# Science-based recommendations to prevent or reduce potential exposures to biological, chemical, and physical agents in schools

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# LIST OF ACRONYMS USED

| | |
|---|---|
| ASHRAE | American Society of Heating, Refrigerating, and Air Conditioning Engineers, a professional organization (e.g., writes guidelines) |
| CARB | California Air Resources Board |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| dB (A) | A-weighted decibels, a measure of noise indoors or outdoors |
| IEQ | indoor air and environmental quality |
| HCHO | formaldehyde |
| HVAC | heating, ventilating, and air conditioning systems |
| LBNL | Lawrence Berkeley National Laboratory |
| $L_{eq}$ | time-weighted average noise level, measured in A-weighted decibels |
| MDL | analytic method detection limit |
| MVOC | microbial volatile organic compounds |
| portables | modular classrooms, also termed portable or relocatable |
| ppm | parts-per-million (molar volume, in air) |
| ppb | parts-per-billion (molar volume, in air) |
| RC | relocatable classroom |
| RH | relative humidity, in indoor or outdoor air |
| T | temperature, in indoor or outdoor air |
| UC | University of California |
| USEPA | United States Environmental Protection Agency |
| USGAO | United States General Accounting Office |
| VOC | volatile organic compound, a toxic or odorous chemical |

ABSTRACT

Previous U.S. Government Accounting Office reports documented survey results on the generally poor conditions of school facilities as of the early 1990s. More recently, the American Society of Civil Engineers conducted a survey that reported widespread poor conditions. In addition, previous review papers examined studies across different time intervals ending prior to 2002 on the relationships between educational facility indoor air and environmental quality (IEQ), including adequate ventilation, and occupant health and productivity. Beyond work done throughout California and the Nordic countries, research on IEQ specifically related to new or refurbished traditional school construction, or modular portable or relocatable classrooms, has been limited. This paper is not another review on the quantitative and qualitative IEQ measurements and/or quantitative and self-reported health symptom data collected in schools or from school age children at home. Instead, we present a concise review of peer-reviewed literature related to school IEQ. Then, in the context of limited resources facing American schools, we present practical science-based recommendations to improve and promote good school IEQ and hence prevent or reduce potential occupant exposure to biological, chemical, and physical agents of concern. We used National Library of Medicine and University of California (UC) library electronic search engines, conference proceeding books, the Internet, and reference lists of papers and reports gathered. We included 302 citations directly involving or highly related to school IEQ and occupant health, attendance, and productivity or performance. The references were 147 peer-reviewed journal papers; 98 papers or abstracts published in conference proceedings and journals (1990-2003); 26 U.S. government and national laboratory reports; 13 state of California and Washington-sponsored reports or policy documents; 3 World Health Organization documents; 13 reports by not-for-profit research institutions (universities, four professional societies, nine); and, 2 doctoral theses (UC). Tables summarize 18 recommendations justified by references in this review. This report was written for various school stakeholders and for policy makers at the federal and state levels to drive change in local school districts.

## Introduction

Many environmental, social, cultural, and personal factors (e.g., health, gender, age/developmental stage, time-location-activity patterns) influence children's exposure to pollutants across media and pathways in the microenvironments they inhabit during daily activities (Cohen Hubal et al., 2000), including differential susceptibility among infants, toddlers, young schoolchildren, and adolescents (Golub, 2000). Schools are one such microenvironment.

Federal reports on environmental threats to children's health (USEPA 1996, 2000, 2002a) have requested more research on toxic air contaminants and biological agents in urban community-based field studies in microenvironments where children spend time (e.g., homes, schools). Earlier federal government reports provided results of surveys on the generally poor conditions of American school facilities as of the early 1990s (USGAO, 1995, 1996a-b). The American Society of Civil Engineers conducted a more recent survey, which reported widespread poor conditions (ASCE, 2003).

The aforementioned USEPA reports also called for improved risk communication and environmental education. Risk communication of school research results, environmental education and recommendations must inherently be based on the best available scientific knowledge, which is condensed and delivered in a clear manner to targeted stakeholders (Shendell et al., 2002a; Shendell, 2003a-b). Asthma, a respiratory malady with acute and chronic effects, has been the leading cause of school absenteeism (millions of days) due to chronic illness in the United States (Mannino et. al, 2002; USEPA, 2002a and 2002b). In addition, a national survey by the American Lung Association and the National Association of School Nurses (ALA-NASN, 2003) reported that asthma among students of minority and under-served populations was an increasing problem. The surveyed nurses believed there were insufficient financial and information resources available to them to address health concerns among these students. In particular, more than half of the surveyed school nurses stated overall awareness of asthma triggers and awareness about asthma management strategies among parent/caregivers were poor.

