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School HVAC

Continuous IAQ Monitoring

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Traditionally, monitoring air quality has required substantial resources and intrusion into the space of building occupants. Consequently, typical investigations have involved short-term snapshot measurements, and these exist in only a small fraction of the nation's building stock.

This article describes results of a different monitoring technique—continuous, unobtrusive monitoring of air quality at 20-second intervals in 85 rooms of eight schools in Minnesota for the 2003–2004 school year.

Hourly, daily and weekly periods of expected values of temperature, relative humidity, and carbon dioxide concentrations were measured. We observed unusual events, with and without the same regularity. In addition, unusual values of carbon monoxide concentrations and volatile organic gas concentrations were investigated.

The study represents schools that volunteered to participate in the project. Those chosen are in districts that showed more interest in IAQ issues than other schools in the state. Despite the bias toward better buildings, we observed significant problems with air quality. While the monitoring project is ongoing, remediation efforts in the schools have begun.

Project Structure

The "Continuous Indoor Air Quality Monitoring in Minnesota Schools" project is sponsored by the Legislative Commission on Minnesota Resources (LCMR). The results, published for the LCMR in "Project Summary Report, Part I"[1] by a diverse project team of multiple Minnesota companies, have implications for schools and legislatures nationwide.

About the Authors

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By design, the schools represent the variety of school ages, types and energy equipment used in Minnesota and are located across the state. Small, fixed, multisensor monitor units about the size of a programmable room thermostat were installed in August and September of 2003. Project analyses of the measurements continued through August 2004.

The monitors are continuously reporting data giving temperatures, relative humidities, carbon dioxide (CO_2) concentrations, carbon monoxide (CO) concentrations, and a total volatile organic compounds (TVOC) measurement converted into a percent value termed organic odors and gases (O&G). These data are transmitted over the Internet to a central project server that translates the data into graphs and charts for user access and viewing using secure passwords on any Internet-compatible computer (*Figure 1*).

Monthly project results were summarized into custom reports for each school. *Figure 2* provides an example of the collected data and shows the average hourly CO_2 data for five rooms during a typical winter school week. The nominal guideline of 1,000 ppm[2] is shown on the graph.

Continuous Monitoring Difference

For purposes of comparison, if a single traditional snapshot measurement of the five IAQ parameters used in this project (which traditionally has been used as a proxy for longer-term observations of a month, a year, or more until another sample is done) were equivalent to one sheet of notebook paper, continuous monitoring at 20-second intervals for only one month is the equivalent to 12, 19-volume encyclopedia sets of data.

This difference became important because the schools were found to not be static buildings. Their IAQ was continuously variable from hour-to-hour, day-to-day and week-to-week. With the benefit of hindsight using continuous monitoring, the project team observed the shortcomings of the traditional, snapshot approach to IAQ measurements. This happened because most of the schools had significant variability in IAQ results in individual rooms over time.

For example, in one school high CO_2 resulted from staff shutting off the ventilation system when occupants complained about low temperatures on cool spring days when the heating boiler was shut off. The rest of the time, this school's CO_2 was very low. Carbon monoxide events were typically episodic, occurring only for one or two days at time. Similarly, significant odors and gases events, such as refinishing of gym floors during school hours, happened only occasionally. All of these events and many more likely would have been missed by snapshot measurements.

As an illustration of the variability of IAQ conditions, using continuous monitoring data the team determined that using a traditional handheld measuring instrument to take snapshot IAQ readings in a school with regularly high CO_2 readings, the probability of catching the room with the highest CO_2 readings in the school within 30% of its monthly peak CO_2 level at the most likely time of day (2 to 3 p.m.) on a randomly selected school day was only about 0.47.

The probability of catching both the first and second highest rooms within 30% of their monthly peaks during the same hour was only 0.16. The probability of catching the top four or more rooms within 30% of their monthly peaks was less than 0.01. Corresponding probabilities in schools with more variable CO_2 levels, or for measurements taken at different times of day would be lower.

