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ABSTRACT

Asserting that the air quality inside schools is often worse than outdoor pollution, leading to various health complaints and loss of productivity, this paper details factors contributing to schools' indoor air quality. These include the design, operation, and maintenance of heating, ventilating, and air conditioning (HVAC) systems; building equipment maintenance and repair; housekeeping practices and equipment; and wind velocity. It includes recommendations on parameters within these areas which can provide optimal air quality. (Contains 15 references.) (EV)

Indoor Air Quality in Schools

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Introduction

Urban residents spend approximately 90% of their time indoors (US EPA 1996b). During their kindergarten, elementary and secondary education years, children will spend a minimum of 23% of their time inside of a school building. By comparison, they spend 5-10% of their time outdoors. Given that it is unhealthy, particularly for children and the elderly, when outdoor pollutant levels exceed the National Ambient Air Quality Standards (US EPA 1997), we become even more concerned when children and the elderly are exposed to environments where concentrations of air pollutants are 2 to 5 times higher than the maximum acceptable outdoor levels (US EPA 1995). Children are at even greater risk in these environments because they breathe a greater volume of air—and hence a greater weight of pollutants—relative to their body weights than do adults. Furthermore, when one considers that if our children spend 2 to 4 times as much time in these environments as outdoors, their exposure (equal to dose x time) to these pollutants can become quite high.

This latter exposure is occurring five days a week for many school children across the United States. According to a 1995 US General Accounting Office report entitled *School Facilities: Condition of America's Schools*, one-third of all US schools requires extensive repair or replacement. Nineteen percent report indoor air quality (IAQ) problems. The poor condition of the nation's schools contributes to serious indoor environment problems, including poor IAQ. IAQ problems are now the most common complaint made to the California Board of Education (Daisey 1998).

Public schools are particularly vulnerable to IAQ problems and less able to deal with them than other entities. Characteristics such as occupant density, pollutant sources, poor construction, building renovations, use of portable buildings, tight budgets, and difficult political climates contribute to the greater potential for schools to develop IAQ problems (Etkin 1996).

IAQ is but one component contributing to the quality of the indoor environment in schools. Indoor environmental quality is the sum of factors experienced by occupants in a building, such as temperature, humidity, ventilation, lighting, noise, cleanliness, odor, building design, materials of construction, quality of construction, maintenance, repair, building operation practices, and exposures to chemical and biological agents. Temperature, humidity, ventilation, and noise can be impacted by the HVAC system. The building design, equipment selected, and maintenance practices can influence lighting, cleanliness, and noise. Odors and exposures to chemicals and biological agents may be the result of activities being conducted in the building, poor maintenance of the HVAC system, and response to and repair of building water leaks.

A high quality indoor environment is essential for education. A poor indoor environment can have serious effects including:

- increasing the potential for long-term and short-term health problems for students and staff
- impacting the student learning environment, comfort, and attendance
- reducing productivity of teachers and staff due to discomfort, sickness and absenteeism
- accelerating the deterioration and reducing efficiency of the school physical plant and equipment
- increasing the potential that schools will have to be closed, or occupants relocated
- straining relationships among school administration, parents, and staff
- creating negative publicity that could damage a school's or administration's image and effectiveness
- creating potential liability problems

Children have little or no control over their environment while at school. It is the responsibility of teachers, parents, school administrators, facilities and maintenance personnel, and district trustees to ensure a healthy indoor environment that supports a positive learning environment.

