

School Conditions Will Continue to Earn Failing Grades

Jeffrey K. Sonne
Senior Research Engineer

Robin K. Vieira
Director, Buildings Research Division
Florida Solar Energy Center
Cocoa, Florida

James B. Cummings
Program Manager

ABSTRACT

This study addresses indoor air quality and general conditions problems in schools throughout the United States. Tools employed to investigate conditions include a nationwide, web-based survey, characterization of actual operating conditions in schools through field audits and diagnostic tests, and retrofits in problem schools.

Survey results found temperature to be by far the greatest comfort complaint in regular classrooms, with indoor air quality (IAQ) and then humidity being the next greatest areas of complaints. Ventilation problems were found at each of eight audited schools. These problems appear to be occurring due to a combination of factors including lack of maintenance, lack of knowledge of the systems and in some cases poor system design. Four small retrofit projects were also completed.

The results from this project indicate that without substantial funding for and prioritization of school maintenance, widespread significant school improvements will not be realized.

BACKGROUND

The issue addressed in this study is the significant indoor air quality problems in schools throughout the United States. These problems are well documented in previous work.

A 1995 report on the condition of public schools by the U.S. General Accounting Office (GAO) to members of Congress provides data on “the overall physical condition and prevalence of schools that need major repairs.” The report is based on estimates given by school officials in a national sample from over 5,000 school districts. It notes that half of all schools surveyed reported at least one unsatisfactory environmental condition involving ventilation, heating, lighting or physical security, most of these schools having multiple problems.

The report breaks down unsatisfactory or very unsatisfactory environmental conditions as shown in Table 1.

Table 1. U.S GAO Identified Unsatisfactory and Very Unsatisfactory School Environmental Conditions

Condition	% of Schools	# of Schools	# of Students
Lighting	15.6	12,200	6,682,000
Heating	18.9	15,000	7,888,000
Ventilation	27.1	21,100	11,559,000
Indoor Air Quality	19.2	15,000	8,353,000
Noise Control	28.1	21,900	11,044,000
Physical Security	24.2	18,900	10,638,000

This GAO study and a number of others have identified classroom ventilation as a major concern. For example, inadequate ventilation of elementary schools in Texas was shown in the Texas Elementary School Indoor Air Study. In this study, single day monitoring of 120 randomly selected Texas elementary school classrooms found time averaged CO₂ concentrations over 1000ppm in 66% of the classrooms and peak CO₂ concentrations of over 3000 ppm in 21% of the classrooms.

A school conditions researcher with experience working in approximately 400 northwest schools notes that his team has found that roughly 40% of all the classrooms they surveyed are under ventilated, that operation and control strategies are rarely optimized and the school personnel lack both the knowledge and resources to monitor and improve conditions.

The same GAO report referred to above estimated that over \$101 billion was needed in 1995 to restore schools to good overall condition. SchoolDude.com (a web-based educational facilities management company) reports a current deferred maintenance and adequacy conditions backlog in K-12 schools estimate of over \$250 billion.

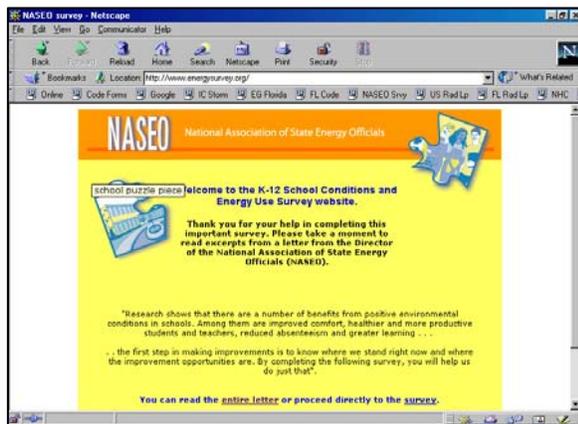
EXPERIMENTAL

School Survey Overview

A two-part, on-line survey instrument was developed. Part 1 had general questions about the school and its operation, and subjective questions concerning comfort conditions at the school. Part 2 included energy use specific questions. The survey was reviewed by six school professionals including a school energy manager, a school energy and

education specialist and a DOE school technical advisor. A number of their recommendations were implemented in the survey. Also, before the survey was made available, approval to use the survey on human subjects was obtained from the University of Central Florida Institutional Review Board.

A web site was developed for the survey (www.energysurvey.org) that includes a project introduction, instructions, a letter from NASEO, support contact information and the two part survey (Figure 1). A toll-free phone number was also



provided for support and/or to allow participants to take the survey over the phone.

Figure 1. School Conditions Survey Web Site

Participants identified their school by entering their zip code and selecting from a schools listing provided by the web site, or by entering their school information. Participants had the option of including their contact information or sending the survey back anonymously. As an incentive it was noted that if contact information was included, the school would be eligible to be selected for one or more energy improvements. While other incentives were considered (including a computer give-away), contract restrictions significantly limited what was possible.

Postcards introducing and encouraging participation in the survey were sent to over 90,000 schools. Figure 2 shows the actual postcard. In addition to the direct mailing, several other means of getting the survey out to schools were employed. A web-based educational facilities management company, SchoolDude.com, emailed its membership requesting that they participate. A number of other school groups were also contacted including school boards, maintenance organizations and a school administrators association. A number of these groups

forwarded the participation request to their members.