That being said, spot measurements by committed staff continue to have value. Often, they are all that is possible due to budget considerations. Insights by staff familiar with operation of the building are crucial to understanding any measurement set. Our perspective is that continuous measurements give us a qualitatively better picture of what is happening in the building.

Summary of Observations

The project analysis continued through August 2004. The results for the 2003–04 school year include:

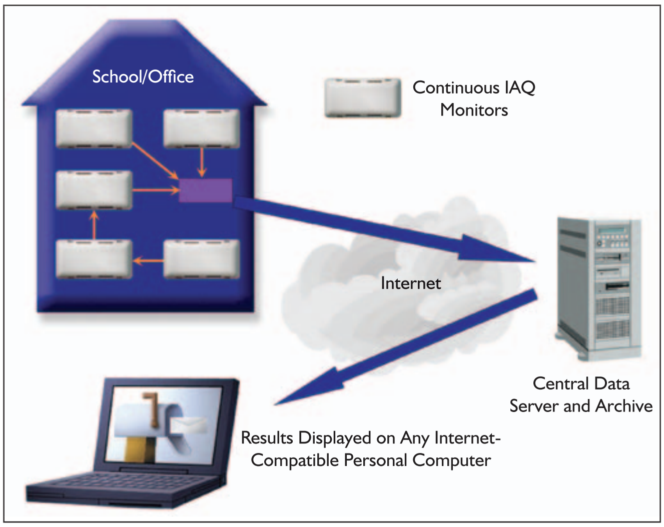

Figure 1: Continuous IAQ monitoring system.

Ventilation

• Data from the initial months of the project showed that most of the participating schools needed ventilation improvement in multiple rooms. Compared to the nominal guideline of 1,000 ppm of CO_2, many rooms saw daily peaks of 1,500, 2,000, 3,000 and occasionally 4,000 ppm when occupied during the school year. Since CO_2 is a lagging indicator of potential ventilation problems, values above the 1,000 ppm guideline indicate insufficient ventilation for the students and teachers in the classroom.[3]

• A need exists for remedial training in schools regarding the importance of ventilation and its implications. The project found that, while all the participating schools had a great interest in the welfare of their students and in IAQ issues, administration and operating staff in the schools with ventilation problems often were not knowledgeable about the importance of ventilation, how their school's ventilation system was actually performing, or when ventilation systems should be operated.

• O&G (VOC) levels can be present, but often are not coincident with or a significant part of occupant activity. They show themselves more often as a buildup when ventilation is stopped, or introduced by a special custodial procedure.

• Three schools (Schools A, B and C on *Figure 3*) consistently showed significantly better ventilation performance than the other five. Their monitored rooms rarely exceeded 1,000 ppm of CO_2 during the entire school year. These three schools recently completed major ($400,000 to $6 million per school) capital HVAC renovation projects, in compliance with a recent Minnesota Department of Education initiative to improve ventilation rates in schools. The project results show that this state initiative to improve ventilation rates is working. However, it also is resulting in significantly higher energy costs, as noted below.

• The school that recently completed the largest and most extensive ($6 million) HVAC capital renovation is reporting significantly increased energy use and costs as a result. At this school (School B in *Figure 3*), natural gas and fuel oil energy use has increased 30% (weather-adjusted Btus) as a result of its ventilation improvements. This occurred with minimal changes in other related factors such as floor space or heating requirements. With recent natural gas price increases, year-to-year increases in its heating bills have approached 100%.

The LCMR project determined that capital limitations at the time the ventilation improvement project was designed did not allow consideration of ongoing energy cost impacts of the ventilation design or operation. As a result, it appears that state efforts to improve ventilation (by the state education and health departments) and save energy (by the state departments of commerce and others) could be better coordinated.