Indicators and Impacts of IAQ Problems

Some of the most common health symptoms associated with IAQ problems (US EPA 1995) are:

- headache, fatigue, and shortness of breath
- sinus congestion, cough, and sneezing
- eye, nose, throat, and skin irritation
- dizziness and nausea

Because indoor environment quality is the result of the interaction of a number of factors controlled by complicated systems, diagnosis of problems is often complex. Further complicating the diagnosis is the fact that many of the symptoms associated with poor indoor air quality are also symptoms that are associated with colds, allergies, fatigue, and the flu. Also, because of varying sensitivity among people, one individual may react to a particular IAQ problem while surrounding occupants do not display ill effects. In other cases, complaints may be widespread. In addition to different degrees of reaction, an indoor air pollutant or problem can trigger different types of reactions in different people. Groups that may be particularly susceptible to the effects of indoor air contaminants include, but are not limited to:

- allergic or asthmatic individuals, or people with sensitivity to chemicals
- people with respiratory disease
- people whose immune systems are suppressed due to radiation, chemotherapy, or disease
- contact lens wearers

Poor IAQ can have significant health effects on children with asthma. According to the American Lung Association (1997), the number of children suffering from asthma increased 72% between 1982 and 1994. Asthma is the principal cause of school absences.

So the first step in diagnosing a suspected IAQ problem is to eliminate the possibility that the health effects and symptoms reported by the personnel are not due to other causes. The guidelines most often used (US EPA 1995) to identify an IAQ problem are:

- the symptoms are widespread within a class or within a school
- the symptoms disappear when the students or staff leave the school building for a day
- the onset is sudden after some change at school, such as painting or pesticide application
- persons with allergies, asthma, or chemical sensitivities have reactions indoors but not outdoors
- a doctor has found that a student or staff member has an indoor-air-related illness

Typical Air Pollutants and Other Factors Influencing IAQ

There are numerous potential sources of indoor air pollutants in and around schools. A list of typical indoor air pollutants found in schools is shown in Table 1. The health effects from each of these air pollutants is discussed in a related article in this issue (*Indoor Air Quality: A Time for Recognition*) so they will not be repeated here. There are also other factors, such as strategies for design, operation, and maintenance of the heating, ventilating, and air conditioning (HVAC) system(s); building and equipment maintenance and repair; housekeeping practices and equipment; and wind velocity that can also impact IAQ.

Design, Operation, and Maintenance of HVAC System(s). When all aspects of the HVAC system are considered, this factor tops every list of causes of IAQ problems found during major research studies conducted. This is not surprising when one considers that ventilation, room temperature, air filtration, humidity, building pressurization, uniformity of air distribution, and spread of air borne contaminants are all controlled (actively or passively) by the HVAC system design, operation, or maintenance. Some would claim that it is not the HVAC system that causes most of the problems but other problem areas that interact with the HVAC system that are the problem. They would further state that the HVAC system just happens to make contact with more of these problem areas than any other single building element. The focus of this article is not to resolve this ongoing dispute but to increase the awareness that these problems do exist in a large percentage of schools and to offer schools suggestions on how to address them regardless of the cause.

Table 1. Typical Indoor Air Pollutants Found In Schools

Indoor Air Pollutant	Sources
Environmental Tobacco Smoke	Tobacco combustion
Formaldehyde	Plywood, particleboard, textiles, adhesives, foam insulation, and pressed wood furniture, cabinets, and shelving
Volatile and Semi-Volatile Organic Compounds (VOCs and SVOCs)	Acetone (cleaners, personal care products, and tobacco smoke), acrolein (tobacco smoke), aromatic hydrocarbons (adhesives, combustion processes, gasoline, paints, pesticides, solvents, and tobacco smoke), benzene (combustion processes, gasoline, solvents, and tobacco smoke), chlorinated hydrocarbons (PCBs, wood preservatives, and solvents), phenols (equipment, furnishings, and tobacco smoke), and methanol (duplicating machines)
Nitrogen Oxides	Combustion processes, welding, and tobacco smoke
Carbon Monoxide	Incomplete oxidation during combustion in gas ranges and unvented gas or kerosene heaters; boilers; furnaces; and auto, truck and bus exhaust
Carbon Dioxide	All combustion processes and human metabolic processes
Allergens and Pathogens	People, animals, and the environment; drapery, bedding, carpet, and other dust collection sources; cooling towers (*Legionella* bactria); dirty cooling coils, humidifiers, condensate drains, and ductwork (can incubate bacteria and molds); and high humidity-bacteria and mold growth
Radon	The earth around some buildings, well water, and some masonry building blocks
Pesticides	May be applied indoors or tracked in from outdoors
Lead	Lead-based paints (now banned by the Consumer Product Safety Commission) on older surfaces
Dust	Soil, fleecy surfaces, pollen, lead-based paint, burning wood, oil, or coal during some renovations

