM produces marginal results in the computer simulations.

The windows and SGDs are not thermally broken with blinds, thus the stagnant moist air next to the aluminum frame tends to condense water.

We recommended a constant volume exhaust fan to guarantee that minimum ventilation is maintained without relying on occupants to open windows. Our calculations from calibrated fan testing indicate that a 30 CFM outside air ventilation rate can be generated with 1 Pa negative pressure using existing openings through the exterior wall to provide the volume of make-up air that will be forced out through exhaust fans. Our balanced airflow measurements also indicated that over 80% of airflow caused by depressurizing the unit would be outdoor air and not unit-to-unit internal air movement. This percentage will be higher when adjacent units are operating at similar negative pressures. We did not recommend a new fan-coil unit with the heating coil downstream of the cooling coil nor the addition of a reheat coil to the existing fan-coil due to construction costs and Code issues.

MOCKUPS

In order to study the effects of the recommended repair, we had to isolate the multiple variables that different tenants could introduce. Establishing mockups in occupied units would not return reliable data because of differences in occupancy, lifestyles and schedules.

To achieve accurate data, unit occupancy had to be monitored in a controlled environment. Two units were made available. Units A and B were the same unit type, side-by-side, facing east on the fifth floor. Unit A was the control unit and was not repaired, while Unit B was the repair unit where a constant volume exhaust fan was installed. Both units were setup identically and loads were computer controlled to simulate 2 adults with an "always home" schedule. By precisely controlling and recording the unit loads and system operations, the mockup is able to directly compare the effectiveness of ventilation in Unit B.

The testing incorporates four significant factors. First, the unit's air conditioner/heater and fan were shut off so the units establish their own heat balance with the adjacent environments. Second, the sensible/latent heat generators simulate identical unit occupants by using electrical resistance sources and evaporating water. Third, bathroom use including fan operation and showering is equal for both units. And fourth, the doors to the bathroom and bedroom follow a set schedule that impacts mixing of the air in the unit.

We reinspected Unit A and B after approximately one week of operation, and found that the biological growth at Unit A's bedroom window had significantly increased. However, we did not find visible evidence of biological growth in Unit B.

Unit B data shows a close correlation to the exterior environment, but Unit A data does not have the same correlation (see Figure 1). This indicates that the constant volume ventilation in Unit B is supplying sufficient outside air to keep the dew point temperatures inside lower, even when the unit is "occupied". Our data showed Unit B dew point temperatures were 5 to 8 degF <u>below</u> the window surface temperature. Whereas, Unit A dew point temperatures are often <u>above</u> the window surface temperature. This indicates condensation occurs on Unit A's windows, predominantly in the late evening to early morning hours when the bedroom is occupied, and explains the biological growth.

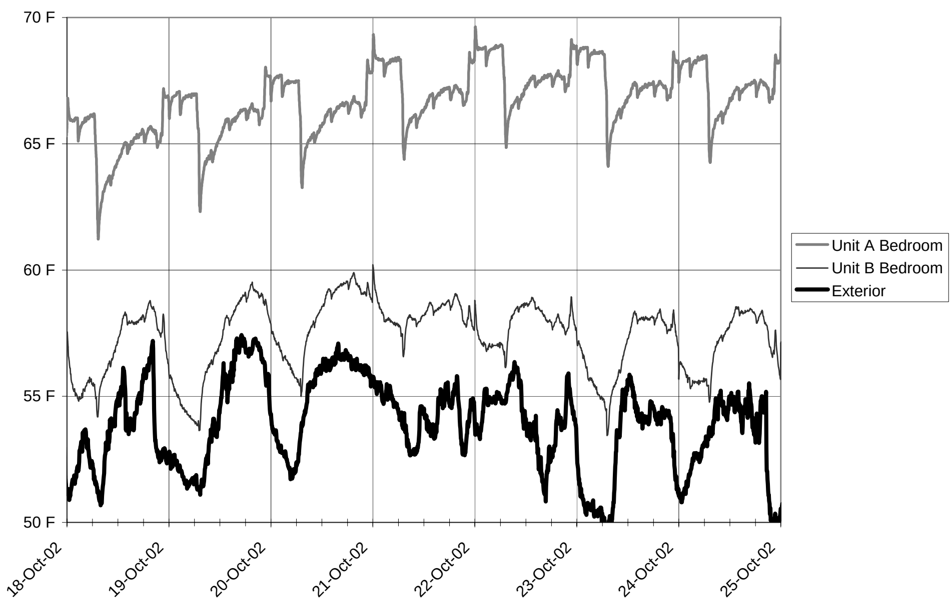

Figure 1 - Graph of Bedroom and Exterior Dew Point Temperatures

CONCLUSION

Analysis of the testing, computer modeling and mockup data conclusively demonstrates that forced ventilation and better source-control keeps interior air dew point temperatures below window and wall surface dew point temperatures. Because the forced ventilation is constantly mixing drier outside air, moisture does not build-up and stay inside the repaired unit. The repair keeps the unit free of long periods where condensation can occur and where relative humidity stays over 70%.

The primary drawback of the constant volume ventilation repair is that it relies on the outside air being drier than the interior air in order to reduce the interior relative humidity. But, if occupants create very high moisture loads, and the exterior absolute humidity is high, then the ventilation repair may not be effective. The repair shown in this study may not be appropriate for hot/humid or cool/humid climates where the RH is typically over 65% for large portions of a day or season. Another drawback is that energy use and waste increases with constant volume ventilation because it exhausts conditioned air. Finally, infiltrating outside air could contain other pollutants in it that the occupant may not desire, such as car exhaust.

RECOMMENDATIONS

The author's opinion is that design teams should address the following issues when developing multi-family housing:

1. Ventilation air must be engineered in multi-family housing. Reliance on occupants to open windows in air-conditioned units is no longer good practice. Only the opening allowed with a security lock engaged should be used for window vent calculations.

2. There will be (is) a new standard of care. The paradox of this project is that the designers delivered a code-compliant, standard-of-care residential building to the developer that became uninhabitable due to biological growth.

3. Cheap bathroom exhaust fans are not worth the money. High-efficiency, low sone, humidistat-controlled exhaust fans should be specified as a standard.

4. Cooling capacity must be designed for reasonable, not peak, loads to prevent short cycles.

References

ASHRAE Standard 62, 2001, *Ventilation for Acceptable Indoor Air Quality*, American Society Of Heating, Refrigerating And Air-Conditioning Engineers, Inc. Atlanta, Georgia, United States of America.

ASHRAE Standard 119, reaffirmed 1994, *Air Leakage Performance for Detached Single-Family Residential Buildings*, American Society Of Heating, Refrigerating And Air-Conditioning Engineers, Inc. Atlanta, Georgia, United States of America.

Energy Plus Software, 2002, The Board of Trustees of the University of Illinois and The Regents of the University of California through Ernest Orlando Lawrence Berkeley National Laboratory, http;//www.energyplus.gov.