•The other five participating schools already are taking or planning action to improve their IAQ, using project results:

· Using project data that identified specific rooms with specific ventilation problems, two of the schools (Schools G and H in *Figure 3*) already have implemented operational, equipment maintenance and controls changes that have improved their ventilation (measured in terms of the decrease in CO_2 levels above guidelines) by 94% to 96%, bringing them within industry guidelines for ventilation. Their out-of-pocket costs to achieve these improvements were only $500 and $2,300, respectively, plus internal staff time.

· Another school (School D in *Figure 3*) used project results to find a unique controls problem in a third floor air-handling unit that was limiting ventilation and adversely affecting air quality during the coldest winter months (*Figure 4*). This school insulated a duct and revised already available controls in Winter 2004–05 to fix this situation. This was also a relatively low-cost fix. This school also is considering a major capital project to upgrade its HVAC systems that will be subject to the Department of Education's ventilation improvement initiative.

· Another school (School F in *Figure 3*) with limited ventilation was planning a major ($400,000) capital upgrade of its HVAC equipment this summer. This school had the dubious distinction of showing the highest CO_2 readings (at times exceeding 4,000 ppm) of all schools in the project.

Although the upgrade has recently been postponed to Summer 2005, they plan to use the LCMR project data to certify that its investment is working. Meanwhile, in lieu of the capital project, targeted remedial actions will be necessary to address observed ventilation issues for the upcoming 2004–05 school year.

· Ventilation systems throughout the eighth school (School E on *Figure 3*) were found to be inoperable, and have been unused for some time. School staff subsequently requested and received a high-level ventilation improvement plan from the project team, and is taking initial steps to implement the plan.

• The results demonstrate that the adequacy of ventilation in multiple classrooms in multiple schools can be determined simultaneously for various time periods (real-time, hourly, daily, and monthly), and monitored remotely over the Internet. This offers a new opportunity for schools, school districts and states to monitor and certify ventilation performance in schools and other buildings on an ongoing basis. The addition of actual IAQ data to existing efforts such as the U.S. Environmental Protection Agency's "Tools for Schools" program, and Minnesota's IAQ Management Plans would further strengthen and extend those IAQ management efforts in schools.

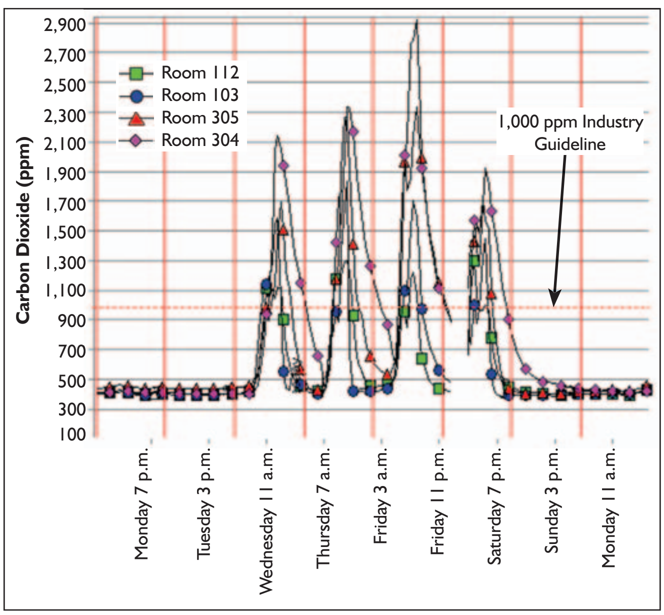

***Figure 2:** Typical weekly CO_2 pattern in LCMR School F; Winter 2003–04; Hourly average CO_2. (Red lines indicate midnight starting the day indicated.)*

<u>Temperature</u>

Project team findings from the temperature monitoring include:

• Room temperatures during the school year winter season were typically warmer than desired ranges in most of the schools. This was particularly true during unoccupied hours at night and on weekends, when no one was present to realize it was happening. The cause of the elevated temperatures was often inoperable, mislocated or mis-set thermostats. In addition, ventilation also was being used to remove excess heat on school days during the heating season. When the ventilation was shut off at night in these rooms, their temperatures increased.

