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ABSTRACT

This article highlights indoor air quality and exposure to pollutants at school. Typical air pollutants within schools include environmental tobacco smoke, formaldehyde, volatile organic compounds, nitrogen oxides, carbon monoxide, carbon dioxide, allergens, pathogens, radon, pesticides, lead, and dust. Inadequate ventilation, inefficient filtration, and poor hygiene of air handling units are the main reasons for poor indoor air quality. The article discusses the scope of inadequate ventilation to emphasize inadequacies in the present framework of codes and practices, examining a case study done as part of a product demonstration in the Exhibit Hall of the Austin Convention Center during the 2002 USGBC conference. Carbon dioxide (CO_2) monitoring was performed in accordance with sampling guidelines from ASTM D6245, Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation. The CO_2 monitoring values indicated that in the morning, the amount of ventilation provided to occupants was only about half of the recommended minimum. This inadequacy was communicated to operators of the building's HVAC system, who increased the opening of the outdoor air dampers to provide more ventilation to the Exhibit Hall. This resulted in significant increases in the ventilation rate at the breathing zone. Overnight monitoring data revealed that the Exhibit Hall's ventilation system failed to flush the space out before occupancy the next day. (SM)

Indoor Air Quality in Schools (IAQ): The importance of Monitoring Carbon Dioxide Levels

By David Sundersingh and David W. Bearg, PE, CIH

In the developed world, ninety percent or more of our lives are dependent on the indoor air quality in homes, workplaces, and vehicles. The technological advances made by the developed world have nearly eliminated the impact of the climate on humans, and we have created artificial climates that allow us to spend enormous amounts of time indoors. With artificial, mechanized climate control we can exist almost anywhere on earth, but we are subject to the indoor air quality we create.

Generally, the quality of the indoor air is directly linked to the quality of the outdoor air, which improves as one moves farther away from urban centers and closer to large amounts of vegetation. The natural process of photosynthesis in vegetation purifies the air , as carbon dioxide is consumed by plants and oxygen is released. Unfortunately, it is not practical to have enough indoor vegetation in our buildings to adequately purify the indoor air. Therefore, the air we breathe is too often found to be of inadequate quality and/or harmfully contaminated. Invisible to the naked eye, these contaminants include living and inanimate materials such as gases, fibers, dust, and microbes.

The Concern

Exposure to more than the maximum acceptable outdoor pollutant levels as established by the National Ambient Air Quality Standards (US EPA 1997) is of particular concern for children and the elderly. Children are at a greater risk in these environments because they breathe a larger volume of air than adults in relation to their body weight. The body burden of the harmful pollutants will be much higher for small children than for adults in similar environments. Pollutants are also more often present at a child's breathing zone than at an adult's breathing zone.

For most students across the United States, exposure to the classroom-learning environment occurs five days a week. Do we understand the impact of these issues on children's health? Do we understand the relationship between air quality in learning environment and student performance? Can we empathize with the parents who may not understand the reasons for their child's fatigue or headache? Children have no control over the environment in which they learn. We provide that to them. It is our responsibility to see that the indoor air quality of our learning environments is safe. It is imperative that all children have acceptable indoor air quality!

Air Pollutants Found in Schools

Typical air pollutants found in schools include: environmental tobacco smoke, formaldehyde, volatile organic compounds, nitrogen oxides, carbon monoxide, carbon dioxide, allergens, pathogens, radon, pesticides, lead, and dust.

Commentary on IAQ and introduction to the Collaborative for High Performance Schools (CHPS), by Sara Greenwood,

You know that unbearable feeling of being trapped in a crowded elevator or bus? Not knowing how near or how far you are to your destination; breathing in hot, stuffy air and yearning for relief? Now imagine that poor air quality in a classroom of some 30 students demanding the teacher's attention. It would make it nearly impossible for students to concentrate on multiplication tables or the War of 1812.

Unfortunately, many schools across the nation are plagued by poor indoor air quality resulting from inadequate ventilation and pollutants. Not only does it create an unbearable learning environment, it also can have lasting effects on children's health. A recent study that was published in the New York Times, found that one of every four children in central Harlem has asthma, which is double the rate researchers expected to find. This is one of the highest rates ever documented for an American neighborhood.