Previous review papers have examined studies, for different time intervals ending prior to 2002, concerning relationships between educational facility indoor air and environmental quality (IEQ), including adequate ventilation, and occupant health and productivity (Heath and Mendell, 2002; Angell and Daisey, 1997; Daisey and Angell, 1998; Wargocki et al., 2002; Daisey et al., 2003). Beyond work done throughout California and the Nordic countries, research on school IEQ specifically related to new or refurbished traditional construction (e.g., Boone et al., 1997) or modular classrooms (portables) (e.g., Naylor, 1997; Ross and Walker, 1999) has also been limited. There was one environmental psychology study examining classroom design, in terms of mobility related to occupant density ($m^2$ $person^{-1}$) and fixed versus movable objects like furniture, on everyday teacher tasks and performance (Martin, 2002). Martin's conclusion was the importance of classroom environmental quality awareness in the training and continuing education of teachers.

This paper will not be a similar review on the quantitative and qualitative IEQ and/or quantitative and self-reported health symptom data. Instead, based on reported studies from 1990 (or earlier, for journal articles) to fall 2003, the limited, schools-based peer-reviewed literature, government reports and Internet sites, and conference proceedings, were concisely summarized to determine what science-based, practical recommendations could be made. The proposed recommendations can help inform school stakeholders to act to prevent or mitigate IEQ problems. The goal is to enhance the learning and work environment of students and staff.

**Methodology**

We used National Library of Medicine and University of California (UC) library electronic search engines and conference proceeding books owned by the authors or accessed through colleagues. In addition, we also examined the reference lists of papers and reports gathered, and were aware of previous or new government and professional association reports and school IEQ initiatives. We focused on work available to the public in print, or by Internet, in the English language. The primary keywords were school, school children, classrooms, portables or relocatables or modular classrooms, and attendance. The secondary keywords were the IEQ topics covered in this paper. The IEQ topics appear below.

1. Observed moisture damage
2. Biological agents in air and dust (bacteria, fungi, allergens)
3. Toxic and odorous volatile organic compounds, including formaldehyde
4. Direct measures and indicators (carbon dioxide) of ventilation
5. Temperature and relative humidity (as thermal comfort parameters)
6. Particles and dusts, and chemical residues like pesticides
7. Carbon monoxide
8. Persistent organic pollutants (polychlorinated biphenyls, phthalates)
9. Specific metals (arsenic, lead, mercury)
10. Asbestos
11. Radon gas
12. Lighting
13. Noise

The peer-reviewed journals of relevance covered the period 1968-fall 2003. Final federal and state of California government reports of relevance available to the public were included; case studies or less formal consultant reports were excluded; unpublished non-peer reviewed reports were also excluded. National and international conference proceeding books searched (years available) were:

1. The triennial International Conference on Indoor Air Quality and Climate (1990-2002)
2. The triennial Healthy Buildings Conference (1997, 2000)
3. Annual conference of the International Society of Exposure Analysis (2000-03)
4. Annual conference of the International Society for Environmental Epidemiology (2002-03)

We identified and have included 302 citations directly involving or highly related to school IEQ and occupant health, attendance, and productivity or performance. The references are:

- 147 peer-reviewed journal papers;
- 98 papers or abstracts published in conference proceedings and/or journals (1990-fall 2003);
- 26 U.S. government and national laboratory reports;
- 13 state of California (12) or Washington (1) agency-sponsored reports or policy documents;

• 3 World Health Organization documents;
• 13 reports by not-for-profit research institutions (universities, four; professional societies, 9); and,
• 2 doctoral theses (UC).

**Concise Review of School-based Studies with IEQ Measurements, and Outcomes**

In general, most school IEQ studies, whether or not they also examined qualitative or quantitative outcome measures, focused on specific agents. These will be discussed in a concise manner by topic. Some studies assessed general or subjective IEQ and health outcomes (Rindel et al., 1987; Smedje et al., 1996a, 1997a; Lundin, 1999; Pettinen et al., 2000; Turk et al., 2002).