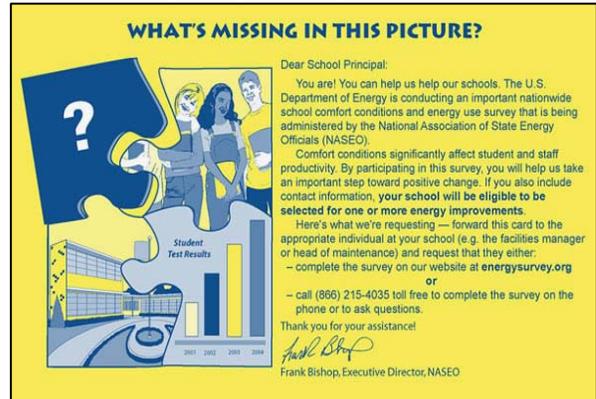


Figure 2. Post Card Sent to 90,000+ U.S. Schools Introducing the School Conditions Survey

Comfort Conditions Audits Overview

A group of 16 “problem” schools and another group of 15 “good” schools were identified from which to select the schools to be audited. Problem schools were defined as schools for which the survey respondents indicated either “many” or “chronic” complaints last year about the indoor air temperature and indoor air quality in regular classrooms. Good schools were schools for which the respondents indicated either “none” or “a few” complaints last year about the indoor air temperature, humidity and air quality in regular classrooms.

An FSEC conditions audit team was formed to perform audits in the southeast states. To perform audits in other parts of the country, five firms and organizations were originally contacted. Each of these groups had been recommended by a nationally recognized building science expert and were further verified to be experienced in conducting school conditions audits. Three firms/organizations were finally selected for the project. The FSEC team conducted three audits (in Florida and Texas), a northwest based team conducted three audits (in Oregon and Washington), a Midwest team conducted one audit (in Minnesota) and a northeast team conducted one audit (in New York) for a total of eight. Figure 3 shows the locations of the audited schools.

While it was intended that all audited schools be selected from the original list obtained from the school survey, there was considerable difficulty in obtaining cooperation from these schools and in the end, only two of the eight audited schools came from

the survey.

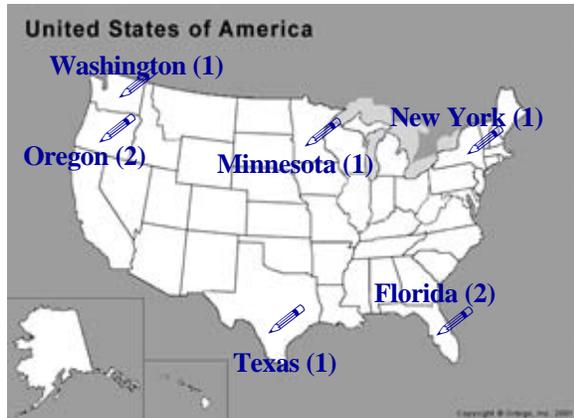


Figure 3. Locations of Audited Schools

One audit incident provides an example of the generally poor level of cooperation experienced in working with project schools. The Midwest audit team was not able to secure cooperation from any of the originally surveyed schools, so they approached schools in their area that they were aware of that had conditions problems consistent with those targeted for the study. After several attempts at locating a school, they were given permission to audit a Minnesota school from the school's principal. However, the school superintendent found out about the audit while it was in progress and asked the audit team to leave immediately. Some useful data had already been collected, but the audit could not be fully completed.

Conditions Audits Process

Audits were either scheduled through the original school survey contacts or by an audit team contacting other schools known to have conditions issues appropriate for this study. Audits generally took 1½ to 2 days and included staff interviews, a visual inspection of the school building and a number of tests designed to determine conditions in the school and identify causes of any existing conditions problems.

The tests performed typically included most or all of the following:

- zone pressure mapping (measuring pressure differences between different areas in the school and between the school building and outdoors)
- a blower door building airtightness test
- tracer gas decay ventilation rate test (designed to test how much outside air is brought into the building under normal operating conditions)
- sampling and monitoring of indoor conditions (typically including temperature, relative humidity and CO₂ measurements).



Figure 4. Tracer Gas Ventilation Rate Testing at a Florida School

Retrofits Overview

Retrofit opportunities were pursued at each audited school based on expected retrofit cost, funds availability and expected school cooperation. It was only possible to provide part of the total retrofit cost at each school, so either a partial retrofit was planned or the school added some funds to those provided through this project.

A total of four retrofit projects were completed. One additional small-scale retrofit was attempted with a Florida school recently audited for a separate project via the Florida Department of Education. A preliminary meeting was held during which it was determined that the school would be good fit for the project, and a retrofit assistance offer was made to the school. However, mainly due to three of the hurricanes that impacted Florida this year, it was not possible to work out details with the school within the project time constraints.

School cooperation was again an issue during the retrofits. In one case, a school agreed to begin retrofit work, but did not actually start the retrofit process, and in another case, after a first retrofit change out was made, other recommendations were not implemented. In general, as in the initial audit process, there were difficulties in getting timely responses and consistent participation.