The quality of school facilities contributes directly to the well being of students and staff. It is for this reason that the Collaborative for High Performance Schools (CHPS) was established in California to facilitate the design of high performance schools:

- Environmental tobacco smoke (ETS) is the combination of two forms of smoke from burning tobacco products: sidestream smoke, (smoke that is emitted between the puffs of a burning cigarette, pipe, or cigar), and mainstream smoke (the smoke that is exhaled by the smoker.)
- Formaldehyde is released by sources such as particleboard, plywood, textiles, adhesives, foam insulation, and pressed wood furniture, cabinets and shelving.
- Volatile organic compounds are released by sources such as commonly-used cleaners, personal care products, adhesives, paints, pesticides solvents, wood preservatives, furnishings, and copying machines.
- Nitrogen oxide is released in the process of combustion, welding, and tobacco smoke.
- Carbon monoxide is released during incomplete combustion or unvented gas, kerosene heaters, boilers, furnaces, auto, truck, and bus exhausts.
- Carbon dioxide is released in all combustion processes and human metabolic processes.
- Allergens and pathogens are released by humans, animals, the environment, draperies, carpet, dust collecting sources, cooling towers, dirty cooling coils, humidifiers, condensate drains, and ductwork, which can incubate bacteria and molds.
- Radon is released by the earth around some buildings, well water, and even some masonry blocks.
- Pesticides applied close to the building can be drawn indoors, polluting the indoor environment.
- Dust is released from the soil, fleecy surfaces, and pollen, burning wood, oil, or burning coal (US EPA Tools for Schools Action Kit 1995).

Reasons For Poor Indoor Air Quality

Inadequate ventilation, inefficient filtration, and poor hygiene of air handling units are the most documented reasons for poor indoor air quality. This article discusses only the scope of inadequate ventilation to emphasize some inadequacies in the present framework of codes and practices. These inadequacies are detrimental to delivering good indoor air quality, especially in schools. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) recommends Standard 62-1999 Ventilation for Acceptable Indoor Air Quality (1999b), as follows:

Table 1

	Application/Area	CFM* per Person
1	Classrooms	15
2	Music Rooms	15
3	Libraries	15
4	Auditoriums	15
5	Spectator Sport Areas	15
6	Playing Floors	20
7	Office Spaces	20
8	Conference Rooms	20
9	Cafeteria	20
10	Kitchen (Cooking)	20
11	Patient Rooms	20

* CFM cubic feet per minute

environments that are not only energy efficient, but also healthy, comfortable, well lit and contain the amenities needed for a quality education. CHPS has created a set of design guidelines to build environmentally sustainable schools.

Children are especially vulnerable to respiratory hazards that may cause illness because of their size, rapid development and metabolic rates, and their behavior, making it vital to monitor and protect indoor air quality in schools. Through the efforts of CHPS, supported by scientific studies like the one presented below, children in our nation's schools will hopefully begin breathing a little easier.

To learn more about the Collaborative for High Performance Schools, or to attend a CHPS Event, please go to: www.chps.net . Nearly 6.2 million children, teachers and administrators (in California alone) spend their day inside a school, both the design and interest to build a high performance school is growing.

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In reviewing these values, the question arises as to why the recommended minimum ventilation rates are less for classrooms than they are for office spaces? Perhaps, though, an even more important question is, "How many schools have been monitored to determine the actual amount of outdoor air for ventilation being provided?" Just as doubling this ventilation rate has been shown to increase office productivity by reducing short-term absenteeism (Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints; Milton, Glencross & Walters; Indoor Air 2000; 10: 212-221), the question arises as to whether this effect would occur in the classroom as well. Unfortunately, the determination of the actual ventilation rate is not yet a standard procedure in the commissioning of schools. The tide is turning in at least one district, Boston Public Schools, where monitoring is being performed to document the amount of ventilation provided.