In general, school absenteeism can be an indicator of the student or teacher's overall health, although attendance patterns result from a complex interaction of many factors (Weitzman, 1986; Chen et al., 2000). Possible associations between types of ventilation, ventilation system renovation or replacement, low ventilation rates, temperature and relative humidity, and/or potential chemical, physical, and biological exposures inside traditional classrooms with student attendance and/or adverse learning or health (student and staff) outcomes have been investigated. (Pepler, 1968; Green, 1974, 1985; Norback et al., 1990; Ruotsalainen et al., 1995; Myhrvold et al., 1996; Myhrvold and Olsen, 1997; Smedje et al., 1997a-b; Wålinder et al., 1997a, 1997b, 1998; Meyer et al., 1999; Åhman et al., 2000; Smedje and Norbäck, 2000, Kim et al., 2002; Sahlberg et al., 2002; Shendell et al., 2003c).
Studies also investigated impacts on child attendance of:
1. Ambient air pollutants (Romieu et al., 1992; Hwang et al., 2000; Makino, 2000; Gilliland et al., 2001), and a hypothesis on ambient and indoor particles (Rosen and Richardson, 1999);
2. Environmental tobacco smoke and children's absenteeism related to respiratory illness (Gilliland et al., 2003);
3. Absenteeism and/or performance related to asthma (Parcel et al., 1979; Silverstein et al., 2001);
4. Various factors on teacher attendance (Ferris et al., 1988).

***Biological Agents***
*Leaks, moisture damaged materials: Underlying conditions to biological growth if not addressed*

Based on location on school grounds, weather, local irrigation, and crawl space cross-ventilation, portable and traditional 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 can also occur in school kitchens (Lignell et al., 2000). Water-damaged building materials containing cellulose and other available nutrients, with or without light, provide a potential breeding ground for fungi (mold) and bacteria. These agents are measured as culturable and/or non-viable spores. Previous studies have demonstrated water-damaged indoor environments are pollutant sources. Measured air and surface concentrations of bacteria and fungi and diversity, including species of potential health concern, were higher than in non-problem buildings (Samson et al., 1994; Haverinen et al., 1999a; Rand, 1999; Sigsgaard et al., 1999; Savilahti et al., 2000; Lappalainen et al., 2001; Meklin et al., 2002a-b). In addition, a case study in the U.S. (Morey et al., 2002) examined whether fungi could enter the occupied air space of school buildings when envelope construction materials were damaged, or enter due to leaks and breaks due to poor design, poor construction, poor siting (for portables), or inadequate commissioning. Barry et al. (2003) reported from a case study that proper school HVAC system design can prevent water condensation on cooled surfaces of building materials, and subsequent moisture damage and mold growth. This appears most pertinent to regions like New England and the southeastern U.S., which have hot, humid conditions in late spring-early fall.

In a Finnish school study reported by Haverinen and colleagues (1999a), the documented moisture damage was caused primarily by poor ventilation and water leaks. The school was subsequently repaired with community input following communication of visual inspection and measurement results. Drainage and crawl space ventilation was improved and damaged materials were replaced. In another Finnish study of 41 buildings at 30 schools (31 moisture damaged, 10 not damaged), there was no clear association between building recorded characteristics and water damage status (Koivisto et al., 2002). However, the authors stated the most common reasons for moisture damage were technical aging of materials (27%)-- especially floors in concrete/brick frame buildings (possibly due to unvented crawl spaces) and external walls in wood frame buildings-- and water leaks (13%).

Meklin et al. (2000) studied 32 Finnish schools (30 with health data available) in 1994-99, which they divided into two groups: moisture damaged; non-damaged, reference schools. Though no statistically significant differences were found in measured total concentrations of airborne culturable fungi, some identified fungal groups differed. Furthermore, children in moisture damaged schools reported significantly more respiratory symptoms.

Meklin et al. (2002a) reported on a case study of two Finnish primary schools constructed of concrete; one was found to be moisture damaged. In the five years between the baseline and follow-up assessments, which included self-administered health questionnaires, IEQ sampling, and surface moisture recorders, the damaged school was renovated. The renovation of the moisture damaged school resulted in significant decreases in the geometric mean airborne concentrations of culturable bacteria ($p=0.006$) and culturable fungi ($p=0.002$). Differences between the damaged school before repairs (higher) and the reference school (lower) with respect to those airborne concentrations, and number of microbial genera identified, did not persist after repairs. In addition, after repairs, significant decreases ($p<0.05$ or better) in reported prevalence of eye symptoms, cough with and without phlegm, and rhinitis, as well as other general symptoms, were observed. A case study of staff from a Danish school rebuilt after a long history of water damage also reported the prevalence of mucosal and general symptoms, including eye irritation (from 29% to 7%), significantly declined (Sigsgaard et al., 1999, 2000).