RESULTS AND DISCUSSION

Survey Results

Most responses were directly on-line, with a few obtained by phone.

There were 239 total respondents (0.25% response rate). There was at least one response from each of 46 states. However, only 48 of the 239 respondents provided energy bill information. Therefore, some of the questions that were attempts to substantiate differences in energy use were not useful. A 1996 Florida survey which included pressure from the Florida Department of Education had a significantly higher return rate and found a number of significant factors that could explain differences in energy use. Those factors had been included in the on-line national survey. In retrospect, without the teeth of each state’s educational department director, the survey should have just focused on the comfort conditions and have been kept shorter.

School characteristics

The mean average enrollment was 504 students with an average daily attendance of 462 and student classroom stations of 396. The mean average enclosed area was 85,000 square feet with a median of 54,000 square feet. On average there were 30 classrooms and 54 employees.

The average age of the oldest school building (in a school district) was 49 years, and 77% of respondents indicated that the majority of the schools were over 20 years old. The majority of schools have weekend events, community nighttime events and non-academic summer events. Classes were in session an average of 9.5 months, with 55% of respondents classifying their school as traditional nine months and 31% as traditional plus summer, and only 1% choosing year-round. Eighty percent of respondents indicated energy was used for cooking at their schools and 98% have hot water with 55% having shower facilities. Only 13 of the 239 schools had pools; eight of them heated by gas, zero by solar and four by “other”.

The majority of schools did not have any portables; however, 16% had three or more portables. Over eighty percent of respondents indicated that all classrooms were of a traditional type with its own door and walls up to the ceiling. Forty-two percent of respondents indicated their school was a single multi-wing building as opposed to single rectangular building (35%) or multi-building (23.5 %). One-story schools represented 57% of the surveyed schools.

About 75% of surveyed schools indicated that most or all of the school roof was flat as opposed to

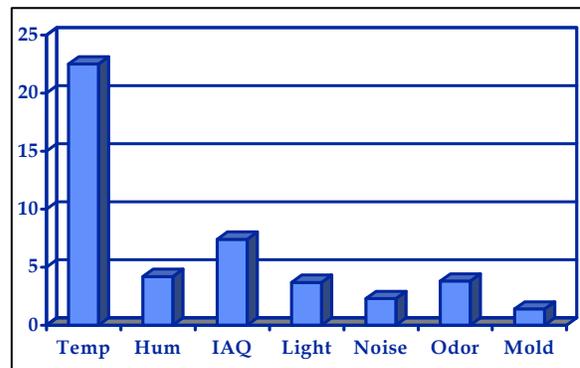
sloped. Carpeted classrooms answers were split, with 54% selecting some or none and 46% choosing most or all. Hallways were typically not carpeted while administrative areas were carpeted.

Complaints

Temperature was by far the greatest comfort complaint in regular classrooms, with 50.5% of respondents indicating “many” or “chronic” problems. Indoor air quality (IAQ) and then humidity were the next greatest areas of complaints in regular classrooms, with 20.4% and 13.1% of respondents indicating many or chronic complaints in these categories respectively.

At 22.5% of respondents, temperature was by far the greatest cause of chronic complaints, followed by IAQ, humidity and odors (see Figure 5 – top of the next page). Only 1.4% of respondents reported chronic mold problems, while 68.7% reported no mold problems. Conversely, only 2% of respondents reported no temperature problems at their school. Twenty-nine percent (29%) of respondents thought most or all the classroom temperature complaints were likely caused by not having enough thermostats or zones, while 37% % thought none of the temperature complaints were due to those factors.

There were very few temperature, humidity, indoor air quality or mold complaints indicated in portable classrooms relative to the regular classrooms. Not surprisingly, 72.5% of respondents indicated water damage in at least some regular classrooms during the “last several years,” while only



20.7% of the portable classrooms indicated the same. Administrative, cafeteria, gymnasium, auditorium and special function rooms were indicated as having fewer complaints than either regular or portable classrooms.

Figure 5. Chronic Complaints by Category

Energy Education

Thirty percent of respondents indicated there was “an active energy educational program” in place at the school, while 40% indicated there was one in place at the school district.

COMFORT CONDITIONS AUDITS RESULTS

Audit teams in the southeast (FSEC team), northeast, midwest and northwest regions completed a total of eight comfort conditions audits between October 2002 and March 2003. The eight school audits are summarized below.

Florida Elementary School #1

This school consists of one main building and a number of portables. Only the main building was tested. This building has about 50,000 square feet of floor space, and about 500 students plus staff occupy this building. Major spaces within the building include 30 classrooms, front office, library, courtyard, cafeteria/auditorium, and kitchen.

Reported complaints came from a number of locations throughout the facility. These complaints appear to be related to elevated humidity, moldy smells, health complaints (head aches, sickness, etc.), cold room temperatures, and general dissatisfaction with indoor conditions.