Case Study
The following study was done as part of the product demonstration in the Exhibit Hall of the Austin Convention Center during the USGBC 2002 Green Building Conference & Expo. The carbon dioxide monitoring was performed in accordance with the sampling guidelines of ASTM D6245, Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality And Ventilation. Results of this study will be useful for projects in which CO2 monitoring is being considered.. The summary of the findings are listed below:

The monitoring of CO2 concentrations at seven floor-level locations in the Exhibit Hall during the Green Building Conference yielded the following key results:

1. During the Opening Reception in the Exhibit Hall from 5:00 to 8:00 p.m. on Tuesday, November 12, 2002, the CO2 monitoring values indicated that the amount of ventilation provided to occupants was only 8 cubic feet per minute (CFM) per person or less. This amount is only about half of the minimum of 15 CFM per person recommended in ASHRAE Standard 62-1999, Ventilation for Acceptable Indoor Air Quality.
2. The next morning, the details of this ventilation deficiency were communicated verbally to the operators of the building's HVAC system, and at noon they increased the opening of the outdoor air dampers to provide more ventilation in the Exhibit Hall.
3. AIRxpert's continual monitoring of CO2 in the Exhibit Hall documented that the new damper position resulted in a significant increase in the ventilation rate at the breathing zone. For the duration of the Conference, USGBC attendees enjoyed a healthier and more productive environment in terms of the amount of ventilation provided.
4. In regard to the LEED certification process, these results call into question the wording of IEQ Credit 1 of LEED 2.1. The section titled "Potential Technologies & Strategies" mentions, without elaboration, the integration of CO2 sensors with the Building Automation System (BAS). Fourteen of the Exhibit Hall's air handlers are equipped with CO2 sensors in the return air streams, and yet adequate ventilation was not being provided at the breathing zone. As this study indicates, the Exhibit Hall's CO2 monitoring system was not living up to its potential of being a commissioning tool to help those in charge of the building learn how to operate the HVAC systems through the benefit of feedback on their actions. By suggesting that CO2 sensors be integrated with the BAS, LEED 2.1 invites confusion between monitoring for diagnostic purposes and monitoring for energy conservation. These are two very different priorities, and they could, perhaps, be understood if a separate credit for CO2 monitoring were added in the Energy Section for Demand Controlled Ventilation (DCV) purposes.

According to IEQ Credit 1 of LEED 2.1, the CO2 monitors in the return air stream above the Exhibit Hall could ostensibly qualify for a LEED Point, even though they fail to achieve the intended amount of ventilation in the breathing zone in the space they serve. This suggests that an effort needs to be made in the ongoing revisions to LEED to clarify this distinction between the two uses of CO2 monitoring.

A related issue is that the CO2 monitors installed in the return air streams may be registering short-circuiting of the supply air that is circulating near the ceiling in this tall Exhibit Hall. If so, the diluted CO2 concentrations measured by these sensors would be incorrectly signaling that the intended ventilation at the breathing zone was being achieved. This situation suggests that, maybe, the LEED Credit for CO2 monitoring should include more specific guidance as to the appropriate number and location CO2 sampling points. (Note that ASTM D 6245-98 recommends against sampling in the return air stream for just these reason.).

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Section 2

Discussion of Monitoring Details

A graph of the monitoring results is presented in Figure 1. The locations depicted in this graph were mostly in the immediate area of the AIRxpert System's booth-one was approximately 50 feet away at the central aisle, between rows 200 and 300.

As can be observed from this data, the CO2 concentration was around 600 parts per million (PPM) at the time sampling began at around 2:00 p.m. on Tuesday, November 12, 2002. This CO2 concentration in the Exhibit Hall increased to about 730 PPM while the exhibitors prepared their booths. By 5:30 p.m., when the Opening Reception in the Exhibit Hall had been underway for 30 minutes, the CO2 concentrations had already begun to rapidly increase. This CO2 concentration increase continued throughout this event, eventually reaching values of almost 1,700 PPM by the time the event ended.