Haverinen et al. (1999b, 2002) reported on a case study of a Finnish upper secondary school before and after comprehensive repairs of moisture damage (see Haverinen et al., 1999a). Self-administered student health symptoms questionnaires, technical inspections, and relevant IEQ sampling were conducted. For students attending the school and responding to the questionnaire twice (1996 and 1997, n=157 of 245) or three times (1996, 1997, 1999, n=49), their paired, individual level observations were examined. Results showed significant ($p<0.05$ or better) declines in the prevalence of eight symptoms at first follow up, including rhinitis and difficulties in concentration. The crude prevalence was lower for 11 symptoms -- including rhinitis, asthma, eye symptoms -- but higher for eight symptoms at second follow-up. Though the small sample size likely precluded significant findings at second follow-up, the authors stated overall results suggested no new cases of symptomatic students were expected after repairs.

Rudblad et al. (2000, 2001) reported results of a study of a Swedish school with a long history of dampness. Staff and 1st grade students (90, 45 each from damp and reference schools) were included. They used, before and one year after renovation, a standardized health questionnaire and two types of quantitative health symptom tests—mucosal sensitivity based on a nasal histamine provocation test, and presence of atopy based on a skin prick test. No differences were observed among students from the damp and reference schools. However, in the damp school after renovations, differences were seen among staff and students—staff demonstrated more mucosal symptoms, but prevalence of atopy among students was about a factor of two higher. These results suggested possible differential susceptibility, in problem and non-problem (or post-renovation) buildings, due to age, gender, underlying health status, and/or agents not studied.

Patovirta et al. (2003) conducted a case study of one moisture-damaged school and one reference school in Finland with teacher health questionnaires, spirometry, and blood samples in the spring before (1997) and after (1999 and 2000) remediation was completed. Asthma prevalence at baseline among participants in the moisture and mold-damaged school (n=31) was 26%, but no new cases appeared during follow-up after repairs. In addition, eye irritation and several respiratory symptoms decreased in prevalence during follow-up.

Three markers in nasal lavage fluid of the inflammatory potential of airborne microbial agents, collected from staff (n=28) in a moisture-damaged Finnish school, were significantly increased ($p<0.01$ for each) during the working period compared to a vacation period (Roponen, 2003).

Other studies in Nordic countries have reported measurements of allergy, respiratory symptoms, and infections among students in moisture and mold-damaged schools or day care centers (Koskinen et al., 1995; Taskinen et al., 1997, 1999; Savilahti et al., 2001). There were also studies with skin-prick tests (Immonen et al., 2001) and of the effect of exposure to airborne (1→3)-beta-D-glucan (Rylander, 1997; Rylander et al., 1998) or to a microbial disinfectant introduced through the ventilation system (Sesline et al., 1994).

*Biological, non-infectious agents in air and dust*

Bacteria and fungi, and cell wall components or metabolites

In several case studies in Finland and the U.S., the most common fungal groups reported from culturable indoor air samples were *Penicillium*, *Cladosporium*, *Aspergillus*, yeasts, and non-sporulating isolates (Sigsgaard et al., 1999, 2000; Kalliokoski et al., 2000, 2002; Meklin et al., 2002a; Morey et al., 2002; Barry et al., 2003). Total culturable airborne bacteria as well as cell envelope components have also been measured (Liu et al., 2000). A laboratory-based environmental chamber study with samples of materials used in school construction and interiors identified metabolites, most of which were non-reactive, from microbes growing on particleboard, gypsum board, and wood (Claeson et al., 2002). However, potentially odorous aldehyde emissions decreased during microbial growth.

Kalliokoski et al. (2002) assessed kitchens, dining halls, and classrooms of six moisture-damaged schools and two reference schools within the Finnish school study population already described. Average total airborne concentrations of culturable fungi, across study areas within buildings, were higher in the moisture-damaged than reference schools, and the difference was statistically significant in the classrooms.

Smedje et al. (1996b) studied measured indoor pollutant concentrations in 96 classrooms and self-administered questionnaire responses on health symptoms of 1410 adult employees (85% response) from 38 participant schools (of 40 randomly selected) in county of Uppsala, Sweden. They reported a significant association between physician-diagnosed asthma and total airborne fungi (odds ratio (OR) 1.6, 95% CI 1.1-2.7, p=0.023) and four microbially produced volatile organic compounds (MVOCs; OR ranged 1.2-3.8, 95% CI did not include 1, p<0.05). Sahlberg et al. (2002) studied sick building syndrome symptoms (SBS) among school staff in the same schools. They repeated questionnaires three times (1993→ 1410 participants or 85%, 1995, 1997) and IEQ measures twice (98 classrooms in 1993, 101 classrooms in 1995). They reported a positive, significant association between total airborne bacteria (number $m^{-3}$) and eye symptoms (adjusted OR 2.5 per 10-fold increase, 95% CI 1.3-4.9, p<0.01). The Copenhagen school study also reported a significant association between visible moisture damage with mold growth and increased prevalence of SBS (Meyer, 1999).

