# Causes and Effects of High Humidity in South Florida Schools

**Roger G. Morse**
*Member ASHRAE*

**Paul E. Haas**

**Dean A. Zehnter**

**ABSTRACT**

*A study was conducted in 77 schools that were experiencing mold contamination due to elevated levels of relative humidity. Temperatures and relative humidity were logged for a one week period at ten locations in each building. Occupants were interviewed to evaluate subjective determinations of temperature and humidity problems. The HVAC equipment was inspected and its conditions and operating parameters were documented. In each building, the causes of the high relative humidity were determined and corrective action was taken.*

*Several lessons were learned from this study. The causes of high relative humidity in air conditioned buildings have been defined and documented. Typically, high humidity was found to be caused by excessive ventilation air, oversized equipment, overwarm coils, and improper operation of HVAC equipment under part-load conditions. Less obvious causes, such as modulating chilled water valves, negative pressure, envelope problems, and improperly mixed outside air, were also found. Practical field measuring and surveying methods have been developed to evaluate HVAC equipment for these problems. Careful analysis of temperature and relative humidity logs was found to be a powerful and practical diagnostic tool. The physical symptoms of mold contamination caused by high humidity have been determined. In many instances these symptoms can be diagnostic of high humidity during a walk-around evaluation before measurements are even taken. Interestingly, building occupants were found to be very tolerant of high humidity levels. Complaints were registered only when there were other indoor air quality problems such as musty odors or there was visible mold present.*

## INTRODUCTION

Elevated relative humidity can be responsible for indoor air quality problems resulting from mold and other microbiological amplification. The building spaces studied had experienced relative humidity exceeding 70% for several cooling seasons and exhibited visible mold growth and musty odors. Typically visible mold growth was found in areas with little air circulation such as corners, behind furniture and behind items hanging on walls. These spaces often had a musty odor from microbiological volatile compounds (MVOCs) generated by microbiological growth. If the air is sampled in these spaces, elevated levels of mold spores and cellular debris are typically found. Occupants of such spaces are often afflicted with allergic type reactions. This problem is particularly acute in hot humid climates, such as South Florida, where ventilation air requires dehumidification to control indoor humidity and mold growth.

Buildings in hot humid environments are generally dehumidified by the air conditioning systems that are installed to cool the indoor environment. Dehumidification is accomplished by cooling air below the dew point so that moisture condenses on the cooling coil. If the temperature of air leaving the coil is low enough, and if the system runs long enough, the resulting conditioned air will be dry enough to maintain the humidity in the building at a satisfactory level. Such systems are universally controlled to maintain a set temperature rather than to control humidity. Despite this, most properly designed cooling systems in schools provide adequate humidity control.

***Roger G. Morse*** *is president,* ***Dean A. Zehnter*** *is vice president, and* ***Paul E. Haas*** *is a certified industrial hygienist at Morse Zehnter Associates in West Palm Beach, FL.*

Problems arose in the studied schools when there was inadequate control over ventilation air, or cooling loads were less than equipment capacity and the cooling coil is warmed or shut down to maintain a thermostat's set point. Under these "part load" conditions, the coil may no longer dehumidify adequately.

The study described in this paper investigated a number of situations where there were reports of elevated humidity causing indoor air quality problems.

## DESCRIPTION OF THE STUDY

This paper presents data from a continuing study of school buildings in South Florida that were investigated to determine the causes of high relative humidity. In each case, the school was investigated in response to reports by teachers and staff of indoor air quality problems and high humidity. To date, 77 schools have been investigated. Each of these schools is comprised of a number of separate buildings. Table 1 summarizes the number of buildings evaluated by type and the HVAC equipment in each type of school. In total, 495 air conditioned buildings served by 1,875 HVAC units were investigated during the study. There were four types of HVAC units encountered during the study. The most common type of unit, found in 45% of units, was a constant volume central air handling unit with supply air ducted to a number of rooms. The next most common type of equipment, at 23% of units, was small fan coil units. These consisted of a cooling coil and fan in a simple enclosure that served a single room. Many of these units were hung directly from the ceilings of classrooms. Unit ventilators were found in 16% of units. These differ from fan coils by having face and bypass damper control over supply air temperature and very long and thin outside air dampers. The cooling coils in 81% of these units were cooled by chilled water supplied by a central chilled water plant. In 16% of units, coils in the air conditioning units operated by direct expansion of a refrigerant (DX units). There were also 55 variable air volume (VAV) units that are not included in this study.