Significant audit observations included low classroom temperatures, high relative humidity levels and operations and maintenance problems (see Figure 6). Room temperatures as low as 64°F were measured during the audit visit, with the average temperature of 13 rooms measured being 68.4°F. Monitored temperature and relative humidity data from 7 classrooms during the week after the audit also showed a number of rooms with low temperatures and high RH levels. Of these, over a two day period with outdoor high temperatures of 86°F and an average dew point temperature of 68°F, temperatures in three classrooms, the cafeteria and library averaged at or below 70°F, and RH levels in one classroom, the cafeteria and library averaged above 65%. Dew point temperatures in Florida are commonly well above 70°F, so maintaining rooms at these low temperatures can create opportunity for condensation in exterior wall cavities, especially if the building operates at negative pressure.



Figure 6.
Main
Return
Grilles
Behind
Stage of

Cafetorium Blocked b/c Maintenance Staff Unaware of Their Locations

Improvement recommendations at this school included

- Adjust (reduce) bathroom exhaust fan flow rates to be consistent with the Florida Mechanical Code and ASHRAE Standard 62.1 calling for 50 cfm per stall or urinal. Reduction in the exhaust flow rates, if possible, would make it easier to achieve positive pressure in the building and likely reduce cooling energy use.
- Provide outdoor ventilation air by means of a dedicated outdoor air ventilation (DOAV) system. One of the great advantages of the DOAV is its ability to strip the high water vapor content out of the summer ventilation air prior to its entering the building or HVAC system.
- Check the airflow balance in the kitchen. When the kitchen exhaust fan operates, it is desirable for the kitchen to operate at slight negative pressure with respect to (wrt) the dining area, but for the entire building (including the kitchen) to be at positive pressure wrt outdoors. The kitchen make-up air is interlocked with the exhaust fan operation. It would be desirable for the outdoor air of the kitchen AC system to also be interlocked with the exhaust fan so that the kitchen airflow balance is dependable. This can, of course, lead to humidity control problems if the OA is brought in across a cooling coil that is not sufficiently cold.
- Evaluate the leak openings in the top of the fan coil units serving the classrooms. Determine, if

possible, why they are there. Since the ceiling space is not intended to be a return plenum, it appears that these return leak openings should be sealed.

- Consider tightening the building envelope. Tightening of the building envelope would be useful for two reasons; 1) to control natural infiltration, especially during unoccupied hours, and 2) to make it easier to get the building to operate at +2 pascals or greater positive pressure. If the building were made much more airtight, then indoor humidity would remain quite low for even up to a few days (such as a weekend) with the HVAC systems turned off.
- If a DOAV system is not installed on this school, then other steps would need to be taken to bring the school humidity levels under control while achieving positive building pressure.

Florida Elementary School #2

The school consists of two main buildings, a separate gymnasium building, and several portables. Only the two main buildings were tested. Building 1 contains the front office, several facility closets (janitor, electrical, etc.), and 16 classrooms. A single bathroom is also located in each classroom. This building has approximately 28,000 square feet of floor space. Building 2 contains the kitchen, cafeteria/auditorium, art and music classrooms, custodial room, media center (library), faculty break room, and 22 classrooms (in addition to the music and art classrooms). It has approximately 48,000 square feet of floor space.

Complaints were reported throughout the facility, and appear to be related to elevated humidity, moldy smells, health complaints (head aches, sickness, etc.), and general dissatisfaction with indoor conditions. Temperature and humidity plots recorded by school district personnel indicate that many rooms have humidity conditions in the range of 60% to 75%, and some in the 85% to 100% range. Considerable testing by the school district has found only isolated incidents of mold.

Significant audit observations include high RH levels (60-70%), leaky building envelopes and several instances of low classroom temperatures. At the time of the audit, portable dehumidifier “band aids” were commonly in use in the classrooms to help control RH levels (see Figure 7).

Figure 7. A Portable Dehumidifier Used to Reduce Classroom Humidity Levels

Improvement recommendations at this school included:



- Tighten the buildings by sealing the eave vents. This will make it easier to get the buildings to operate at positive pressure, reduce the natural infiltration rate, and allow indoor humidity levels to remain below 60% for extended periods (even several days at a time) with the conditioning systems off.
- Reduce the air handler flow rates to improve their dehumidification performance.
- Adjust the outdoor air intakes to 15 cfm per person based on average occupancy. It is expected that once the buildings are tightened, the outdoor ventilation air will be sufficient to produce pressures in excess of a +2 pascal target.
- Operate the air conditioners in the fan “auto” mode during hot and humid cooling periods. The “auto” fan setting will optimize latent removal (dehumidification) performance.
- Cooling system fans can be set to fan “on” on days when the outdoor dew point temperature is say 62°F or below.
- After making changes, monitor indoor relative humidity during hot and humid weather. If reducing air handler flow rates and operating the fan in the “auto” setting when the dew point temperature is 63°F or higher does not achieve indoor humidity levels below 60% nearly all of the time, then some additional steps may be required to improve humidity control, such as the following. 1) Install dedicated outdoor air conditioning units to precondition the outdoor air. 2) Install high efficiency dehumidifiers to serve spaces which experience elevated humidity (note that dehumidifiers are, in general, inefficient means for humidity control, but high efficiency dehumidifiers operate with much

lower energy use per unit of moisture, and are much quieter than standard dehumidifiers). Humidistats can be installed to cycle these units as needed.

