Science-Based Recommendations to Prevent or Reduce Potential Exposure to Biological, Chemical, and Physical Agents in Schools

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ABSTRACT: *The US General Accounting Office (GAO) documented generally poor conditions of school facilities in the early 1990s. Previous papers examined, for time intervals ending before 2002, relationships between education facility indoor air and environmental quality (IEQ), including adequate ventilation, and occupant health and productivity. Research on IEQ related specifically to new or refurbished traditional school construction, or portable classrooms, is limited. A review of school IEQ literature through fall 2003 was conducted. Then, acknowledging the limited resources and competing priorities facing American schools, practical science-based, best practices recommendations to promote IEQ and hence prevent or reduce potential occupant exposure to biological, chemical, and physical agents of concern were proposed. Electronic search engines, conference proceedings, the Internet, and reference lists of peer-reviewed papers and reports were used. Eighteen best practices based on scientific references are presented.* (J Sch Health. 2004;74(10):390-396)

Federal reports on environmental threats to children's health called for improved risk communication and environmental education. Communication of research results, environmental education, and recommendations must be based on the best available science, condensed and delivered to stakeholders.

Previous review papers examined studies and federal government reports, for time intervals ending prior to 2002, concerning relationships between education facility indoor air and environmental quality (IEQ), including adequate ventilation, and occupant health and productivity.[1,2] Except for work done in California and the Nordic countries, research on school IEQ related specifically to new or refurbished traditional school construction, or modular classrooms (portables), is limited.

This paper does not review quantitative and qualitative IEQ or quantitative and self-reported health symptom data. Instead, based on studies reported through fall 2003, school-based scientific literature was summarized to determine science-based, best practices recommendations to encourage school stakeholders to mitigate or prevent IEQ problems.

SEARCH PROCEDURES

Methodology

National Library of Medicine and University of California library electronic search engines and conference proceedings books were used. In addition, reference lists of papers and reports gathered were examined, as were government and professional association reports and school IEQ initiatives. The focus was on work available to the public in print, or by Internet, in English.

Primary keywords were school, school children, classrooms, portables or relocatables or modular classrooms, and attendance. Secondary keywords were IEQ topics covered: observed moisture damage; biological agents in air and dust (bacteria, fungi, allergens); toxic and odorous volatile organic compounds, including formaldehyde; direct measures and indicators (carbon dioxide) of ventilation; temperature and relative humidity (thermal comfort parameters); particles and dusts, and chemical residues like pesticides; carbon monoxide; persistent organic pollutants (polychlorinated biphenyls, phthalates); specific metals (arsenic, lead, mercury); asbestos; radon gas; lighting; and noise.

Peer-reviewed journals covered the period 1968 through fall 2003. Federal and California government reports available to the public were included. Case studies or informal consultant reports were excluded. Citations (n = 302) directly involving or highly related to school IEQ and occupant health, attendance, and productivity or performance were identified. References were tallied by category and IEQ topic (Table 1). National and international conference proceedings books searched (years available) included: Triennial International Conference on Indoor Air Quality and Climate (1990-2002); Triennial Healthy Buildings Conference (1997, 2000); Annual Conference, International Society of Exposure Analysis (2000-2003); and Annual Conference, International Society for Environmental Epidemiology (2002-2003).

Only peer-reviewed journal articles most directly justifying recommended best practices were referenced. This

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paper was not a meta-analysis. Studies reviewed (Table 1) did not represent every school, were not always representative of the geographical area studied, and sometimes described the school environment and potential exposures but not health outcomes.

CONCISE SCIENCE LITERATURE REVIEW

Most school IEQ studies, whether or not they examined qualitative or quantitative outcome measures, focused on specific agents.

Table 1
School IEQ Studies and Highly Related References Identified by Type of Reference and IEQ Category