Each school was subjected to a detailed evaluation. The first step of the evaluation was to review previous reports and prepare floor plan diagrams of each building. An initial visit was made to the school to interview administrative personnel, maintenance staff, and teachers. The purpose of the interview process was to determine if there were additional complaints and to determine the extent and duration of the reported elevated humidity. A HOBO® H8 data logger was placed in each problem room, as well as in a random selection of rooms. Typically, ten loggers were installed for each school. The loggers were set to monitor temperature and relative humidity at approximately 4 minute intervals for a seven day period. In this manner, the effects of weekday and weekend temperature control cycles could be evaluated.

In each school, all large air handling units and a representative sampling of small units, such as fan coils and unit ventilators, were selected for evaluation. Each HVAC unit was subjected to an engineering evaluation to determine its condition and operational status. In each case, the unit was observed through the complete range of its normal operation, from full loads to partial loads. The fresh air, supply air, and return air paths were inspected and deficiencies were noted. Each unit was subjected to a detailed inspection and the condition and operational status of all components was noted. A detailed listing was prepared showing the repairs needed to return the unit to a state of good repair. The assessment included an evaluation of unit operation and its ability to maintain space conditions and relative humidity below 60%. This assessment considered temperature control operation, fan operation, ductwork and air distribution. Piping of chilled water or refrigerant was reviewed for valve operation and condition. The useful life of each unit was estimated. The quantity of and control over ventilation air was also assessed. This included an evaluation of the amount of ventilation air and excess ventilation. Problems that existed from excess ventilation reported included exhaust fans running during unoccupied periods, lack of automatic dampers on fresh air intakes, and improper design or operation of HVAC units. Building pressurization was evaluated to determine if the building was operating at a positive or negative pressure relative to the outside. Heat gain calculations were performed for each space and the capacity of the unit serving the space was compared to the requirement for the space. If the equipment was oversized, this problem was noted. Cost estimates were developed for the repair and/or replacement needed to return all HVAC systems in each school to good operating condition that would control humidity.

Each unit that was evaluated was categorized according to its condition. A unit was judged to require replacement if it was too worn to repair or if it would be more economical to replace than to repair (39% of units). If a unit required major repair to return it to good operating condition, it was judged as requiring "repair" (36% of units). If a unit required only minor work or adjustment to return it to good operating condition, it was judged as needing "service" (11% of units). Table 2 summarizes the HVAC condition evaluation by type of unit, and Table 3 shows the percent of each type of unit in each condition category.

The HVAC units varied in age from more than 20 years old to virtually new. Table 4 summarizes the age of the equipment evaluated during the study.

## CAUSES OF HIGH RELATIVE HUMIDITY

The cause of high humidity in each problem space was determined in the field through an engineering evaluation of the equipment serving the space and the operation of that equipment. A report was developed for each school that detailed the causes of high relative humidity in each of the measured spaces. The study found that, in most cases, elevated relative humidity was associated with either insufficient control over ventilation air or improper operation of HVAC equipment. In a small number of cases, building envelope problems, such as leaks, were the cause of humidity issues.

**Table 1. Types of Buildings and Associated HVAC Equipment**

| Buildings | | | Type of HVAC Equipment | | | | |
|---|---|---|---|---|---|---|---|
| **Type of School** | **Total Buildings** | **Buildings with HVAC** | **Air Handling Unit** | **Direct Expansion Cooling** | **Fan Coil Unit** | **Unit Ventilator** | **Total** |
| Elementary | 403 | 292 | 479 | 174 | 334 | 164 | 1,151 |
| Middle | 84 | 69 | 156 | 69 | 41 | 65 | 331 |
| High | 75 | 60 | 161 | 5 | 27 | 17 | 210 |
| Vocational | 83 | 74 | 104 | 44 | 35 | 0 | 183 |
| Totals | 645 | 495 | 900 | 292 | 437 | 246 | 1,875 |
| Percentage | | | 45% | 16% | 23% | 16% | |

**Table 2. Condition of HVAC Units**

| Type of Unit | Replace | Repair | Service | OK | No Assess | Total |
|---|---|---|---|---|---|---|
| Fan Coil Unit | 110 | 199 | 43 | 79 | 6 | 437 |
| Unit Ventilator | 81 | 66 | 68 | 16 | 15 | 246 |
| Air Handling Unit | 420 | 315 | 106 | 57 | 2 | 900 |
| Direct Expansion | 43 | 113 | 55 | 74 | 7 | 292 |
| **Total** | 654 | 693 | 272 | 226 | 30 | 1,875 |