Texas Elementary School

The Texas elementary school consists of two main classroom buildings, separate cafeteria and gymnasium buildings and several portable units. The two main buildings total just over 50,000 square feet, and accommodate approximately 750 students.

Significant audit observations include dust accumulation, negative pressure in part of the building, low ventilation rates and musty odors (see Figure 8). A visual inspection showed dust accumulation throughout the building, especially in the ceiling space, likely due to inadequate filtration of outdoor air or outdoor air bypassing the filters. Blower door tests showed that both main buildings are very airtight (south wing ACH50 = 1.0 and north wing ACH50 = 1.5). Pressure mapping found that with all operational HVAC equipment running, the main area of the south building was operating under significant negative pressure (-8 Pa) and the north building was operating under somewhat positive pressure (+2.3 Pa).



Figure 8. Dust in Return Duct after Outside Air Intake

Tracer gas decay testing was also performed and indicated a ventilation rate of 0.47 ach or approximately 8.5 cfm per student in the south building, and an extremely low 0.10 ach or approximately 1.1 cfm per student in the north building. It was also noted that two of the nine exhaust fans on the south wing were not working, and none of the exhaust fans on the north wing were working.

Improvement recommendations for this school

included:

- Get exhaust systems operating per original design parameters.
- Install exhaust air on the janitor's closet.
- Repair bathroom fans and make sure bathrooms operate at negative pressure with respect to all adjacent spaces including the bathroom ceiling spaces. Also eliminate cases where the bathrooms are being depressurized by the adjacent mechanical rooms (which are acting as return plenums).
- Air conditioner fans should be set to "auto" to enhance the dehumidification performance of the system. However, the fans can be set to "on" for days when the outdoor dew point temperature is below 60°F, because dehumidification of the indoor air will not be a critical issue under these conditions.
- Bring outdoor air into the building to meet two objectives; 1) to produce (approximately +4 Pa) positive pressure in the building and 2) to meet the ASHRAE Standard 62 ventilation rates (15 cfm per person or slightly less using occupancy averaging).
- Provide a high level of filtration of the outdoor ventilation air to eliminate the entry of most of the fine dust that is common outdoors. The filters must have almost no bypass. Install a motorized damper on the dedicated outdoor air units so that they can be closed (to make the building tight) when not in use.
- Turn off the cooling system and all exhaust fans during nights and weekends. Exception: keep the janitor's closet exhaust fan operating continuously to control odors related to the mop bucket.
- During extended unoccupied periods (e.g., summer break), it may be necessary to run the cooling systems intermittently in order to maintain the desired humidity control.

Washington State Elementary School

The original single story brick building was built in the 1950s, with an addition of a library and 5 classroom in 1992 and a total remodel and addition in 2001/2002. Total building size is approximately 45,000 ft². During the recent remodeling, wall R-values were increased to R-19; ceilings to R-38; and window u-values to 0.60. The building has carpet throughout except a hardwood floor in the gym.

Reported complaints include sewer gas odors in one classroom and odors in the gym since the

renovation.

The most significant audit observation was a heavy odor in the gym (believed to be associated with off gassing from the curing hardwood floor finish). Tracer gas testing in the gym found that adequate outside air entering the system, but the supply air was being short circuited to the return and not properly mixing. The gym has high ceilings (30') and the CO₂ pooled in the first 10 feet above the floor, with almost no mixing. The upper portions of the gym were very well ventilated, but little of that ventilation reached floor level where people are located. The odor problem associated with the curing floor finish is at least in part due to the failure to flush the VOCs at the floor level.

almost useless in mild weather or when teachers close the doors to their rooms.



Improvement recommendations at this school included:

- Adjust the throw of the supply diffusers in the gym to obtain improved mixing and help dissipate the odor resulting from the pooling VOCs.
- Consider CO₂ ventilation controls.

Oregon Elementary School #1

The main two-story concrete block building was constructed in 1928. Floors are tile with some area carpets. Windows in the building are single glazed, metal framed, and were modified to reduce the original glazing area. There is also a smaller wood frame “portable” complex with 6 classrooms. Total building area is approximately 64,000 square feet.

Reported complaints at the school include periodic comfort issues (too hot, too cold), stuffiness and odors.

Significant audit observations during the December audit include a classroom temperature over 76°F, odors and ventilation issues (see Figure 9). Measured unit ventilator outside airflows and CO₂ measurements showed that almost all of the classrooms appear to be under ventilated for their occupancy (average outside air flows were around 150 cfm where 300 to 375 cfm were appropriate). All of the exhaust fans in the restrooms had low flows (less than 50 cfm) and one was not functioning. The “portable” unit that has been in use for at least 40 years has no reliable system for providing outside air. The system of passive stacks in the central hall provides some air exchange but is dependent on wind conditions and outdoor temperature and becomes

Figure 9. Unit Ventilators Outside Air Intakes at the Oregon Elementary School #1

The common areas of the main building including the gym, cafeteria and auditorium appear to be over ventilated for their occupancy. The main air handler serving these areas is operating at high speed and outside air set for full occupancy during the entire HVAC “occupied” time. A program to schedule operation of this system in coordination with actual use and occupancy patterns could save considerable energy. Controlling the outdoor ventilation air by means of CO2 control could provide an even more effective match between ventilation and occupancy.