IEQ Category or Topic	Peer-Reviewed Journal Papers	Conference Proceedings or Published Abstracts	Government (Federal, CA or WA, or WHO) Final Reports and Guidance Documents	Not-For-Profit Research Reports or Professional Association Documents	Doctoral Dissertations
Biological Agents	**31**	**35**	**1**	**1**	**0**
Leaks, Moisture Damage	14	16	0	0	0
Bacteria, Fungi	4	12	0	0	0
Allergens	13	7	1	1	0
Chemical Agents and Particles	**20**	**34**	**13**	**0**	**2**
VOCs, Toxic, and Odorous	15	16	7	0	1
Interior finish materials and furniture as "sources" and "sinks"	0	4	2	0	0
Particles, including pesticide residues	5	9	1	0	0
Carbon monoxide and combustion-related pollutants from outdoors	0	5	3	0	1
Physical Agents and Related Characteristics of Schools	**65**	**42**	**11**	**7**	**3**
Measures of ventilation	11	25	3	1	1
Thermal comfort (T, RH)	3	7	1	1	2
A-weighted noise levels	37	9	6	4	0
Fluorescent lighting / daylighting	14	1	1	1	0
PCBs and Phthalates	**6**	**2**	**2**	**0**	**0**
Asbestos, Radon, and Specific Heavy Metals of Concern	**0**	**2**	**9**	**0**	**0**
Asbestos	0	0	1	0	0
Radon	0	1	4	0	0
Arsenic	0	0	1	0	0
Lead	0	1	3	0	0
Mercury	0	0	0	0	0
Introduction and Other Background Text	**34**	**15**	**11**	**5**	**1**
Number of Times References Used (in total)	156	130	47	13	6
Number of Unique References (302 total)	147	98	42 (26+13+3)	13	2
Number of References Used for Multiple Topics	9	32	5	0	1

NOTE: Only references directly related to recommendations were summarized and cited. An individual reference could be used more than once.

Biological Agents

Leaks, moisture damaged materials, and bacteria, fungi, and allergens. Based on location on school grounds, weather, local irrigation, and crawl space cross-ventilation, classroom floors constructed of plywood, as well as roofs and inside walls, may be subject to water condensation build-up then damage. Moisture build-up also can occur in school kitchens. In a Finnish study,[3] documented moisture damage was caused primarily by poor ventilation and water leaks. After visual inspection and measurement results were presented to the community, they improved drainage and crawl space ventilation and replaced damaged materials.

Studies in Nordic countries reported measurements of allergy, respiratory symptoms, and infections among occupants of moisture and mold-damaged schools or day care centers, and improvements after renovation.[4-9]

Water-damaged building materials containing cellulose or other available nutrients, with or without light, provide a potential breeding ground for fungi and bacteria. Measured air and surface concentrations of bacteria and fungi, and diversity including species of potential health concern, were higher in damaged schools than in non-problem buildings or after renovation.[3,10-12] In case studies from Finland and the United States, the most common fungal groups reported from culturable indoor air samples conducted in school facilities were *Penicillium*, *Cladosporium*, *Aspergillus*, yeasts, and non-sporulating isolates. Total culturable airborne bacteria and cell envelope components also were measured.[13] Studies in Taiwan suggested indoor exposure to bioaerosols may have health implications in schools[14] and child care centers.[15,16]

Allergens in floor and surface dust in school classrooms likely were transported on children's clothes from homes, and may influence prevalence and severity of asthma symptoms and allergies.[17-28] Pollen allergens, however, are predominantly from outdoors. There have been sensitization and symptoms guidelines[29] for cat allergen (*Fel d 1*, 8 ug g^{-1}) and the dust mites *Der p 1* and *Der f 1* (2 μg^{-1} and 10 μg^{-1}, respectively). Tortolero et al[30] assessed 385 classrooms in 60 elementary schools in southeast Texas. Only 2.5% of rooms exceeded recommended guidelines for *Der f 1*, and only 10% of rooms exceeded the recommended threshold for cockroach allergen (*Bla g 1*) though it was found in every school. These findings may reflect adequate cleaning practices. Wickman et al[31] examined effects of general cleaning, ventilation, and occupant pet ownership on allergen levels in day care centers.

Chemical Agents and Particles

Volatile organic compounds (VOCs). Materials used to construct and furnish portables, and traditional school buildings especially if new or modernized, may off-gas toxic and odorous VOCs as a function of age, temperature, and relative humidity.[32] For example, formaldehyde is a known sensory and respiratory irritant and allergen.[33]

Several VOCs, especially odorous compounds, and potential endocrine disrupters and neurotoxicants including phthalates, have been measured in indoor air of homes, offices, and schools, and found in various consumer products including personal care products, cleaning compounds, and teaching supplies and materials.[27] A study reported acute respiratory irritations and behavioral abnormalities in normal mice after exposure to eight different felt-tip markers and a white dry-erase board cleaning solution, which emitted a mixture of VOCs.[34] School studies suggested use of chemical cleaning compounds and air fresheners during occupied hours and/or during overnight custodial cleaning, when there was likely inadequate ventilation, drove measured concentrations.[35]

Building interior finish materials and furniture. Studies documented carpets and other flooring surfaces, adhesives, and office equipment typically found in schools as sources of VOCs.[32] Other studies examined carpets and open shelves (flat, exposed surfaces) as reservoirs for and thus sources of indoor pollutants like dust particles, which can contain allergens and pesticide residues. Carpets, which can cover large surface areas and vary in pile thickness, can hold large quantities of dust unless vacuumed well.