Norbäck et al. (2002) assessed 1414 participating students from 10 schools in Shanghai, China (of 1435, 99%) with a self-administered questionnaire in winter 2000. In 30 home-classrooms, indoors and outdoors, qualitative inspections and quantitative sampling of airborne total and viable (culturable) bacteria and fungi as well as MVOC, and settled dust for markers of these biological agents, were conducted. Forty-five percent of the students reported respiratory infections, which were positively and significantly associated with culturable airborne fungi (p=0.04), culturable airborne bacteria (p=0.02), and a MVOC, 3-methylfuran (p=0.04). Studies in Taiwan have also suggested indoor exposure to bioaerosols may have health implications in schools (Su et al., 2001) and child care centers (Li et al., 1997a-b).

Allergens

Allergens in floor and surface dust in school classrooms, which likely were transported on children's clothes from homes (Berge et al., 1998), may influence the prevalence and severity of asthma symptoms and allergies (Dybendal et al., 1989; Dybendal and Elsayed, 1992; Munir et al., 1993; Dotterud et al., 1997; Patchett et al., 1997; Perzanowski et al., 1999a-b; Almqvist et al., 1999, 2001; Smedje and Norbäck, 2001a-b; Douwes et al., 2003). Pollen allergen, however, is predominantly from outdoor air (Kvernes et al., 1999; Matson et al., 2002).

Wady et al. (2003) sampled allergens and microbial components in settled dust in two schools (one rural, one urban) in each of Jordan, Poland, and Sweden. Dust was collected on plates suspended from ceilings at children's breathing zones. Though the marker of bacterial biomass exhibited minimal variation, markers of identified groups and fungal biomass varied considerably. These results suggested different potential exposures to microorganisms inside school classrooms between countries, seasons, and urban versus rural settings.

Ramachandran et al. (2002) compared IEQ and outdoor measures at a newer school building with an older school building in metropolitan Minneapolis, MN. Reported measurements were below current sensitization or symptoms guidelines (IOM, 1993; AIHA, 1996) for cat allergen (*Fel d 1*, 8 ug g-1) and dust mites *Der p 1* and *Der f 1* (2 μg $g^{-1}$ or 10 μg $g^{-1}$, respectively). Also, most cockroach allergen (*Bla g 1*) measurements were low (<MDL (method detection limit) to 3 μg $g^{-1}$). Tortolero and colleagues (2002) assessed 385 classrooms in 60 elementary schools in southeast Texas. They reported only 2.5% of rooms had *Der f 1* exceeding recommended guidelines, and only 10% of rooms were over the recommended threshold for *Bla g 1* though it was found in every school. These findings may reflect adequate cleaning practices. Wickman et al. (1999) examined the effect of general cleaning, ventilation, and occupant pet ownership on allergen levels in day care centers.

Floor dust was collected from 23 classrooms in county of Uppsala, Sweden, where floors were cleaned daily by staff and desks wiped by students 1-5 times per week. Floor dust was also collected from 30 classrooms in Shanghai, China, where students cleaned floors and desks daily. Four allergens (*Der p 1* and *Der f 1*, *Bla g 1*, and mold allergen *Alternaria alternata*, *Alt a 1*) were never reported above MDL. Again, these results were likely due to the good cleaning practices. Furthermore, *Fel d 1*, dog (*Can f 1*), and horse (*Equ cx*) allergens were almost always below MDL in the Chinese schools, but always much higher than the MDLs in the Swedish schools. One could infer this was not only because of cultural characteristics and outdoor surroundings, but also because of the relatively higher frequency of reported desk cleaning among schools in Shanghai. (Mi et al., 2002)

A mechanical HVAC system with a common fine filter has been demonstrated to remove 95-99% of birch tree pollen grain allergen (*Bet v 1*), depending on the filter efficiency rating (Ekberg et al., 2000). Matson et al. (2002) measured indoor and outdoor air concentrations of *Bet v 1* in one pre-school and one day care center in Sweden. Indoor/outdoor ratios (I/O) were below one, confirming the dominant outdoor source. The I/O was over a factor of three lower when the HVAC was off, windows were closed, and occupant activity was minimal compared to when the HVAC was on, windows were open, and occupant activity was high. When windows were closed but the HVAC on and activity high, the relative difference was about a factor of two. These results suggested several open windows, relative to operation of the mechanical HVAC system with filtration, drove indoor *Bet v 1* levels.