Source: US EPA Tools for Schools Action Kit (1995)

Ventilation. Ventilation for the sake of this article is defined as the amount of outdoor air introduced into a space to replace oxygen and to dilute to desirable levels the chemical and biological agents found in the space, i.e., odors and microbes in the air. Design ventilation rates have changed over the years. In the early 1900s, when professionals were concerned about the spread of airborne diseases like tuberculosis, they recommended large quantities–30 cfm per person–of outside air for ventilation. During the energy crisis of the mid 1970s, 5 cfm per person was recommended. Today it is 15 cfm of outside air per person for school classrooms when classrooms are occupied. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) ventilation standards are used as the basis for many building codes. A table of outdoor air quantities in school areas as recommended by *ASHRAE Standard 62-1999 Ventilation for Acceptable Indoor Air Quality* is shown in Table 2.

Table 2. Selected Outdoor Air Ventilation Recommendations (Minimum)

Application/Area	CFM* per Person
Classrooms	15
Music Rooms	15
Libraries	15
Auditoriums	15
Spectator Sport Areas	15
Playing Floors	20
Office Space	20
Conference Rooms	20
Cafeteria	20
Kitchen (cooking)	15
Patient Rooms	25

*Cubic feet per minute

Source: ASHRAE Standard 62-1999, Ventilation for Acceptable Indoor Air Quality (1999b)

It should be pointed out that the values in Table 2 assume sedentary activities in the classroom. In general, children in elementary school classrooms during a typical day are far from sedentary. Also, the values in Table 2 assume a 100% ventilation efficiency of the outside air use, i.e., that 100% of the fresh air makes its way to a building occupant before it is removed by the building return air system or an exhaust system. Few buildings have ventilation efficiencies of 100%. So it is desirable to plan for quantities of outside air slightly in excess of the values shown in Table 2 to account for these two factors. However, in no instance should the values be less than these recommended minimums (ASHRAE 1999b).

Unfortunately the actual ventilation rate is seldom, if ever, measured in the classroom. Instead, the carbon dioxide, CO_2, concentration is measured to deduce the adequacy of ventilation. Today, ASHRAE (1999b) recommends a maximum CO_2 concentration of 1000 ppm (parts per million of air). It is not uncommon to measure levels in classrooms in excess of 3000 ppm, particularly in relocatable buildings, i.e., portables. One reason for this is the ventilation rate that the mechanical engineer actually used in designing the HVAC system may have been 5 to 7 cfm per person. Perhaps a less obvious reason is that many HVAC units, like the ones used in portables and other school classrooms, only deliver outside air when the unit cycles "on" due to the thermostat detecting a difference between the actual space temperature and the thermostat's set point. When it cycles off, no outside air is delivered to the space. Some research suggests that even 1000 ppm may be too high. Armstrong Laboratories (1992) found that 15–33% of the population will have symptoms from CO_2 exposure at 600–800 ppm, 33–50% will have symptoms at 800–1000 ppm, and 100% will show symptoms at greater than or equal to 1500 ppm.

Room Temperature. Perhaps the most obvious role of the HVAC system is control of room temperature. For the most part, room temperature problems arise when systems are either severely over designed or under designed. The latter will occur when unanticipated thermal or moisture loads are introduced into the building. Severely under designed HVAC systems will have a detrimental effect on the air temperature that we sense and will tend to operate almost continuously. If the system is severely over designed, then the air temperature will reach the set point before all of the latent—moisture—load is removed. Hence this will lead to higher than desired relative humidities and the potential for mold growth.