• These warm temperatures in the Minnesota winter season represent a potential energy conservation opportunity. This will be examined further as the project continues. Corresponding opportunities are possible in the summer season for buildings that are air conditioned.

<u>Relative Humidity (RH)</u>

• Relative humidities in all rooms in all eight schools frequently dropped into the 10% to 20% range during the Minnesota winter. Although such low humidities have impacts on student and teacher comfort, in the absence of mechanical humidification this condition cannot be significantly mitigated.

<u>Carbon Monoxide (CO)</u>

• Carbon monoxide readings above sensor background readings of 1 to 3 ppm were generally rare during the school year. Occasionally, very low-level CO readings were observed in chemistry laboratories (from gas-fired Bunsen burners), in a home economics laboratory with natural gas cooking equipment, and in classrooms located near a busy city traffic intersection. None of these signals was large enough to be a safety concern.

• Three schools saw more significant CO signals during Spring 2004. In all three instances, CO was observed in the monitored classroom located nearest to the school's automotive and welding shops. In all three cases, the CO signals appeared during hours when the school ventilation system was shut down. In two of these cases, these periods happened during weekend hours. In one of the cases, the school ventilation system was shut down during school hours, and CO levels in the rooms nearest the source briefly approached U.S. and international safety guidelines.

• False CO readings occasionally occurred during conditions of elevated O&G signals, when independent instrumentation showed no CO was actually present. This indicates the CO sensor becomes activated by some non-CO substances. As a result, the project team developed the habit of always checking for coincident high O&G readings when a CO reading was observed.

<u>Odors & Gases (O&G)</u>

• In general, rooms and schools with the best ventilation had the lowest O&G signals, and vice versa. The results showed that monitored rooms with low CO_2 usually had low O&G levels as well. In those rooms, the ventilation system was doing a good job of venting both occupant-related (CO_2) and non-occupant related (O&G) air contaminants. This is consistent with the goals of a well-ventilated room.

• Upon investigation, most of the O&G signals were found to come from non-threatening sources such as food preparation in cafeterias, whiteboard markers, and dry hand washing stations. However, instances existed where floor refinishing, carpet glue, disinfectants and similar commercial cleaning products resulted in increased O&G signals. When they occurred, signals from these sources were often highest during unoccupied hours at night and on weekends, and decayed slowly when the school ventilation system was shut down.

• Elevated O&G signals over extended periods of time resulted in saturation of the O&G sensors in about half the rooms before the school year was completed. This condition, which occurred more frequently in rooms with limited ventilation, caused the sensors to indicate O&G readings that were higher than actual. The pattern of increasing O&G readings due to saturation was easily recognized, and periodic recalibration of the sensors resolved this condition.

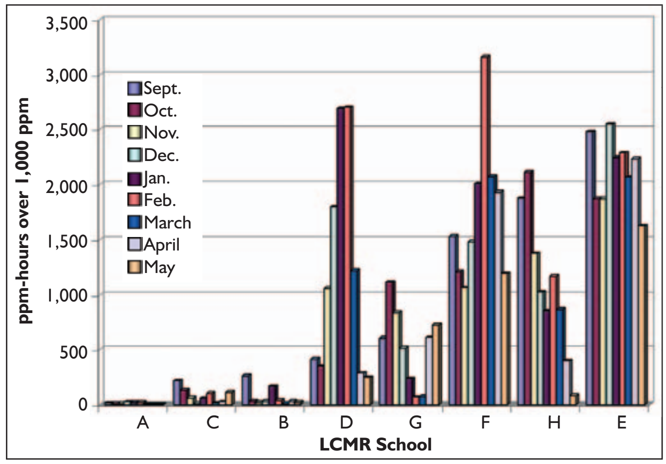

***Figure 3:** Comparing ventilation adequacy in multiple schools using the CO_2 index (2003–04 school year). Average per room per school day.*