**Table 3. Percent of Each Type HVAC in Each Condition Category**

| Type of Unit | Replace | Repair | Service | OK |
|---|---|---|---|---|
| Fan Coil Unit | 25% | 46% | 10% | 18% |
| Unit Ventilator | 33% | 27% | 28% | 7% |
| Air Handling Unit | 47% | 35% | 12% | 6% |
| Direct Expansion | 15% | 39% | 19% | 25% |
| **Total** | 35% | 37% | 16% | 12% |

**Table 4. Age of HVAC Equipment in Study**

| Age of Equipment | >20 Years | 16–20 Years | 11–15 Years | 5–10 Years | 0–4 Years |
|---|---|---|---|---|---|
| Number of Units | 570 | 193 | 869 | 185 | 55 |
| Percentage of Units | 32% | 9% | 46% | 10% | 3% |

The frequency of occurrence of each cause was tabulated and is presented in Figure 1. It was found that ventilation issues (77% of reports) were the most common cause of high relative humidity. This was followed by problems with the operation of air conditioning equipment (21%). Although the study was not directed at building envelope (walls and roof) issues, it was found that problems in this area accounted for 3% of reports.

### High Relative Humidity Due to Ventilation Issues

When the causes of high relative humidity due to ventilation issues were analyzed in greater detail (see Table 5) it was found that 56% of total reports resulted from lack of control over ventilation air during unoccupied periods. In 40% of these cases, moisture laden air infiltrated into the occupied space through open outside air dampers at night and on week-

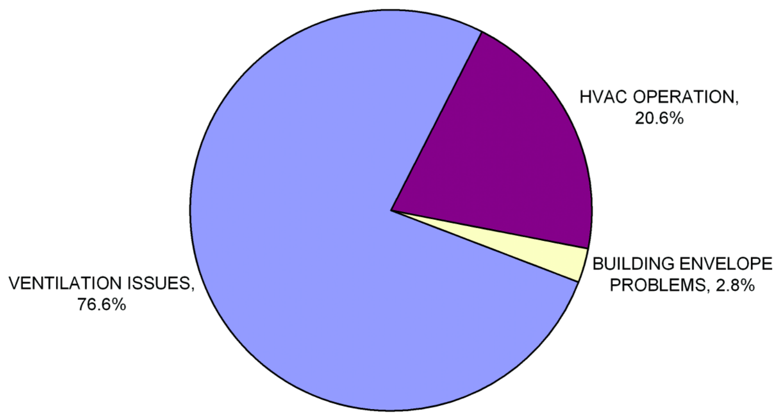


***Figure 1*** *The primary cause of high humidity in the studied schools was lack of control over ventilating or infiltrating outside air, rather than problems with the operation of equipment.*

**Table 5. High RH Causes Due to Ventilation Issues**

| Cause | Number of Occurrences | % of Occurrences |
|---|---|---|
| Outside Air Dampers Open at Night | 997 | 40% |
| Exhaust Fans Run at Night | 389 | 16% |
| Negative Pressure | 344 | 14% |
| Excessive Ventilation | 180 | 7% |
| **Total** | 1,910 | 76.6% |

ends. An even more rapid increase in humidity levels was found in 16% of cases where toilet exhaust fans were running during unoccupied periods and outside air dampers were left open. Indoor humidity increased more slowly where fans were running and outside air dampers were closed relative to those where dampers were open. It appears that, under these circumstances, air pressure inside the building becomes negative relative to that outdoors, causing infiltration through the building envelope. The building envelopes of the buildings studied apparently offered greater flow resistance to infiltrating air than did open dampers. This caused the fans to operate at a point on their fan curve where there is an increased pressure differential and less flow. The impact this situation has on infiltration of humid air into building envelope components was not a part of this study. High relative humidity was caused by infiltration due to the building operating at a negative pressure relative to outdoors in 14% of cases with ventilation issues. Outside air dampers were completely missing or stuck in an open condition in 7% of reports.

