THE RELATIONSHIP BETWEEN HUMIDITY AND INDOOR AIR QUALITY IN SCHOOLS

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ABSTRACT
Indoor air quality differences were investigated among five schools with and five schools without active humidity control systems. The active humidity systems provided approximately 15 cfm/person of ventilation air, while the schools without the active humidity control systems averaged less than five cfm/person. The space humidity levels in varying widely without active humidity control, and rose to unacceptable levels during summer shut-down periods. Field data and modeling showed that if the schools without active humidity control systems were operated at ventilation rates above five cfm/person, >70% relative humidity levels might occur for extended time periods. This research showed the importance humidity control and adequate ventilation in schools for contaminant control, comfort, and energy savings.

INDEX TERMS
Schools, Humidity control, IAQ, Ventilation

INTRODUCTION
Schools are susceptible to developing indoor air quality problems, and the occupants -- children -- are more significantly affected than adults (EPA 1998). School facilities, by design, are densely populated, making the task of maintaining an acceptable indoor air quality more difficult than in many other types of facilities. Another consideration is that the sole purpose of a school facility is to foster the learning process, which is impacted directly by the quality of the indoor environment (Boone 1997). Bascom (1997) states that “schools are facing two epidemics: an epidemic of deteriorating facilities and an epidemic of asthma among children.” He notes that while clinicians are trying to instruct schools with environmental control measures for children with asthma, these clinicians have little information about the conditions and practical means in schools. The schools are ill equipped to receive the recommendations, assess their reasonableness, and effect the recommendation at a reasonable cost. He points to the need for a controlled indoor air quality research study so that effective indoor air quality plans can be developed and implemented.

The US General Accounting Office stated that one in five schools in the US has indoor air quality problems (GAO 1995, 1996). According to the same studies, 36% of the schools surveyed listed HVAC systems as a “less-than-adequate building feature.” Numerous researchers have indicated that poor indoor air quality significantly affects human health and productivity (Samet, 1993 and Milton, 2000).

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Controlling indoor humidity levels is a major component of good indoor air quality and an optimum-learning environment. Increased humidity levels can result in indoor microbiological growth and discomfort. Controlling indoor humidity levels while providing adequate ventilation levels can be a challenge, particularly in hot and humid climates. Methods to maintain control of indoor temperatures and humidity can dramatically differ in initial and operating costs, as well as energy usage and costs (Kosar 1998). Minimizing these costs are critical for the financially strapped school systems, while adequate control of humidity and indoor air quality is crucial for children’s health.

In order to quantify the importance of humidity control in schools and to provide at the ASHRAE recommended ventilation rates for better school indoor environments, the indoor environment in ten schools in the hot and humid climes of the Southeastern US was monitored. Five of the schools had conventional ventilation systems and five used desiccant-cooling systems for active humidity control. The schools were non-complaint schools, according to the officials of the school systems in which they were located. Additionally the project provided baseline data about the indoor environment in schools in hot and humid climates, and provided data for the development of recommendations and HVAC system designs for improved school indoor environments.

METHODS
Ten schools were selected in conjunction with the participating school systems in as closely matched pairs as possible within the constraints of the school systems and a field-based research project. Each pair included a school with a conventional HVAC system design and a school with a desiccant cooling system. Parameters that were matched as closely as possible and within the constraints of the school systems, included school size, age, location, education level, and were identified by the school officials as being non-complaint schools. The schools were located in four school systems in three Southeastern cities, each in a hot and humid climate. Although more accurate statistical correlations could be obtained if only one type of desiccant cooling system was used in the study, two different desiccant cooling systems were targeted to prevent partiality to one manufacturer. Only two systems were included to increase the statistical validity with such a small sample size.

A combination of longitudinal on-site sampling and continuous monitoring for approximately one year was conducted (Bayer et al, 2001). On-site sampling included monitoring levels of VOCs, aldehydes and ketones, bioaerosols, particles and aerosols, CO₂, CO, temperature, relative humidity, and air change rate. NO₂ was monitored in the last two project sampling periods. A continuous monitor measuring temperature, relative humidity, and CO₂ levels and a VOC diffusion tube were placed in one classroom in each school. The continuous monitoring data proved to be most useful to determine and predict the impact of excess humidity on the schools. Application of the EPA IHAT model was used to predict the impact of changing ventilation rates on the humidity levels in the schools. The DOE 2.1E simulation program was used to predict the affect of changing classroom temperature levels on energy consumption and costs.

RESULTS AND DISCUSSION
The impact of active humidity control was clearly shown in looking at the continuously collected space humidity levels with and without the desiccant-cooling systems operating. Controlling indoor humidity levels is a major component of good indoor air quality and an optimum-learning environment. Increased humidity levels can result in indoor
Sampling Date

Figure 1. Space humidity level variance with and without desiccant systems operating.

(Figure 1). When the desiccant system was not operating there were wide variations in the space humidity levels, ranging from approximately 20 to 120 grains of moisture. In contrast when the desiccant system was operating the variations in the space humidity levels were much less, ranging from approximately 60 to 100 grains of moisture.