In order for the CO2 concentration in this space to increase this high over the outdoor conditions of about 400 PPM, the ventilation would have to be no more than 8 CFM of outdoor air per person. The mathematical relationship between the increase of CO2 concentrations indoors over outdoors assumes that equilibrium conditions have been achieved. In the absence of these steady-state conditions, this calculation yields an estimate of the ventilation rate that is greater than is really being provided. Consequently, this ventilation rate determination is reported as no more than 8 CFM. This value is clearly less than the ASHRAE recommended minimum of 15 CFM of outdoor air, so a ventilation deficiency exists.

After the event ended and the hall emptied out at approximately 8:00 p.m., the CO2 concentration decreased down to less than 900 PPM. For some reason this CO2 concentration began increasing again in the late evening, perhaps, because of housekeeping activities, and rose to over 1,100 PPM. Overnight the CO2 concentration slowly decreases down to almost 700 PPM. It then quickly dropped to around 630 PPM, presumably when the HVAC system came on. The CO2 concentration began increasing again as people started to enter the Hall. This overnight monitoring data reveals another aspect of the Exhibit Hall's ventilation deficiency --- the failure of the system to flush the space out before occupancy begins the next day.

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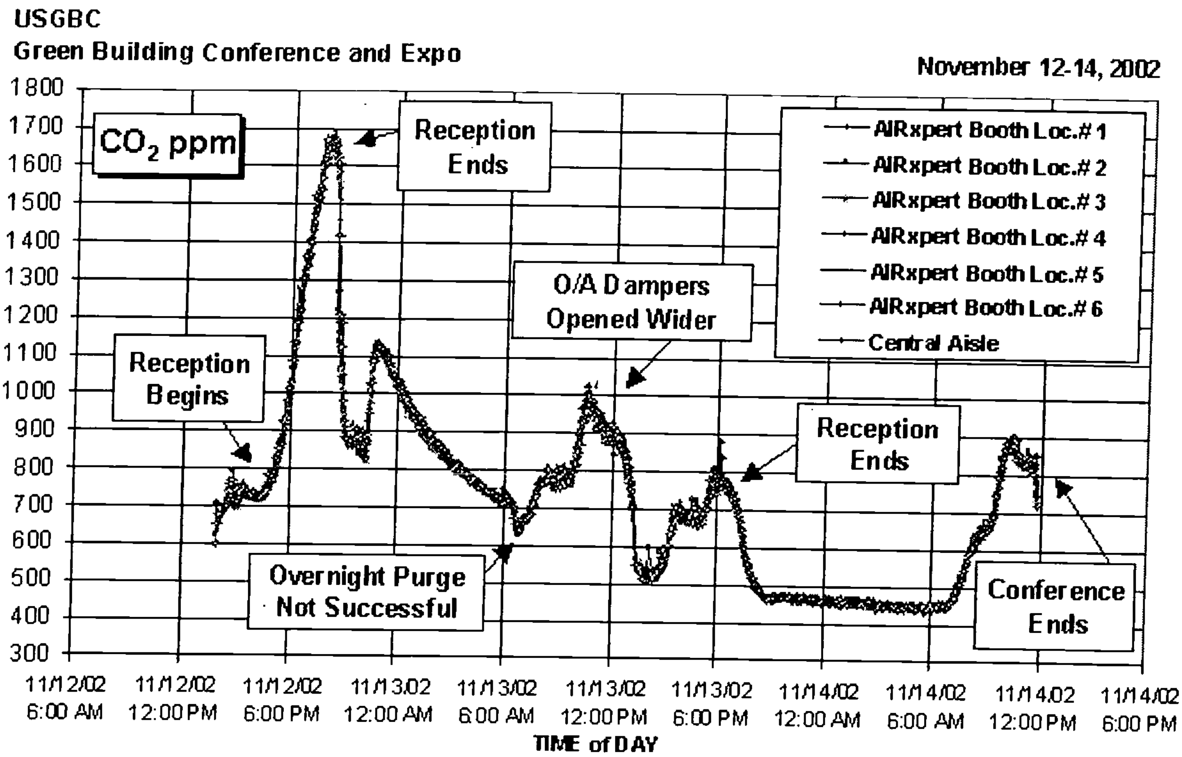