Particles including pesticide residues. Particles with aerodynamic diameters in the respirable ranges – coarse (2.5-10 μm), fine (0.1-2.5 μm), and ultrafine (< 0.1 μm) – are of public health concern. Particle sources in schools include soil tracked in from outside; resuspension from carpets or smooth flooring acting as reservoirs, as a function of occupant activity and overall cleaning; penetration of the building envelope from the outdoors; delivery through a mechanical HVAC system with insufficient filtration; and, generated by combustion sources within buildings (eg, boiler room).

Few studies investigated pesticide residues, and metals and polycyclic aromatic hydrocarbons (PAHs) of potential health concern, in settled dust collected from classroom surfaces. Nevertheless, increasing evidence exists on pesticides as neurological and developmental toxicants to young children. Insecticides and pesticides inside classrooms or on school grounds may be used in varying quantities, frequencies, durations, and times of day and seasons. In the California Portable Classrooms Study (CPCS) (see http://wwww.arb.ca.gov/research/indoor/pcs/pcs.htm), chlorpyrifos was found above analytic method detection limit (MDL) in >80% of monitored classrooms. Chlorpyrifos has been subjected to a mandatory phase out of sale and use in homes and schools since late 2001. Existing stock purchased before federal and local legislation, however, could be used, with or without proper notice.

Mechanical HVAC systems, which filter the combination of fresh outdoor air and recycled indoor air, can reduce indoor levels of dust particles and constituents. Nevertheless, HVAC system filters may be sources of chemical and microbiological pollutants, and odors.

Buses and trucks (gasoline and diesel-powered) should not be allowed to idle near school facility outdoor air intake vents (assuming dampers open), a particular concern for portables with wall-mount, not rooftop, HVAC systems, to reduce indoor concentrations of particles and other pollutants of health concern (carbon monoxide, PAHs, nitrogen oxides).

Physical Agents and Related Characteristics of Schools

Direct measures, or carbon dioxide (CO_2) concentrations as indicator, of inadequate ventilation. Classrooms including childcare facilities are usually more dependent on mechanical ventilation to provide fresh outside air than windows, if operable, and doors. ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, Ga.) Standard 62-1999 stated 15 ft^3 min^{-1}

person[-1] of filtered outdoor air should be supplied to occupied indoor spaces.

Quantitative ventilation rate measurements for school classrooms have been conducted during occupied hours with a non-toxic perfluorocarbon tracer gas.[36] Ruotsalainen et al[37] reported quantitative spot measurements of exhaust air flow as an indicator of ventilation system performance in day care centers in Finland at the time of measured equilibrium CO_2 levels. Measured indoor air concentrations of CO_2, produced by human respiration, and CO_2 decay curves have been used worldwide as indicators of inadequate ventilation in schools.[30,38-40] Daisey et al[2] reported ventilation and CO_2 data from the United States, including NIOSH investigations, indicated inadequate outdoor air ventilation in school classrooms and poor HVAC system maintenance. After new ventilation systems were installed in 12 of 100 classrooms in 39 randomly selected schools in Uppsala County, Sweden, measured ventilation rates increased while concentrations of several monitored pollutants and relative humidity decreased.[41]

Thermal comfort parameters. Ventilation, mechanical and natural, also affects occupant thermal comfort, a combination of indoor air temperature (T) and relative humidity (RH) as well as air velocity and clothing. ASHRAE Standard 55-1992 provides guidelines for acceptable occupant thermal comfort during winter (heating season) and summer (cooling season). However, it was developed for adults, typically in office environments, and how well these conditions apply to children in school environments remains unknown. Furthermore, guidelines may not always be appropriate for tropical climates like Hawaii.[42]

The LBNL relocatable classroom (RC) study[43] suggested mechanical ventilation, natural ventilation as desired and possible, and appropriate teacher T set points could allow RCs to achieve good IEQ and compliance with acceptable seasonal ranges of T and RH. When ASHRAE Standard 55-1992 guidelines were not met, it was usually due to measured indoor air RH. In the LBNL and UCLA school studies,[36] indoor air T and RH measured adjacent to the dry-erase board at three different heights, and/or near the teacher work station at standing height, were influenced by several factors, including afternoon cooling and morning heating demands on HVAC system operation; attributes of the mechanical HVAC system technologies; occupant density, and occupant activity levels, ie, respiration and perspiration; ambient conditions; and, teacher T set point preferences.

Indoor air RH can also indicate condensation build-up on interior surfaces, and thus potential moisture damage of materials and subsequent mold growth.