### High Relative Humidity Due to Equipment Operation

The vast majority of humidity problems (19.6% of total reports) where high relative humidity was caused by the operation of the HVAC equipment was due to oversizing of the cooling capacity of the unit. In 9% of reports (HVAC Operating Under Partial Load, 6%, and Oversized Equipment, 3%), the investigator did not report specifics aside from noting that the equipment was oversized. In 3% of instances, the capacity of the equipment was over twice the cooling load, resulting in the equipment operating at part loads under all conditions. Ten percent of reports were for situations involving chilled water where the cooling coil was too warm to adequately cool supply air to meet dehumidification requirements. This was specifically ascribed to modulating chilled water valves coils in 6% of cases. Modulating chilled water valves partially open or close as required to maintain the temperature set by a room thermostat. As such, the cooling coil may operate for prolonged periods of time with the valve in a partially closed position, starving the coil for water. This reduces the cooling capacity of the coil, resulting in a warmer coil and a higher exiting air temperature. In 6% of instances, this condition resulted in the coil producing a supply air temperature too high to adequately dehumidify. In an additional 4% of reports, a warm coil was identified as the problem, but the cause of the warm coil was not indicated. In some of these instances, the cause of the warm coil was chilled water reset; to reduce energy consumption, the temperature of the chilled water supply was being reset to a higher temperature during periods when the cooling loads were reduced. In some instances, the reset temperature was too high, resulting in a coil that was too warm to adequately cool air for humidity control. In 1% of reports, paper objects in media centers were becoming damp due to lack of dehumidification during the night. It was found that hygroscopic materials, such as paper and cardboard, would adsorb moisture at night, but not give up all the absorbed moisture during the day when HVAC equipment was

**Table 6. High RH Due to HVAC Operation**

| Cause | Number of Occurrences | % of Occurrences |
|---|---|---|
| HVAC Operating Under Partial Load | 159 | 6% |
| Oversized Equipment (>100%) | 81 | 3% |
| Modulating Chilled Water Valves | 139 | 6% |
| Coil Temp Too Warm | 100 | 4% |
| Media Center High RH at Night | 34 | 1% |
| **Total** | 513 | 20.6% |

**Table 7. High RH Causes Due to Building Envelope**

| Cause | Number of Occurrences | % of Occurrences |
|---|---|---|
| Building Envelope Problems | 69 | 2.8% |
| **Total** | 69 | 2.8% |

dehumidifying. As a result, the moisture content of these materials would ratchet up, resulting in moisture levels high enough to support mold growth.

### High Relative Humidity Due to Building Envelope

Only 3% of reports attributed high humidity to building envelope problems. The majority of these problems were due to water leaks from roofs or walls, causing wet materials and mold growth. It is likely that this category has been underreported, as the buildings were specifically being evaluated for HVAC issues. In general, the investigators reported only the most egregious of envelope problems. In some instances, the envelope problem consisted of air leaks that allowed the infiltration of outside air. Several of these were situations where the plenum above the ceiling of the occupied space was open to the outside through soffit vents. These situations sometimes also suffered from air pressure inside the building that was negative relative to outdoors.

## EQUIPMENT TYPE

Logs of relative humidity were reviewed to determine the humidity range maintained by the air conditioning unit serving that space. The humidity resulting from operation of the equipment was tabulated by type of equipment. Four humidity ranges were used: less than 50%, indicating that there was good control over relative humidity; 50-60%, indicating adequate control; 60-69%, indicating inadequate control of humidity; and greater than 70%, indicating failure to control humidity. Areas with humidity greater than 60% were counted as being "At Risk" for mold growth. These levels were based on the arithmetic mean of readings taken. It was observed during the study that periodic excursions above 60% did not typically result in mold growth as long as these periods did not extend for more than a day or two, and there was time for materials to dry out between excursions. The exception to this rule was in media centers, where absorption of moisture by paper could result in books reaching a sufficiently high moisture content to support mold growth with periodic, usually daily, excursions. As a result, media centers require evaluation differently from other school spaces. This information is summarized in Table 8.

As can be seen from the data in Table 8, fan coil units were the least successful at maintaining control over relative humidity. In all instances, the fans in these units operated continuously to provide ventilation and the cooling coil was cycled to maintain temperature. Frequently, this mode of operation results in moisture evaporating off coils when they are not being chilled, thus increasing humidity in the conditioned space. In the units studied, it was more frequently found that chilled water coils were operating at a temperature too high to adequately dehumidify, for reasons described previously. Relative humidity was logged in spaces served by 40 fan coil units. Six of these spaces had relative humidity greater than 70% and 20 had relative humidity between 60% and 69%. These 26 spaces were considered to be "At Risk" for mold growth. This means that 26 out of 40 fan coil units (65% of units) were unable to maintain relative humidity at levels low enough to prevent mold growth. Aside from the problems with coil temperatures discussed earlier, fan coils were found to have coils with insufficient depth to deal adequately with the latent loads in humid outside air. The coils in virtually all the units studied had only two or three rows of cooling tubes, as opposed to six or seven rows in coils generally used for dehumidification of outside air. It was found that 58% of unit ventilators were unable to maintain acceptable humidity units. Generally this was due to leakage in the long narrow outside air dampers found in these units. 53% of air handling units and 27% of direct expansion units were unable to maintain acceptable humidity levels in the spaces they served.