One contributing factor at this school was that on-site custodial staff in the district had all been replaced in the past year, and the new staff had no historical perspective and little understanding of HVAC operation.

- Improvement recommendations for this school included:
- Adding a ventilation control strategy for the gym, cafeteria and auditorium air handlers to better match outside air with actual use and occupancy patterns. Such a strategy could potentially save significant heating cost while still maintaining adequate ventilation
- Outside air on all the unit ventilators should be adjusted and maintained to provide at least 15 cfm per occupant
- Bathroom exhaust fans should be fixed/upgraded to help contain pollutants and odors
- Active ventilation systems should be added to the wood frame portable complex, including exhaust fans in the restrooms and outside air directly to each of the six classrooms.

Oregon Elementary School #2

This Oregon elementary school is similar to the other Oregon school. The main three story concrete and brick building was constructed in 1928. Floors

are tile with some area carpets. Windows are single glazed, metal framed, and retrofitted to reduce the original glazing area. There are also three “portable” classrooms. Total building area is approximately 72,000 square feet and is used by approximately 330 students and staff.

Reported complaints at the school included stuffiness and comfort issues. One teacher reports frequent headaches, and as a result almost always keeps a window open.



There were several significant audit observations. While the average measured unit ventilator outside air flow rate was 230 cfm, within the 225 cfm and 330 cfm range of required ventilation, three classrooms were found to need maintenance. As was the case in the other audited Oregon elementary school, the common areas of the main building including the gym/cafeteria and auditorium appear to be over ventilated for their occupancy. The main air handler serving these areas is providing outside air for full occupancy during the entire daily-occupied time. Also, a urine smell was observed in two of the portable unit bathrooms.

This school is in the same district as Oregon elementary school #1, so in this case again the district custodial staff had all been replaced in the last year with new personnel who have no historical perspective and little understanding of HVAC operation.

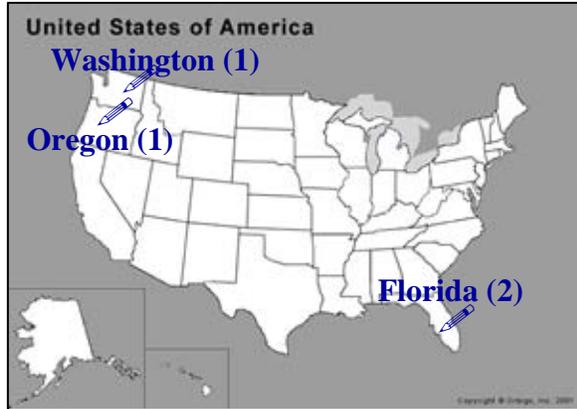
Improvement recommendations for this school included:

- Adding a control strategy for the gym/cafeteria and auditorium air handlers to better match outside air with actual use and occupancy patterns. Such a strategy could potentially save significant heating cost while still maintaining adequate ventilation
- Adjusting unit ventilators in three classrooms
- Maintenance for exhaust fans in two of the portable units.

Minnesota High School

The audit of this Minnesota high school was

abbreviated due to the fact that the audit team was forced to leave the school five hours into the audit (the principal of the school had agreed to the audit but the district supervisor found out about the audit after it was begun and did not allow it to continue).



Some observations were still made (see Figure 10). There was a general lack of maintenance of HVAC systems because of equipment replacement scheduled for the upcoming summer. In one case, an air handler drive belt was not repaired since the air handler was going to be replaced in the summer. Also, most of the unit ventilators were turned off because of the noise they generate. The audit team reported measured CO₂ levels in one classroom over 3300ppm.

Figure 10. Unit Ventilators at Minnesota School Partially Blocked by Books

New York High School

This school is an un-insulated two story brick and masonry building that was constructed in 1961. It consists of an administration wing, a gymnasium and cafeteria, a classroom wing, and an additional wing that was converted from a residence to classrooms and offices. Total floor space is about 58,000 square feet.

Significant audit observations include a number of inoperable exhaust fans, areas without thermostat control (requiring the windows to often be opened during cold weather to cool the rooms) and other controls problems. The audit report also notes that the school is poorly ventilated but spending the same amount on accidental ventilation that it would if it was air-sealed and properly ventilated.

Improvement recommendations for this school include:

- Finding and air-sealing building envelope air

leaks.

- Restoring operation of the ventilation equipment.
- Repairing the thermostats controlling the convectors in the wing formerly used as residential rooms.
- Removing the existing outdoor air reset controls from the steam to hot water exchanger and replace them with new controls.
- Replacing the light sensor controlling the outdoor lights.
- Several boiler room changes as outlined in the testing report.

SCHOOL RETROFITS

A total of four school retrofits were conducted for this study, two in the northwest and two in Florida (Figure 11). Each retrofit project is summarized below.