*Summary: Biological agents*

In conclusion, these studies collectively suggested remediation of moisture and mold-damaged school buildings, particularly classrooms, and primary prevention through diligent operations, maintenance, and cleaning practices, improved IEQ and occupant health. In addition, the studies on measurements of biological agents in school classrooms around the world collectively suggested levels in air and surface dust are generally low relative to outdoors, especially when good hygiene practices are present.

***Chemical Agents and Particles***

*Toxic and odorous volatile organic compounds (VOCs)*

Materials used to construct and furnish portable classrooms, and traditional school buildings especially if new or modernized, may off-gas toxic and odorous volatile organic compounds (VOCs) including formaldehyde (HCHO) and acetaldehyde as a function of age, temperature, and relative humidity (Lewis, 1991; CARB, 1993; Hodgson et al., 1993, 1999, 2000, 2001, 2002, 2003; Norbäck, 1995; Zhang et al., 1994; Kelly et al., 1999; Claeson et al., 2002). Associations between emissions from such materials and other indoor sources with adverse child respiratory outcomes were investigated (Jaakkola et al., 1999, 2000; Herbarth et al., 2003). These studies included potential exposure to HCHO, a known human sensory and respiratory irritant (CARB, 1991; USEPA, 2003a) and allergen (Wantke et. al, 1996; Garrett et. al, 1999). Nikolic (2000) studied IEQ over 20 consecutive winter days in classrooms of two primary schools in Nis, Yugoslavia; "school 1" was located in an industrial zone near a busy street, and "school 2" was situated away from major outdoor pollution sources and enclosed by vegetation. Low integrated daily indoor HCHO concentrations were associated with no new construction materials and furnishings; measured concentrations in "school 1" were relatively higher than in "school 2" possibly due to relative proximity to primary and secondary ambient HCHO sources.

Several VOCs, especially odorous compounds, and potential endocrine disrupters and neurotoxicants including phthalates, have been found in constituents of various consumer products and measured in indoor air of homes, offices, and schools. These included personal care products (hair, facial beauty, nail polish and remover), cleaning compounds, and teaching supplies and materials (Wallace et al., 1991, Hodgson, 1999; CARB, 1991, 1993, 2001; Smedje and Norback, 2001a; Martins et al., 2003). The European Union task force on school IEQ cited the presence of multiple VOC sources such as paints, cleaners, interior finish materials and furnishings (Carrer et al., 2002). A recent laboratory toxicology 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 (Anderson and Anderson, 2003). School studies have suggested the 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 of VOCs (Cavallo et al., 1993; Torres et al., 2002; Shendell, 2003; Shendell et al., 2002d, 2003a; Batterman et al., 2003a).

Reactive, unsaturated organic chemical compounds (e.g., d-limonene, alpha- and beta-pinene), which are common constituents of cleaning compounds with recognizable odors, and other VOCs in heterogeneous reactions on indoor surfaces, especially in the presence of ozone entering from the outdoors, may produce concentrations of other pollutants of health concern. These include fine and ultrafine particles and oxidation products. (Wainman et al., 2000; Wolkoff et al., 2000; Fielder et al., 2002; Klenø and Wolkoff, 2002; Rohr et al., 2002; Wilkins et al., 2002; Fan et al., 2003).

*Building interior finish materials and furniture: "sources" and "sinks" of VOCs and particles*

Carpets and other flooring surfaces, adhesives, and office equipment typically found in schools such as photocopiers and laser printers, have been demonstrated in laboratory environmental chamber and field studies to be sources of VOCs (Hansen et al., 1987; Hodgson et al., 2001, 2002, 2003; Lee et al., 2003). Other studies focused on carpets and open shelves (flat, exposed surfaces) as sinks for and thus sources of indoor pollutants such as dust, which can contain particles, allergens, and/or pesticide residues (e.g., Hansen et al., 1987). Floor carpets, which can cover a large surface area and vary in pile thickness, can hold a large quantity of dust unless properly vacuumed. In a study of 181 classrooms in 48 schools in the county of Uppsala, Sweden (Smedje and Norbäck, 1999a), HCHO concentrations and settled dust were higher in classrooms with more fabrics ($p<0.05$) and with more open shelves ($p<0.001$). This finding persisted after adjusting for measured ventilation rates, which correlated ($p<0.01$) with several IEQ measures.