Air Filtration. When greater quantities of outside air are introduced into the building, a potential is created for a correspondingly greater level of airborne particulate matter to be deposited onto the cooling coils of the HVAC evaporator and to be delivered to the space. Particulate matter degrades evaporator performance and indoor air quality and affects occupants' health. Therefore, filters with appropriate efficiencies for removal of the target particulate matter should be used. ASHRAE (1999a) has recently released *ANSI/ASHRAE Standard 52.2–1999 Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Size*, which establishes a rating system for air filter efficiency based on particle size.

Aerosol particles from 0.1 to 10 μm (μm = 1×10^{-6} meters) in aerodynamic diameter are of health concern because they can be easily inhaled. Particles less than 2 μm are of most concern because they are small enough that they can be retained in the lung's alveoli. Particles larger than 8 to 10 μm in diameter are separated and retained by the upper respiratory tract. Intermediate sizes, 2 to 8 μm, are deposited in the conducting airways of the lungs, from which they are rapidly cleared and swallowed or coughed out. Particles larger than 10 μm settle fairly rapidly and can be found suspended in air only near their source (ASHRAE 1997). Table 3 lists the sizes of some common particulate matter. Common filters can remove particles in the range of 1 to 100 μm, with some types of HEPA filters able to remove particles as small as 0.01 μm (NAFA 1996).

Humidity. ASHRAE (1992) recommends that HVAC systems be designed to control relative humidities (RH) to 30–60%. Unfortunately, most HVAC systems do not actively "control" RH. If the RH drops below 30%, as can happen during cold weather, most systems cannot add moisture to the air. When the air is below 30% RH, drying of the skin and nasal passages can occur leading to infections and other health problems. If the room RH exceeds 60% for extended periods—greater than 48 hours—of time, then mold growth occurs. Mold will begin to grow in localized areas that, due to uneven mixing of the air, may be at RHs above 60%. Furthermore, relative humidity is seldom measured and therefore not actively controlled in schools. The presence of localized high RH can been detected and mold prevented in many cases if RH is measured and kept within the desired range of 30–60%.

Table 3. Selected Aerosol Particle Diameters

Particulate Matter	**Diameter, μm***
Viruses	0.003 to .06
Bacteria	0.4 to 5
Lung damaging dust	0.4 to 5
Molds	3 to 10.5
Plant spores	10 to 30
Pollen	10 to 100
Human hair	30 to 200
Dust mites	250 to 300

*μm = *1 x 10^{-6} meters = 1/25,400 inch*
Source: ASHRAE. *1997 Handbook: Fundamentals-I-P Edition (1997)*

Humidity can also increase in buildings due to water leaks, diffusion of water through slabs, and infiltration of air with high humidity. Water leaks from roofs, walls or at windows that dampen or, even worse, saturate ceiling tiles, wood, gypsum wallboard, and other organic or cellulose-based building materials, should be repaired immediately. If materials that become wet are allowed to remain damp for 48 hours, mold will begin to grow. This same condition can occur if air with high humidity (>60% RH) is allowed to come in contact with organic materials for this same period of time, particularly if the organic surface is below the dew point for the air flow and condensation occurs on the organic surface. One less known manner in which moisture is transmitted into buildings is through concrete walls and slabs where the vapor pressure of the outside environment or soil as the case may be, is greater than the typical vapor pressure of the conditioned (inside) space. If so, the vapor pressure differential will drive moisture through the concrete and into the conditioned space increasing the local RH and providing a potential site for mold growth. Figure 1 shows mold growth on gypsum wallboard due to excessive moisture migration through the concrete slab.

Building Pressurization. Two primary ways contaminants enter a building are through cracks and when the occupants enter and leave the building. The outside air that enters is neither filtered or conditioned. Therefore particulate matter, including mold spores, can enter the building through this mechanism. One method of minimizing this infiltration is through slight positive pressurization of the building, i.e., where the building air pressure is slightly higher, 0.01–0.02 inch H_2O, than the outside. This pressure differential causes air to flow from inside the building to the outside, generally preventing outside air from flowing into the building.