Figure 11. School Retrofit Locations

Florida Elementary School #1 Retrofit

At the Florida Elementary School #1, the conditions audit testing and monitoring had found that the buildings were significantly leaky, to a large extent due to vented soffits that were connected to the ceiling space above the T-bar ceiling. High humidity levels and low air temperatures were also found in a number of the classrooms. It was decided that retrofit work would concentrate on one of the two main classroom buildings. Based on the findings, main retrofit and improvement recommendations included:

- tightening the building at the eave vents
- reducing air handler flow rates
- adjusting outdoor air intakes to 15 cfm per person based on average occupancy
- operating the A/C systems in the fan “auto” mode during hot and humid periods.

After discussions with school personnel, it was decided to begin retrofit work by sealing soffit vents around the perimeter of the building and make AC equipment changes in one of the classrooms as a test case.

Although outside soffit sealing was specified, the contractor was planning on attempting to seal off an opening inside the space above the eave. This plan still would have left significant areas unsealed at a cost of approximately \$3,000 more than what was

specified finally budgeted. Figure 12 below shows the differences in the specified and planned sealing solutions.



Figure 12. Specified vs. Contractor-planned Soffit Sealing Solutions

After school personnel reported that the soffit sealing was completed, FSEC staff returned to the school to retest building airtightness. At that time however, it was noted that about 25% of the building perimeter soffit had not been sealed. The building airtightness test was still completed, and results adjusted to account for the missing length of soffit sealing. After the soffit sealing was fully completed, additional CO₂ and RH monitoring was conducted.

The building is now significantly tighter, but the other three recommended modifications to the building were never implemented. Repeated phone calls and emails recommending further retrofit work went without response. As a result of the general lack of participation, it was not possible to realize the potential benefits that the retrofits might have provided.

Florida Elementary School #2 Retrofit

At the second Florida elementary school, issues identified from the conditions audit included low classroom temperatures, high relative humidity levels and operations and maintenance problems. Room temperatures as low as 64°F were measured during the audit visit, with the average temperature of 13 rooms measured being 68.4°F. Monitored temperature and relative humidity data from 7 classrooms during the week after the audit also showed a number of rooms with low temperatures and high RH levels. Dew point temperatures in Florida are commonly well above 70°F, so maintaining rooms at these low temperatures can provide surfaces on which water can condense. Recommended retrofits included:

- A dedicated outdoor air ventilation system
- Tightening building envelope / evaluate fan coil

leak openings.



Figure 13. Air Handler in One of the Florida Elementary School #2 Classrooms

See the Florida Elementary School #2 Testing Report in Appendix B for the complete, detailed list of retrofit recommendations. Primarily due to the scope and cost of the recommended retrofits, school personnel in this case were not willing to undertake the project. However, one of the most pressing issues at this school was the apparent occurrence of mold in two classrooms. In order to resolve this situation, school personnel installed a ceiling mounted dehumidifier for the two classrooms. Pre and post dehumidifier installation conditions were monitored in the classrooms.

Relative humidity levels were found to be running between 40% and 50% most hours in these two classrooms, which is a significant drop from before the installation. While this retrofit strategy did not provide the school-wide conditions and energy benefits that the more comprehensive retrofit recommendations were designed to provide, the results do indicate that the dehumidifier is effectively controlling humidity in this area of the school. A school board engineer also later reported back that the dehumidifier was working well and the previous mold problems in these classrooms have not continued post retrofit.

Washington State Elementary School Retrofit

During the conditions audit at the Washington State Elementary School, three concerns were identified as targets for possible retrofit work. Ventilation for both the gym and large multipurpose community room was controlled by timers set for periods of occupancy. The occupancy of these areas vary greatly even within the normally occupied. Controlling ventilation based on occupancy using CO₂ sensors was proposed as a way to meet

recommended ventilation and save on heating cost by reducing periods of over ventilation. The audit also identified a mixing problem in the gym. Ventilation air was short-circuiting from the supply to the return without mixing into the occupied zone. The retrofit proposal included modifying and redirecting the supply diffusers to better ventilate the occupied area in the zone.

Actual retrofit work at the school included adding CO₂ sensors to the control circuits for the gym and multipurpose room and altering the supply diffusers in the gym to provide more mixing and minimize short-circuiting to the returns. Temperature, relative humidity and CO₂ levels in the gym and multipurpose room were monitored for over 3 weeks both pre and post retrofit. Data on natural gas consumption for the monitoring period was collected and ambient weather conditions recorded. Outside air damper positions for the gym and multipurpose room were also recorded for the pre and post monitoring periods.

While initial analysis of the collected data indicated lower energy use in the building post retrofit with normalized weather, a review of recorded damper positions suggested that the control settings may not have been properly set for implementation of the desired control strategy. The control program was reset, and school district personnel confirmed that the changes made have, in fact, improved the existing air mixing problem, and complaints about odors from off gassing of the floor finish have ended. Also, no problems were reported from going to CO₂ based ventilation control for the multipurpose room and gymnasium.

Oregon Elementary School #1 Retrofit

During the conditions audit at the Oregon Elementary School #1, three concerns were identified as targets for possible retrofit work,

Control ventilation based on occupancy as indicated by CO₂ sensors to maintain recommended ventilation and potentially save on heating cost by reducing periods of over ventilation

General maintenance was proposed for 27 unit ventilators to increase outside air to recommended levels while maintaining temperature control Add mechanical ventilation for a six classroom portable with restrooms that are presently without any mechanical ventilation.