*Particles generated, tracked in as soil, and/or re-suspended, 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. Numerous studies have supported their role, when measured in ambient air, personal air, and in the indoor air of residential or occupational settings, in adverse respiratory and cardiovascular outcomes. Sources of particles in schools include soil tracked in from the outside; re-suspension from carpets or smooth flooring acting as reservoirs (sinks), as a function of occupant activity and overall maintenance (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 (e.g., boiler room). For example, Elfman et al. (2000) conducted a case study of the reopening of a refurbished, thoroughly cleaned school in Sweden. Airborne levels of particles increased over the first two months and varied due to occupant activity.

Few studies have been conducted regarding pesticide residues, and/or metals and polycyclic aromatic hydrocarbons of potential health concern, in settled dust collected from carpets, smooth flooring, and other surfaces inside classrooms. Insecticides and pesticides inside classrooms (Fischer and Eikmann, 1996) or on school grounds may be used in varying quantities, frequencies, duration, and times of day and seasons. In the California Portable Classrooms Study (CARB, 2003c), chlorpyrifos was found above MDL in over 80% of monitored portable and traditional classrooms. Morgan et al. (2003) presented preliminary results on concentrations of chlorpyrifos and its metabolite, 3,5,6-trichloro-2-pyridinol, in day care centers of 130 recruited North Carolina pre-school age children. Levels in dust were about 1-2 orders of magnitude relatively higher than in samples from adjacent outdoor soil, hand wipes, indoor air, and urine. Wilson et al. (2003) reported preliminary results (1st year) of a pesticide exposure study of preschool children. Chlorpyrifos has been subjected to a mandatory phase out of its sale and use in homes and schools since late 2001. However, use of existing stock purchased prior to federal and local legislation could occur in homes and schools, with or without proper notice. Thus, measured concentrations could represent recent and/or historical use.

A study of senior high school students and personnel (8853 and 1023, respectively, 16 schools) in metropolitan Stockholm reported a high prevalence of dust and dirt, and high indoor air temperatures, as perceived IEQ problems from self-administered surveys (Andersson et al., 2002). Reported symptoms were higher among students, and females in general. In the previously described Swedish study by Sahlberg et al. (2002) of SBS among school staff, there was a positive and significant association between respiratory dust ($\sim PM_{10}$) and respiratory infections (adjusted OR 1.31 per 10 $\mu g\ m^{-3}$ increase, 95% CI 1.06-1.58, $p<0.05$). Smedje and

Norbäck (1999b) conducted a study with two separate rounds of classroom assessments and self-administered questionnaires of 1476 pupils (of 2034 invited) between ages 7-13 from 39 schools (of 40 randomly selected) in county of Uppsala, Sweden. Students attending schools with higher amounts of measured settled dust on floors and furniture and dog allergen had a higher incidence of current asthma symptoms. However, asthma symptoms were lower among students attending schools where new HVAC systems had been installed between the two investigations in 1993 and 1995. These results may reflect how 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, some studies have suggested, based on laboratory experiments and office building assessments, HVAC system filters can be sources of chemical and microbiological pollutants including odors (e.g., Souto and de Oliveira Fernandes, 2000).

The Copenhagen study on school facility conditions and building related symptoms (BRS), based on 7884 of 11978 returned employee and student self-administered questionnaires, included 75 schools and 78 of 112 identified classrooms. Among the results, data suggested the *in vitro* inflammatory potentials of settled dusts collected from floors were significantly higher ($p<0.0001$) among the ten schools with the highest mean prevalence of eight reported BRS ("worst") compared to the ten "best" schools. The substance within the dust's organic fraction causing inflammatory potential was not identified. (Meyer et al., 1999; Allermann et al., 2002).

Norbäck et al. (2000) and Wålinder et al. (1999, 2000, 2001) reported on the use of acoustic rhinometry, nasal patency, and nasal lavage fluid biomarkers as quantitative indicators of effects of settled dusts, cleaning practices and products, and building characteristics, in Swedish schools.