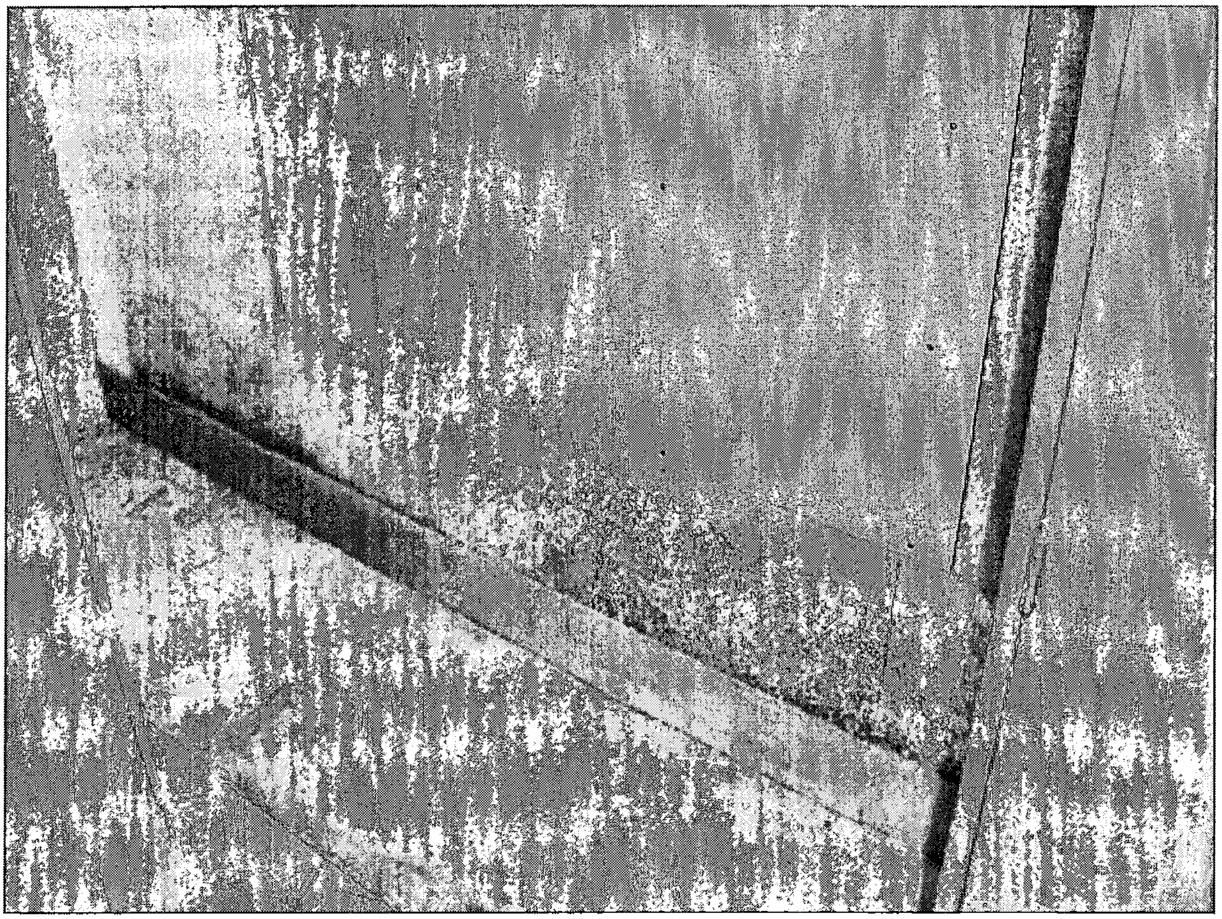

Figure 1. Mold (*Penicillium*) found on gypsum wallboard in an elementary school that was closed due to extensive mold contamination.