Considering the dehumidification performance of all units, it can be seen in Table 8 that relative humidity logged in spaces served by 106 units exceeded 70% and that relative humidity logged in spaces served by an additional 222 units was in the 60-69% range. This means that 328 out of the 659

Table 8. Mean Humidity Range Resulting from Operation of Each Type of Equipment

| Type of Unit | Range of RH,% | | | | | | | | | | Percent | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Units | | | | | Percent of Units | | | | | At Risk | Safe |
| | >70% | 60%–69% | 50%–60% | <50% | Total | >70% | 60%–69% | 50%–60% | <50% | | <60% RH | >60% RH |
| Fan Coil Unit | 6 | 20 | 12 | 2 | 40 | 15% | 50% | 30% | 5% | | 65% | 35% |
| Unit Ventilator | 5 | 10 | 3 | 8 | 26 | 19% | 38% | 12% | 31% | | 58% | 42% |
| Air Handling Unit | 82 | 177 | 185 | 44 | 488 | 17% | 36% | 38% | 9% | | 53% | 47% |
| Direct Expansion | 13 | 15 | 46 | 31 | 105 | 12% | 14% | 44% | 30% | | 27% | 73% |
| **Total** | 106 | 222 | 246 | 85 | 659 | 16% | 33% | 38% | 13% | | 50% | 50% |

units studied, or approximately 50%, were unable to maintain relative humidity at levels low enough to protect the conditioned spaces from mold growth.

It can be seen that direct expansion units were the most effective at controlling relative humidity in the studied spaces, followed by air handling units and unit ventilators. Fan coils were least effective in controlling relative humidity.

## EQUIPMENT AGE

Reports from occupants of the conditioned spaces were collected to gain data on subjective evaluations of HVAC equipment operation. These reports indicated whether there were no problems, or problems with temperature, humidity or indoor air quality in the conditioned space. In total, 893 reports were filed. Of these, 322 (36%) indicated that there were no problems. The remaining 64% reported problems with high or low temperatures, 307 reports (34%); high humidity, 96 reports (11%); or indoor air quality, 168 reports (19%). The most common indoor air quality problem reported was a musty smell caused by high humidity, so actually 30% of reports resulted from the lack of humidity control.

The report data were analyzed by age of the equipment to see if there was a relationship between age of the equipment and equipment problems. Figure 2 displays this data. This chart shows that older equipment is less able to maintain temperature, but that humidity and IAQ problems appear to be correlated to some other factor rather than age. Equipment inspections during the study found that the primary reasons for poor temperature control were outdated (mostly pneumatic) and worn temperature control equipment. In some instances, occupants of the building had reduced the temperature set point on a thermostat to gain more continuous operation of air conditioning equipment in an attempt to increase dehumidification. In virtually all cases, this resulted in sub-cooling of the space and increased relative humidity due to the lower temperature.

As can be seen from Figure 2, the number of complaints related to temperature control and air quality increased with increasing equipment age. There were few temperature complaints (less than 1%) about newer equipment (0-4 years old), increasing to 15.1% of reports for equipment that was over 20 years old. Humidity and IAQ also increased, but less so. IAQ complaints increased from less than 1% of reports for equipment that was 0-4 years old to 6.4% of reports for equipment that was over 20 years old. Humidity increased slightly from 0.4% to 2.8% of complaints. Interestingly, there appears to be no correlation between equipment age and its ability to perform well enough so that there are no complaints. More importantly, for purposes of this study, there is only a weak relationship between equipment age and its ability to maintain relative humidity at acceptable levels.

The data were then correlated by equipment type to see if this had a bearing on performance. Temperature complaints are more closely related to temperature controls. The data for humidity and IAQ complaints was tabulated.