It was anticipated that the energy savings from more efficient operation of the ventilation provided to the common core of the building (gym, cafeteria, and auditorium) would offset the added cost of providing proper ventilation to the classroom areas.

Within the limitations of the funding for this study and with additional funds provided by the school district, it was decided to address the first two items.

Maintenance performed by the district to address the unit ventilator recommendation was completed during the summer of 2003. Unit ventilators were cleaned including outside air intakes and calibrated. Dampers, controls and valves were checked, adjusted, and replaced as needed.

Ventilation of the gym, cafeteria, and large auditorium was also improved. The multizone fan system was reconfigured so that these areas could be operated as isolated zones by the operation of dampers controlled by CO₂ sensors for the cafeteria and auditorium and an occupancy sensor for the gym. Installation of ventilation controls by an outside contractor proved to be problematic. A review of the installation identified incomplete work and non-functioning parts. These problems delayed the completion of the project and its review for a number of months.

Temperature, relative humidity and CO₂ levels in the cafeteria, auditorium and selected classrooms were monitored pre and post retrofit. Maintenance on the unit ventilators in the classrooms produced a significant improvement in measured flows of outside air provided to each room with average outside air flows going from 149 cfm pre-retrofit to 356 cfm post-retrofit with 16 out of 20 rooms appearing to be adequately ventilated now versus only 2 of 20 pre retrofit. CO₂ monitoring also confirmed improved ventilation rates.

Much of the CO₂ data collected post retrofit in the cafeteria and auditorium appears corrupted making it difficult to confirm post retrofit system operation. Based on an energy audit performed by a private company as part of the state of Oregon's SB 1149 program, however, energy savings from the multizone fan system retrofit are estimated at 308 MMBtu/year with a dollar savings of \$1,997/year. This yields a simple pay back of 4.5 years on the \$9,000 investment. Note though that ventilation rates

and energy saving are unconfirmed for the cafeteria, gym and auditorium.

General Audit and Retrofit Observations

Problems were encountered in the audit stage of the project. There was significant difficulty for all audit teams to secure initial school cooperation for the conditions audits, even with clear problems present and school personnel aware that funds might be available to help pay for retrofits. The Minnesota school, where the auditors were forced to leave the school, illustrates that there is often a greater desire to hide problems than have them resolved.

Significant ventilation problems were present in each of the eight audited schools. These problems appear to be occurring due to a combination of factors including lack of maintenance, lack of knowledge of the systems, and in some cases poor system design. It also appears that since ventilation air problems are not easily identified unless comfort or other conditions issues arise, they typically go unresolved. In cases where a problem has been detected, a solution may be provided that does not resolve the root problem(s). It was also common to find that bathroom and other exhaust fans were either non functional or inadequate.

Audited schools were somewhat more open to going forward with retrofit work, but since the funding offered through this project would have only covered a small percentage of the work, none of the schools opted for any large scale retrofits. However, two of the audited schools were willing to carry out more modest projects and were also willing to provide additional funds to accomplish them.

Problems were encountered in the retrofit stage of the project. Once a retrofit was underway, it was often very difficult to get timely follow-through cooperation from the schools. Also, in two cases, although clear retrofit specifications were provided, the specifications were modified by the school or contractor. Had these modifications actually been implemented, they would have resulted in a less effective retrofit in one case and an ineffective retrofit in the other case. The northwest audit team lead noted that “even when resources are made available, successful implementation of changes in equipment and operational strategies is a hit and miss situation if not coupled with thorough commissioning including education of onsite staff.”

While the above problems limited the effectiveness of the retrofits or the ability to confirm benefits, post-retrofit monitoring and resurveying did indicate that there was still some limited success realized in several schools.

CONCLUSIONS

While the level of participation in the survey, audits and retrofits was significantly less than desired, some conclusions can still be made. These include that:

- School conditions improvements are possible. The limited results from project retrofits indicate that conditions problems can be successfully diagnosed and solved.
- Schools must have real incentive(s) to participate.
- A qualified energy analyst must be paid to supervise all work. From initial testing to verification of retrofit effectiveness, a knowledgeable professional needs to initiate, closely follow and verify all project steps.
- Schools in humid climates need to be designed with separate means of treating outside air.

The results from this project and even the lack of participation on the part of the schools indicate that without substantial funding being made available for school maintenance, widespread significant improvements will not be realized.

Even beyond funding issues, there is a matter of priorities for schools. School boards and administrators need to prioritize the health and welfare of the students, and that in turn requires better maintenance of school facilities. As seen in this project, even when problems persist and relatively low cost solutions are found, proper maintenance is not implemented. Education departments may need to provide energy/air quality specialists with decision authority in order to ensure acceptable comfort conditions for school children.

There has been a concerted effort across the country to assure that students are meeting learning objectives through standardized tests as early as elementary school. Quality building design, construction, operation, maintenance and continuing commissioning is essential if we want those students to have a healthy learning environment. States need to work on continuing education efforts for school facility managers and inspection programs/goal setting that creates incentives school administrators to create and maintain excellent buildings. The alternative will likely be an escalation of lawsuits.

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