A-weighted noise levels. Noise is any unwanted, extraneous sound. Children require better acoustic quality than adults in classrooms, because good speech recognition is necessary for optimal comprehension and learning during language and reading acquisition. Children are ineffective listeners to speech (ie, cannot hear and understand) in noise until adolescence. Children with hearing impairments, and learning and attention disorders, are especially susceptible and have unique needs, as do those learning in a second language.[44]

Typical classroom sources of noise include: noise from outdoors, such as playgrounds, construction, and nearby traffic; mechanical noise, such as when the HVAC system operates and adjacent classroom surfaces vibrate to produce airborne noise; and, noise from other indoor sources such as occupants, TV/VCR, and lighting ballasts and dimmers (transformer humming), including reverberation.

Few published scientific studies examined quantitative exposure to noise levels in school classrooms due to indoor and outdoor sources, although non-regulatory guidelines have been established. The LBNL study[43] reported mean school day average noise (L_{eq}), across classrooms and wall-mount HVAC systems, was approximately 56 dB (A).

Fluorescent lighting and daylighting. Few studies investigated lighting and daylighting, through windows and skylights, and physical development and academic performance.[45] Newer, improved fluorescent light bulbs, fixtures, and electronic ballasts may provide energy, economic, and pollution reduction benefits due to longer life spans and changes in component materials. At present, few data exist on health and performance in schools due to relative advantages or disadvantages of artificial versus natural light, though emerging work suggests benefits of natural light. Some occupants may be more susceptible to artificial light due to light-based health and learning issues, termed Irlen Syndrome or Scotopic Sensitivity Syndrome, caused by hypersensitivity to physical properties within light sources (spectrum of colors, wavelengths). Medical studies examined this class of learning disabilities in school children, which includes reading disorders and attention deficits.[46,47]

Other Topics of Interest

Persistent organic pollutants and possible endocrine-disrupting chemicals. Polychlorinated biphenyls (PCBs) are likely present in schools with fluorescent light fixtures not replaced after 1979. US production of PCBs stopped in 1978 due to the Toxic Substances Control Act of 1976. PCBs, with low electrical conductivity, were used in small magnetic capacitors and insulating material. Older ballasts break down and become susceptible to leaks and fires, hence accidental exposures.

PCBs and other persistent organic pollutants, especially endocrine-disrupting chemicals, have been shown to mimic hormones and disrupt the endocrine system, which may lead to other adverse health consequences, eg, child neurobehavioral and physical development, reproductive health of young female teachers.[48] Nevertheless, Longnecker et al[49] reported evidence was not strong for endocrine disruption in humans with background-level exposures. Concerns included pesticide residues, fertilizers on grounds, and plasticizers including phthalates. Phthalates can be found in foods, consumer products, and certain interior finish materials. Potential exposures of young children at school may occur due to mouthing, chewing, or gnawing soft, flexible toys and other materials containing or covered with chemical residues. Polyvinyl chloride (PVC) flooring contains plasticizers like phthalates and, given PVC is low cost and easy to maintain and clean, has been used in school classrooms and other areas around sinks and lab benches.

Asbestos. Exposure to asbestos through inhalation of loose fibers of this naturally occurring mineral substance, found in ceilings and walls (eg, fire retarding insulation on structural beams, soundproofing materials), has been shown to cause lung disease. Federal requirements for schools for inspection, notification, and containment in bound form or proper removal of loose, friable asbestos fibers (keep wet, seal off work area) were formally established by the Asbestos Hazard Emergency Response Act of 1986.

Radon. Radon is an inert, colorless, odorless, radioactive gas. Epidemiological studies demonstrated a causal association between radon and lung cancer. Radon derives from uranium present in soils and rock. The US EPA published several reports on mitigation of radon gas entry into schools in geographically susceptible areas due to known geology and soils, including design and construction of foundations and ventilation system design, installation, operations and maintenance issues.[50]

Arsenic. Arsenic can be found in soil tracked into school classrooms on shoes or clothing, especially after recess on playgrounds and in sandboxes near equipment constructed with wood treated with certain preservatives, eg, chromated copper arsenate (CCA). Portables were usually sited on prepared areas including CCA-treated wood to raise modules above ground level to allow cross-ventilation. Pesticides used on school grounds may contain arsenic. The CPCS reported some classrooms had levels of arsenic in settled floor dust above MDL, and in relatively more portables than traditional classrooms (See http://www.arb.ca/gov/research/indoor/pcs/pcs.htm). The US EPA enacted a voluntary phase-out of CCA, so CCA is no longer on the approved list of chemical pesticides, and New York State banned CCA on new playground equipment.