As can be seen from the data in Table 9, the ability of air handling units with either chilled water or direct expansion (DX) coils to dehumidify is relatively independent of age. In this study, the equipment with DX coils was more effective at dehumidification than the equipment with chilled water coils. It is notable that direct expansion units produced fewer humidity complaints than any of the other units investigated. It was found that this occurs because direct expansion units under all operating conditions chill air sufficiently to dehumidify. This compares to chilled water coils, which, in this study, were sometimes found to be warmed by water starvation from partially closed control valves to the extent that they could not

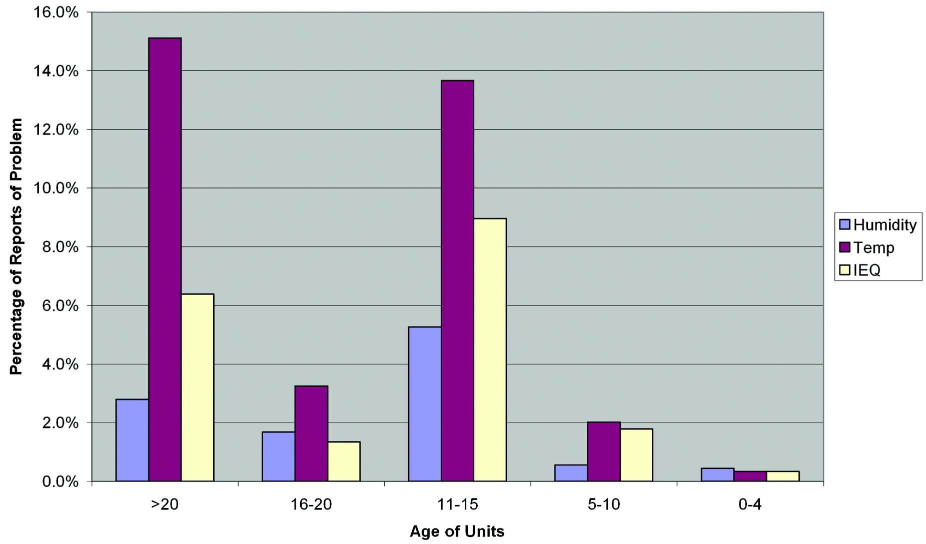


***Figure 2*** *Temperature complaints increased with age of equipment, but complaints related to RH and IAQ were relatively independent of age. This showed that older pneumatic temperature controls were less effective than newer digital controls and that even old air-conditioning equipment was able to dehumidify.*

**Table 9. Percentage of Units with Reported Problems by Age of HVAC Units**

| Type of Unit | Reported Problem | Age of Units | | | | |
|---|---|---|---|---|---|---|
| | | >20 | 16–20 | 11–15 | 5–10 | 0–4 |
| AHU-CHW | Humidity | 7% | 14% | 9% | 2% | 20% |
| | IEQ | 18% | 11% | 19% | 12% | 15% |
| | Total | 25% | 25% | 28% | 14% | 35% |
| AHU-DX | Humidity | 17% | 24% | 8% | 0% | 0% |
| | IEQ | 8% | 19% | 23% | 20% | 0% |
| | Total | 25% | 43% | 31% | 20% | 0% |
| Fan Coil | Humidity | 17% | 0% | 0% | 24% | 0% |
| | IEQ | 25% | 0% | 0% | 41% | 0% |
| | Total | 42% | 0% | 0% | 65% | 0% |
| Unit Ventilator | Humidity | 0% | 0% | 45% | 0% | 0% |
| | IEQ | 0% | 0% | 33% | 0% | 0% |
| | Total | 0% | 0% | 78% | 0% | 0% |

dehumidify adequately. The cause of the difference in dehumidification performance between chilled water equipment and direct expansion cooling equipment is one of the topics being considered in the continuation of this study. If equipment with chilled water coils was modified by the addition of face and bypass dampers, or by some other temperature control scheme that allowed the coil to remain cold, the retrofitted equipment was able to control humidity as well as equipment with DX coils. As can be seen from the data in Table 9, fan coils were less effective at maintaining humidity at acceptable levels than air handling units, and unit ventilators were very ineffective at humidity control.