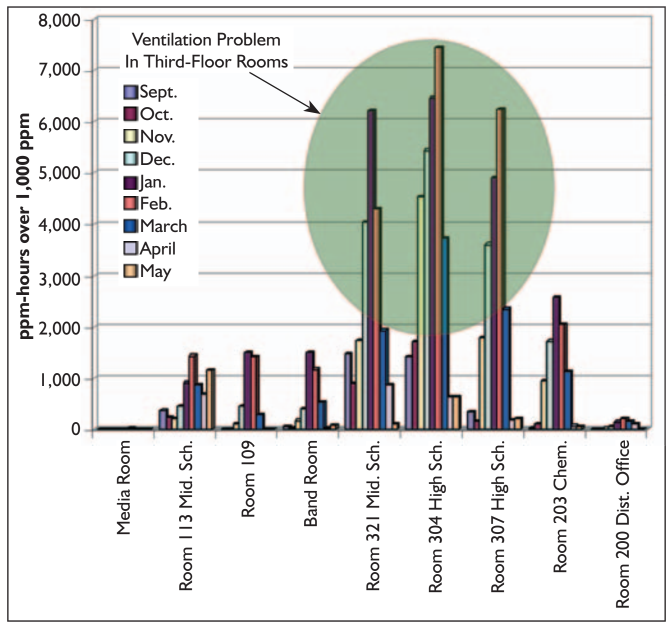

***Figure 4:** Comparative CO_2 index by room by month; LCMR project School D. Average per room per school day for the 2003–04 school year.*

Communication Issues

During the project, the team used the continuous data to develop new IAQ indices that allow quick comparison of IAQ results between schools and between individual rooms in each school.

For CO_2, the index is the area under the hourly average CO_2 curve but above the 1,000 ppm guideline on school days between the hours of 8 a.m. and 5 p.m. As such, the index is a measure of how often and how much CO_2 levels exceed the 1,000 ppm guideline.

Similar indices are used to compare school and room temperatures during various school day, school night, weekend and holiday periods, to identify additional potential energy savings from improved temperature control.

In fact, the team used the indices to discover that the recent Minnesota Department of Education initiative encouraging improvement in state schools to 15 cfm (7 L/s) per occupant was working. Schools that have invested to comply with the initiative (Schools A, B and C in *Figure 3*) clearly had the best ventilation results. These three schools rarely exceeded 1,000 ppm of CO_2 in any of their monitored rooms throughout the school year. The indices also confirmed the month-by-month improvements that other schools made to their ventilation systems during the school year (*Figure 3*).

Calculation of room-by-room indices for each school also revealed the third-floor controls problem in School D that occurred only in the third-floor air handler and only during the coldest winter months (*Figure 4*).

Similarly, the team has developed a reverse CO_2 index that quantifies the amount individual rooms and schools are below 800 ppm during occupied school day hours. This reverse index, along with corresponding O&G data for non-occupant sources of air contaminants, can help highlight which schools and rooms could possibly save energy by reducing ventilation when they are relatively unoccupied.

Because of the unique continuous monitoring being used in this project and in an identical energy conservation-focused companion project, "Schools Air Monitoring Project for Learning and Energy Efficiency (SAMPLE2)" in three additional Minnesota schools in 2003, the project team is seeing clear contrasts between the use of traditional ASHRAE ventilation rate standards (in cfm/occupant), and guidelines based on actual CO_2 concentrations.[4]

These contrasts show that use of the ventilation rate standards typically meet the CO_2 operational guidelines, but are relatively energy-intensive compared to operationally controlling ventilation based on actual, real-time CO_2 levels. This contrast is at the core of the higher energy bills seen by the project school that recently renovated its HVAC systems to conform to ASHRAE ventilation rate standards. These results support design strategies that control ventilation rates in spaces based on measures of occupancy (such as CO_2 concentrations).