The impact of not controlling the space humidity in schools and the development of a sick school building is shown pictorially in Figure 2 as the “Sick School Cycle”. The cycle shows the steps that are usually taken by the facility managers in an effort to try to mitigate complaints. Several of the schools participating in this research project already had embarked along this cycle. The schools were trying to control indoor humidity by lowering the ventilation rate and then lowering the space temperature to attempt to increase comfort. The lowering of the ventilation rate results in a build-up of contaminants in the space. The lowering of the temperature increases the energy usage and the costs to the school system. As the occupants began to complain about odors and sick building symptoms, the ventilation fans were being set by many of the teachers to run continuously while school is in session. This may have increased the comfort, but did not solve the problem. When school is not in session, for the day, the week, and for the summer, the ventilation system is turned off resulting in no humidity control. Then the space humidity levels, in these hot and humid climates, may rise close to or above the dewpoint for long time periods (Figure 3). These are good conditions for microbial contamination to take hold.

The ventilation rate in the schools with the desiccant cooling systems, with the desiccant systems operating, averaged 15 cfm/person, while the ventilation system in the schools with the conventional HVAC systems averaged 5 cfm/person. The impact of raising the ventilation rate in the schools with the conventional systems on the indoor humidity levels was modeled using the EPA IHAT model. The model showed that if the ventilation rates in these schools were raised to the ASHRAE recommended 15 cfm/student, the indoor humidity
New School Facility Constructed and Occupied:
Most School HVAC Systems utilize conventional packaged equipment that is not designed to process high quantities of outdoor air.

Code Compliance
Designed with 15 cfm/student of outdoor air using packaged equipment. Facilities managers quickly realize that space comfort cannot be maintained.

Non-Compliance with Code
Designers understand the limitations of conventional packaged equipment and decide to ignore ASHRAE 62 and design for 5 cfm/student and cycle the fan with the coils.

System Alteration to Achieve Comfort
Facilities managers are forced to cycle fans with the coil/heater and/or reduce the ventilation air quantity to avoid high humidity swings and uncomfortable space conditions.

During Spring and Fall when Heating/Cooling Requirements are Low, Ventilation Rates Decrease Further
The sensible load from the occupants and lights will often heat the space. The fan will not operate for long durations resulting in very low ventilation rates.

Space Contaminants from Various Sources Build and Occupants Begin to Complain of Odors or Stale Air
Contaminants come from markers, bioeffluents, pesticides, building products, aquariums and many other sources. Undesirable concentrations of CO2, VOCs etc.

Facility Managers Respond by Running Fans Continuously to Increase Ventilation Rates and Improve IAQ. Few Other Options Exist.
Occupants report that the IAQ is improved with fans operated continuously.

Humid Weather During Cooling Season-Summer Break Raises Indoor Humidity
Indoor humidity levels are in excess of 70% RH for long durations, high dewpoint results in condensation on ductwork, under carpet, etc.

Extended High Space Humidity Results in Microbial Infestation
Carpeting, books, ceiling tiles and other parts of the school allow microbial activity to proliferate.

Facility Managers Respond by Opening Outdoor Air Dampers Further to Increase Ventilation and Reduce Odors
Odors Linked to Microbial Activity Causes More Numerous and Serious Complaints of Poor IAQ
Microbial Activity Releases MVOCs Resulting in distinct “dirty socks” odor and causing respiratory problems for many occupants.

Sick School Results with High

Figure 2. Sick School Cycle
Figure 3. Impact of summer shut-down on space humidity levels in school with conventional HVAC system.

levels would rise to unacceptable levels (Figure 4). At 4 cfm/student, the average ventilation rate found in this particular conventionally ventilated school, the dewpoint is exceeded several days. When the ventilation rate is increased to 8 cfm/student, the number of days that the dewpoint is exceeded is increased, but at 15 cfm/student, the space humidity remains above the dewpoint continuously. The temperature for these three days averaged during occupied hours 78.6°F, 75.0°F, and 74.8°F September 26-28 and during the unoccupied hours 79.9°F, 77.2°F, and 77.5°F for the three days.

Figure 4. Modeled impact of changing ventilation rate on indoor humidity levels.
CONCLUSIONS AND IMPLICATIONS
Overall this research project demonstrated the importance of humidity control and adequate ventilation in schools to provide the best learning environment for the students. The schools with the active humidity systems generally had higher ventilation rates and lower pollutant rates, while the schools without the active humidity control systems had lower ventilation rates and higher pollutant rates. The schools with the conventional systems used lower ventilation rates in an attempt to unsuccessfully control indoor humidity. Model predictions of changing the ventilation rate in a school with a conventional HVAC system showed that increasing the ventilation rate in these schools to the ASHRAE recommended 15 cfm/person probably will result in unacceptable indoor humidity levels. The results from this research can be used to give guidance to school facility to managers to specify ventilation systems with active humidity control whenever possible and to investigate ways to better control humidity in the existing school buildings.

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REFERENCES