## EFFECT OF SEASON

At the start of the study it was thought by some investigators that humidity problems were primarily caused by "part load" operation of air conditioning units. If this were the case, high relative humidity in the schools would be associated with times of the year when the sensible cooling load was lower. Cooling units are typically designed for the worst case conditions of temperature and humidity that generally only occur during the summer. At all other times of the year, the units are dealing with only part of the loads for which they were designed, hence "part loads." During "part loads," cooling coils either run for shorter periods of time or run at higher temperatures in order to maintain the temperature set point in the conditioned space. Either operating mode reduces the capacity for the cooling coil to dehumidify. The effect that "part load" operation has on the ability of the studied HVAC units to control relative humidity was evaluated. The percentage of units associated with high relative humidity was charted against the seasons of the year (see Table 9).

It can be seen in Figure 3 that the incidence of high humidity is greatest in the fall and summer and least in the winter and spring. This is the opposite of what would be expected if poor dehumidification during "part load" operation were the driving force behind the humidity problems experienced at the schools. Review of dry bulb temperatures during the study period (Figure 4) shows that the lowest sensible load, and hence most severe "part load" condition, occurs during the winter and spring. Analysis of Figure 3 shows that it is at this time that control of relative humidity is at its best, indicating that the governing factor lies elsewhere than "part loads." Review of the humidity ratio during the study period (Figure 5) shows a similar pattern between humidity ratio and humidity problems. The percentage of HVAC units with humidity control problems increased as the humidity ratio of the outside air increased. The frequency of humidity problems was reduced when the humidity ratio outdoors was reduced during the winter and spring. This makes it apparent that the predominant cause of high relative humidity in the studied schools was improper management of humidity in outside air introduced to the building as ventilation air or through infiltration rather than part load operation of HVAC equipment.

## SUMMARY AND DISCUSSION

Our study of elevated relative humidity in 77 South Florida schools provided the opportunity to amass a considerable amount of information about the causes of high indoor humidity in hot humid environments. There were a number of observations that came from this study.

Seventy-seven percent of relative humidity problems are caused by uncontrolled ventilation.

- The most frequent problem (40%) was air dampers left open at night, allowing humid outside air to infiltrate through the HVAC system into the building when the air conditioning system was not operating. In some cases (16%), this was exacerbated by operation of toilet room fans at night. These two problems accounted for over half of the humidity problems that were encountered.
- Imbalance between ventilation and exhaust air, causing the interior of the building to operate at a negative pressure relative to the outside, accounted for an additional 14% of the problems.
- Excessive ventilation air that exceeded the capacity of the cooling coil to dehumidify was responsible for humidity problems in 7% of instances.

Twenty-one percent of reported humidity problems were caused by improper operation of HVAC equipment. Generally the problem was that supply air was insufficiently cooled to remove sufficient moisture to control humidity. The causes of this included the following: part load operation of cooling units, modulating chilled water valves starving coils for chilled water, and oversized equipment. Additionally, media centers were a particular concern, as the books and papers would absorb and retain moisture and reach a moisture content high enough to support mold growth. This problem can be solved by dehumidification during unoccupied periods when air conditioning is shut down.

In a small number of cases (3%), building envelope problems, such as roof or wall water leaks, caused humidity problems.

Humidity problems were found to be related to the types of equipment used to condition the space in the studied buildings.

- It was discovered that 51% of fan coils and 76% of unit ventilators were unable to control humidity.
- Central station constant volume air handling units did a better job, but still did not control humidity, in 26% of spaces conditioned with units equipped with chilled water coils and in 30% of spaces conditioned by units with direct expansion coils.

Equipment age had a strong influence on the ability of the unit to maintain temperature and provide indoor air quality acceptable to the occupants.

- Complaints about temperature increased with the age of equipment. This was due to aging and outmoded temperature controls rather than to operating capabilities of the HVAC units.
- Age had little effect on humidity control. The number of complaints varied, but did not increase with increased equipment age.
- There did not appear to be a relationship between equipment age and areas with no complaints. It appears that equipment of any age can be capable of conditioning spaces well enough so there would be no complaints.