Next Steps

The team is working to complete the last three summer months of IAQ data analysis. In addition, in a literature search of national research efforts regarding children and IAQ being performed as part of the project, the importance of CO_2 as a potential risk factor for airborne disease transmission has emerged as an important hypothesis in the review.[5]

Another recent study has found an association between CO_2 concentrations and student absenteeism.[6] If this hypothesis is supported by additional field testing, it will have a profound impact on school perceptions and priorities regarding the importance of air quality and the need for good ventilation.

Other project deliverables completed during 2004 included development of energy conservation recommendations for the schools, and a set of online maintenance tools for school operating personnel to help them analyze and take action on their own IAQ data. This information can be viewed on the project Web site at www.mnk12IAQEnergyuse.org.

Looking beyond the current project, the project team is working to expand the sample to a larger group of schools in multiple states. This work will possibly be combined with related studies by others that are now working to correlate the effects of IAQ on school children absenteeism and productivity. The federal No Child Left Behind (NCLB) Act of 2002 is of particular interest.

Title V, Subpart 18 of NCLB is entitled "Healthy, High Performance Schools." In that section, Congress envisioned a future where the U.S. Department of Education, the U.S. Department of Energy, the Environmental Protection Agency and state agencies would work together to help schools monitor their IAQ, improve and periodically certify how good their IAQ is on an ongoing basis, and strike an effective balance between IAQ and energy use. This project demonstrates that such a vision is realistic, achievable, and necessary.

Acknowledgments

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Project contacts at the participating schools include: Chisholm Public Schools: Jim Varichak, superintendent; Edina Public Schools: Jay Willemssen, director of business services and Mike Greiner, building supervisor; Fergus Falls Public Schools: Mark Masten, district business manager; Highland Catholic School: Bill Elmquist, business manager; Lakeville Public Schools: Stan Fredrickson, building and grounds supervisor and Ron Kes, head custodian; Mankato Public Schools: Joe Meixl, IAQ coordinator; Renville County West Public Schools: Sue Mitchell, finance supervisor and health and safety coordinator; St. Anthony Village Public Schools: Tom Foley, supervisor of buildings and grounds. The project team is grateful for their interest, help, honesty and encouragement.

References and Notes

1. Schulte, R., B. Bridges and D. Grimsrud. 2004. "Continuous Indoor Air Quality Monitoring in Minnesota Schools, Part I, IAQ Characterization for the 2003/2004 School Year." Legislative Commission on Minnesota Resources.

2. ASHRAE Standard 62-2001. Although the specific definition of the guideline is 700 ppm above outside ambient conditions, the guideline in use during construction of many of the schools and commonly used industry guideline in practice is 1,000 ppm.

3. The converse, that levels below 1,000 ppm mean that adequate ventilation is present, is not true. During the first hours of occupancy each day, all rooms have CO_2 concentrations less than 1,000 ppm, whether adequate ventilation is present or not.

4. In SAMPLE2, the team found the three project schools all used constant velocity ventilation systems operating at only 40% to 60% of the current ASHRAE standard of 15 cfm (7 L/s) of outside air per occupant. However, all monitored rooms in the three schools typically met the operational guideline of 1,000 ppm of CO_2, with few exceptions. Monitored O&G levels also were seen to be minimal. Therefore, increasing their ventilation rates to 15 cfm (7 L/s) would have energy cost implications and only marginal IAQ improvement.

5. Rudnick, S. and D. Milton. 2003. "Risk of indoor airborne infection transmission estimated from carbon dioxide concentration." *Indoor Air* 13:237–245.

6. Shendell, D.G., et al. 2004. "Associations between classroom CO_2 concentrations and student attendance in Washington and Idaho." *Indoor Air* 14:333–341.