Uniformity of Air Distribution. Once an HVAC system is tested and balanced to ensure that design air flow rates are delivered to each space, there are no tests that are typically performed to assess the mixing of air in the room or the amount of air that short circuits and flows to the return air duct straight from the supply duct. Good mixing of air is needed to help ensure that pollutant concentrations are kept to a minimum rather than having localized areas of both high and low concentrations. When the conditioned air delivered to the space short circuits, the effective amount of outside air available to the building occupants is reduced and the CO_2 concentration measured can be higher than desired or expected.

Spread of Airborne Contaminants. Most HVAC systems do not isolate air flows from individual rooms or zones, i.e., they usually commingle return air. This means that airborne contaminants can be spread rapidly when rooms are designed for 3 air changes per hour. Additionally, when doors to classrooms are opened, air flows from one room to the next or even into corridors and down the halls.

Most molds produce spores, mycotoxins, and volatile organic compounds (VOCs). In general, it is the mycotoxins and the microbial VOCs that are the allergens that cause the greatest health effects on humans (Godish 1995). They both tend to be the smallest of the three and are therefore most easily transported by the air currents in the building and the HVAC system. Hence, once mold begins to grow and produce mycotoxins and VOCs, these contaminants are rapidly spread by the HVAC system, exposing large percentages of building occupants.

Building and Equipment Maintenance and Repair. Many school buildings built in the 1950s and 1960s suffer from problems due to inferior construction. When poor construction results in water intrusion or unanticipated sensible or latent thermal loads for the HVAC system, the potential for occupant discomfort and mold growth increases rapidly. The correct and adequate repair should be performed soon after the problem is discovered and before other problems develop. The costs for these unanticipated repairs is usually not included in the operating budget so other sources of funds must be identified to make the needed repairs. This process can take months or, if these amounts are large, even years. When equipment appears to operate adequately without failure, there is a tendency to perform maintenance less frequently than recommended by the equipment manufacturer, to save money. Deferring repair or equipment maintenance accelerates deterioration of the capital investment and in most instances will cost orders of magnitude more to repair when the repair is finally performed than if it were repaired when first detected.

Housekeeping Practices and Equipment. It is ironic that housekeeping practices could actually create IAQ problems rather than prevent them as desired. Most housekeeping problems arise in dusting, the cleaning of vinyl floor treatments, and vacuuming of carpeted areas. Vinyl flooring is usually wet mopped during the evening hours when HVAC systems are turned off or set back to save energy. The frequency of wet mopping varies from school to school. The use of excessive quantities of water often allows water to run under walls and cabinetry where it becomes difficult to dry and may result in mold growth if it comes in contact with organic materials.

Dusting of furniture and chalk or dry erase boards results in redistribution of the particulate matter if it is not performed in conjunction with HEPA (high efficiency particulate air) filtered vacuums. As these larger particles fall to the floor, are stepped on and broken into finer particles, it increases the concentration of fine particles (less than 2.5 μm) in the building. Although much of the newer carpet is designed to minimize the potential for IAQ problems if cleaned as recommend by the manufacturer, practically speaking this is difficult to do in many schools, particularly elementary schools. Additionally, carpets should be vacuumed with vacuum cleaners that have

HEPA filtration to ensure capture of fine particulate dust. If not, these areas will be sinks that contribute to increases in the level of fine particulate matter in the school.

Wind Velocity. When wind blows against a building, it forces the air through cracks and small openings in the buildings' exterior walls allowing unconditioned air into the building. It can also disturb the buildings' positive pressurization. This will also result in unanticipated infiltration of unconditioned air. If the building has an open plenum return system, strong winds can cause back drafts in return plenums causing odors, dust and other particulate matter to be reintroduced into the occupant space.

Conclusion

IAQ in schools is the result of many building characteristics and systems. Analysis and identification of contaminant sources can be complex and usually requires a team of individuals with expertise in building design and construction, HVAC systems, mycology, remediation of mold contamination, and IAQ. IAQ complaints in schools should be investigated thoroughly when first reported or the end result will be much more costly to correct, cause greater disruption in school activities—possibly even closing the school—and increases the extent and severity of health symptoms experienced by building occupants.

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