Lead. Likely sources of lead in older schools, particularly settled floor dust, included: (1) Peeling or chipping paint applied prior to 1970, which contaminates dust on indoor surfaces or adjacent outdoor soil. Soil can be tracked in on shoes or enter through natural ventilation. (2) Poorly contained and monitored renovation activities.

Mercury. Exposure to mercury, in its elemental or bioaccumulative organic (methylated) forms, has adverse health effects. In schools, older fluorescent light bulbs contained mercury, but new, energy-efficient, high-quality bulbs do not. Some states banned mercury from light bulbs and required labeling. Mercury also may be present in secondary schools with chemistry laboratories, and in general in health clinics (thermometers) and thermostat and computer hardware. When potential sources are identified, they should be carefully contained and their use managed until replaced with alternatives and properly disposed of as hazardous waste. New sources should not be introduced.

RECOMMENDED BEST PRACTICES

1) Prevent leaks and subsequent moisture damage to materials.

2) Replace wet and damaged materials, including drying out underlying surfaces, as soon as possible.

3) Frequently wash floors and other surfaces occupants contact for general hygiene and to minimize pet allergens and bacteria.

4) Use non-toxic or least toxic cleaners, preferably during unoccupied hours but not immediately before school or near the end of lunch.

5) Use non-toxic or least-toxic teaching supplies and materials.

6) Allow sufficient time for mechanical and natural ventilation to air out classrooms after painting and receiving new furniture or teaching materials.

7) Conduct biannual or annual HVAC system inspections, and more frequent inspections and replacements of filters, to provide at least adequate ventilation (ASHRAE Standard 62) with filtration of particles and pollen allergens of outdoor origin. If possible, given weather conditions, local safety policies, and potential adjacent outdoor sources of pollution or noise, use operable windows to add natural ventilation.

8) Consider the design, installation, and commissioning of mechanical HVAC systems based on year-round ambient conditions to prevent water condensation build up on interior surfaces, leading to moisture damage and subsequent microbial growth.

9) Consult current classroom enrollment data so HVAC system damper settings allow adequate fresh outdoor air ($\geq$15 ft^3 min^{-1} $occupant^{-1}$).

10) Consider criteria more specific to children and schools in future revisions to Standard 55 on occupant thermal comfort in buildings by ASHRAE. An interesting discussion point is the potential trade off between acceptable thermal comfort and adequate ventilation in climates with higher ambient relative humidity, or if HVAC technology either cannot dehumidify air or cools air using water vapor.

11) Assess in future case studies and surveys the average occupant exposure to noise from present sources during school hours and, as resources allow, contract acoustics specialists to determine spectral characteristics or frequencies of potential sources. Given noise-induced hearing loss has no physical symptoms, the key to prevention is education and reduction of noise at the source with engineering controls or improved HVAC system technologies. For example, in the LBNL study of new relocatable classrooms,[43] minimum measured six-minute dB (A) data suggested alternate interior finish material classrooms had lower background noise levels than standard material classrooms. This finding may constitute evidence of a secondary benefit from alternative ceiling tiles, their higher noise reduction coefficient rating (NRC). They were originally chosen since they were determined not to be formaldehyde sources.[32]

12) Consider NRCs of interior finish material options, especially for large surface areas (ceiling tiles). Reverberation time, persistence of sound after the source stops or is removed from an unoccupied classroom, may also decrease.[44]

13) Encourage prevention of exposure through source control and proper removal and disposal for persistent organic pollutants (PCBs, phthalates), and radon, asbestos, arsenic, lead, and mercury.

14) Promote policies for pollution prevention programs on environmentally preferable purchasing of school construction and interior finish materials, and teaching and cleaning supplies.

15) Avoid building new schools near freeways, due to health concerns from air pollution and noise.

16) Forbid diesel buses and trucks to remain idling near school outdoor air intake vents (assuming dampers open), to minimize indoor concentrations of vehicle-related combustion pollutants.

17) Reduce glare from incidental sunlight reflecting off surfaces (desks, computer screens) to the extent practical, and do not place student desks directly in front of windows.

18) Turn off fluorescent lights when natural light

through windows or skylights is sufficient, which also saves energy and money.

CONCLUSION

This paper provided a concise school IEQ literature review of about 300 scientific citations and offered 18 recommended best practices to reduce or prevent potential occupant exposures to biological, chemical, and physical agents of potential concern in American school facilities, in particular classrooms. This manuscript can educate school stakeholders and policy makers, with the goal to improve and promote good school IEQ, occupant attendance and health, and academic achievement. Timelines and implementation costs will inherently vary, but most of the proposed best practices are initially low-cost or can result in long-term savings. ■

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