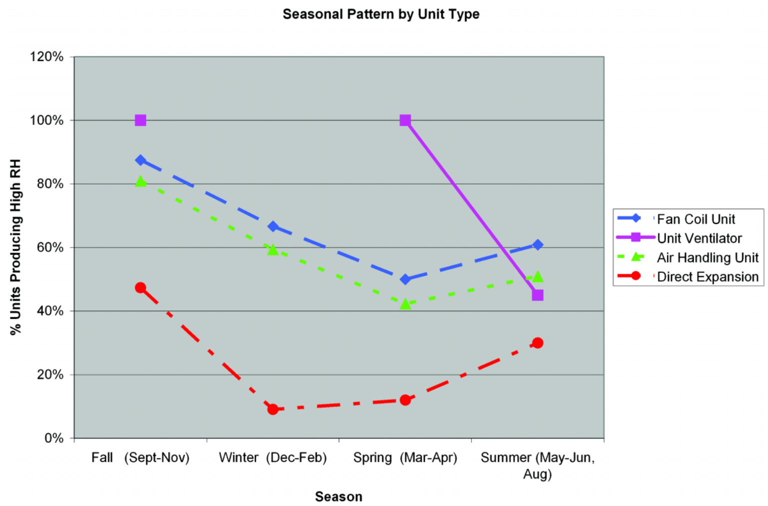


***Figure 3*** *Humidity problems were related to outdoor humidity rather than temperature, showing that the control of ventilation and infiltrating air was the primary cause of humidity problems rather than part load operation of air conditioning equipment.*

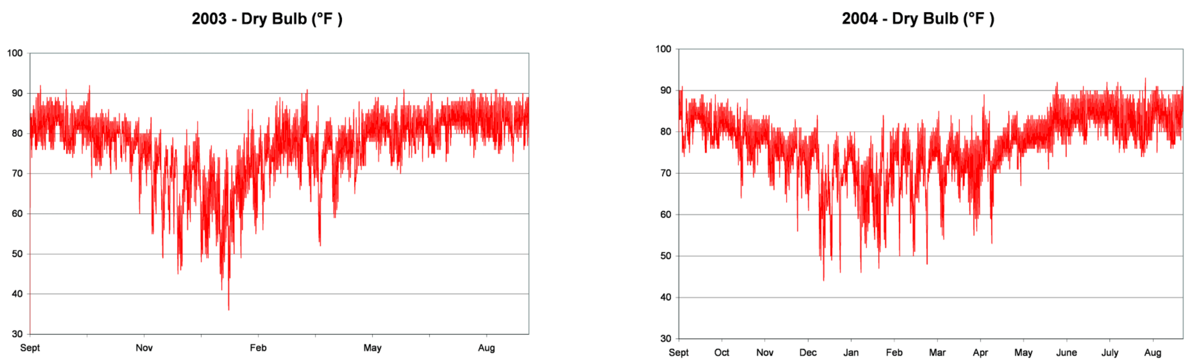


***Figure 4*** *Sensible cooling loads were reduced in the winter months causing part load conditions. However, this was not the time that humidity problems occurred in the schools. This indicates that part load operation of air-conditioning equipment was not the primary cause of the humidity problems occurring in these schools.*

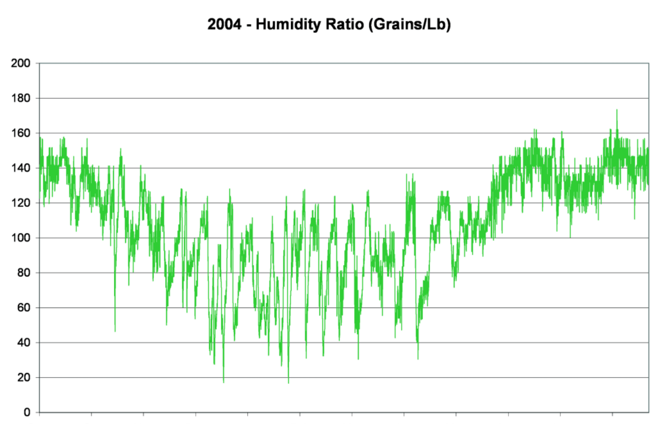


***Figure 5*** *Humidity ratio is a measure of the amount of moisture in the air. It can be seen that humidity problems occurred in the studied schools at times of high moisture content of the outside air. This indicates that the cause of humidity problems was lack of control over ventilation and infiltrating outside air.*

One goal at the start of the study was to determine whether the high relative humidity in the studied spaces resulted from part load operation of the air conditioning equipment. Temperature and relative humidity were logged during different seasons of the year. It was found that air conditioning equipment had the greatest difficulty maintaining humidity control when the moisture content (humidity ratio) of the outside air was high. In the environment studied, this occurred in the summer and fall, causing increased humidity problems at those times. There were fewer humidity problems in the winter and spring when equipment was operating at part loads but outdoor humidity was lower. This indicates that humidity problems are more related to inadequate control of humidity in ventilation air and to air infiltration than they are to part load equipment operation.

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