Figure 1. Graph of Monitoring Data

During the late morning of Wednesday, November 13, 2002, a meeting with the HVAC operators was arranged to communicate this information about the ventilation system's performance. As a result, the position of the outdoor air dampers was increased around noon on this day. The change in ventilation rate resulting from this damper position change was quickly observable. The CO2 concentration decreased in the Hall down to around 530 PPM by 1:30 p.m., and its peak around 6:00 p.m. was only around 800 PPM in the early evening. The Exhibit Hall closed at 7:00 p.m. that evening. The upper limit to the ventilation rate could now be calculated to be 26 CFM per person, far more conducive to keeping exhibitors and visitors awake and alert in this now healthier and more productive environment. The overnight purge was also much improved with the CO2 concentration decreasing to around 470 PPM by midnight. These monitoring results also raise questions about the appropriateness of the CO2 set point controlling the air handlers, as well as the lack of any assessment to make sure that the system was working as intended to provide a given amount of ventilation to the space's occupants.

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Performance Loss Evaluated (EPA 402-F-00-009)

An EPA document (http://www.epa.gov/iaq/schools/images/perform.pdf) gives the following findings:

- a study was done in Europe, involving 800 students from eight different schools, to measure student performance related to indoor air quality.
- The data collected indicated health symptoms and the student's ability to concentrate as related to CO2 measurements in the classroom.
- The students were given a health symptom questionnaire on which to record the data, and a computer-based program scored their ability to concentrate.
- In classrooms where CO2 levels were high (low ventilation rates),

students' scores were low and their health symptoms responses were high.

- The data also concluded that poor IAQ could reduce one's ability to perform specific mental tasks requiring concentration, calculation, or memory.
- The tests were statistically significant and tend to confirm that, with IAQ management including source control and adequate ventilation, student performance can improve.

The main source of CO_2 is from exhaled breath and the main mechanism to remove it is by ventilation. High levels of CO_2 in classrooms are an indication of low rates of ventilation. Proper monitoring of CO_2 levels can correct this to give the space a good indoor air quality.

Lessons to be Learned

Given the fact that indoor air is invisible, it is always a challenge to properly design for both quality and quantity. CO_2 levels give a good idea of the quality of indoor air. Monitoring of CO_2 levels is a necessity for knowing the quality of the indoor air in any space. When the space is an instructional space, especially when the facility houses an early childhood learning environment, the need is even greater, since young children are the most vulnerable to the effects of poor indoor air quality. Innovative mechanical engineers have always designed for higher values of CFM (cubic feet per minute) than required just to make sure that there is more ventilation than the prescribed minimum. In the 1960's it was not uncommon to design for indoor air at the rate of 30 CFM per person; this dropped to 5 CFM at the time of the first energy crisis in the early 1970's. We have over time reached 15 CFM. The question is, "Do we always have to design for the minimums? Shouldn't we be designing systems to achieve the higher values needed by children?" Innovative system designers will be proactive in utilizing higher ventilation rates to ensure that indoor air is of the highest quality. CO_2 monitoring is a must for maintaining that high quality in the classroom.

Owners, architects, and engineering professionals have benefited thus far by the efforts of the U.S. Green Building Council, which has supplied the building community with facts and figures on the benefits of "green" buildings. Since the average life of a well-designed school is between forty and sixty years, it is important that educational facility planners and educational architects assist in educating school officials and their communities on the latest in "green design," so that they will be open to design issues that address indoor air quality for the children that they ultimately serve. The next step is to establish appropriate design criteria for learning environments.

Can we aspire to improve our indoor air quality? Will the United States Green Building Council be proactive in its next round of LEED rating system criteria and give more credit and points for achieving better indoor air quality? Will the USGBC define ventilation levels and better monitoring of indoor air quality at the correct breathing zone for children? We say that we want to leave a better place for our children and future generations. Are we serious about a higher ideal of excellent indoor air quality in the future? The future is here... Are we willing to change?

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