*Carbon monoxide and combustion-related pollutants from nearby outdoor sources*

Sahlberg et al. (2002) reported low levels of carbon monoxide (CO) in a previously described Swedish school study (average 0.2 $\mu g\ m^{-3}$, range <0.1-0.9). Shendell (2003) reported CO concentrations inside Los Angeles Unified School District portable classrooms of varying ages in winter 2001. The mean and median weekend and daily morning and afternoon integrated averages were low (< 2 parts-per-million (ppm)). However, the maximum reported indoor value was on a morning when researchers observed and teachers reported medium-sized diesel and gasoline fueled trucks idling while delivering supplies for the cafeteria and main office stockroom before and into school hours. The specific influence of school buses, particularly conventional, older buses powered by high or low sulfur diesel fuel, on children's exposures was recently studied by the University of California (CARB, 2003a; Fitz et al., 2003; Behrentz et al., 2003; Sabin et al., 2003; Winer et al., 2003). Although the study focused on the range of exposures inside buses during different commuting routes, under various defined conditions, there were specific aspects of their findings and concurrent policy actions relevant to school IEQ. Loading and unloading children at the participating schools contributed less to overall commute-related exposures, due to the low concentrations in ambient air found at those locations and the relatively shorter lengths of time involved. The investigators made several recommendations to reduce children's exposure to bus-related pollutants, including reducing idling time. In December 2002-July 2003, the California Air Resources Board initiated and approved an airborne toxic control measure (CARB, 2003b). This action limits school bus idling prevalence and duration within 100 feet of school buildings (e.g., < 30 seconds while loading students at school). Similarly, the USEPA initiated in April 2003 the "Clean School Bus USA Program" to reduce unnecessary idling and to increase the retrofitting or replacement of older diesel school buses (USEPA, 2003b).

In summary, neither buses nor trucks powered by diesel or gasoline engines should be allowed to remain idling near school facility outdoor air intake vents, which is particularly a concern for portable classrooms or buildings with wall-mount, not rooftop, HVAC systems. Such a policy would reduce indoor concentrations of CO, particles, and other vehicle-related combustion pollutants such as polycyclic aromatic hydrocarbons and nitrogen oxides.

***Physical Agents and Related Characteristics of Schools***

*Direct measures, or carbon dioxide concentrations as indicators, of inadequate ventilation*

Portable and traditional classrooms including childcare facilities are usually more dependent on mechanical ventilation to provide fresh outside air than windows, if operable, and doors. ASHRAE Standard 62 (1999) stated 15 $ft^3$ $min^{-1}$ $person^{-1}$ of filtered outdoor air should be supplied to the occupied indoor space. Review articles (Angell and Daisey, 1997; Daisey and Angell, 1998; Daisey et al., 2003) have stated reported ventilation and $CO_2$ data from the U.S., including federal NIOSH investigations, indicated inadequate outdoor air ventilation in many school classrooms and poor HVAC system maintenance. A USEPA school evaluation program for radon reduction (26 schools, eight regions) found most schools did not meet current standards for school ventilation (Chmelynski and Leovic, 1992; Parker, 1992). Each school reported having one or more ventilation problems, and the various HVAC systems were usually not designed or operated properly. One case study examined effects of operable window installation in a "sealed" school without mechanical HVAC (Landrus et al., 1987).

The California Energy Commission (1995) found measured ventilation rates (air changes per hour, ACH or AER, $hr^{-1}$) in one-third of classrooms tested were < 50% of the level required by state codes and ASHRAE Standard 62. Quantitative measurements of ventilation rates for school classrooms have also been conducted during unoccupied hours with sulfur hexafluoride tracer gas decay (Shaughnessy et al., 1997; Turk et al., 1997) and during occupied hours with a non-toxic perfluorocarbon tracer gas (Shendell, 2003; Shendell et al., 2003b). Ruotsalainen et al. (1993) reported quantitative spot measurements of exhaust air flow as an indicator of ventilation system performance in day care centers in Espoo (metropolitan Helsinki), Finland at the time of measured equilibrium carbon dioxide ($CO_2$) 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. (Bakke and Levy, 1990; Norbäck et al., 1990; Thorstensen et al., 1990; Kurnitski and Enberg, 1997; Myhrvold and Olsen, 1997; Rodríguez et al., 1997; Shaughnessy et al., 1997; Turk et al., 1997; Lee and Chang, 1999, 2000; Smedje and Norbäck, 1999a; Braganza et al., 2000; Scheff et al., 2000; Kinshella et al., 2001; Corsi et al., 2002; Pasanen et al., 2002; Prill et al., 2002; Ramachandran et al., 2002; Ribéron et al., 2002; Sowa, 2002; Tortolero et al., 2002; Batterman et al., 2003b; Fox et al., 2003)

A European Union task force, which examined 73 journal papers or conference proceedings from 1990-2000 on IEQ in European schools, reported inadequate ventilation in schools as indicated by elevated $CO_2$ concentrations and relative humidity (Carrer et. al, 2002). After new ventilation systems were installed in 12 of 100 classrooms in the 39 randomly selected schools in the previously described Swedish school study in county of Uppsala, Smedje and Norbäck (2000) reported the measured AER increased and concentrations of several monitored pollutants as well as relative humidity declined. In 15 Finnish school buildings, which received ventilation renovations (mechanical or natural), although indoor air temperatures remained high before (mean 23ºC) and after (mean 22ºC) renovations, the measured indoor $CO_2$ concentration range decreased from 1200-2400 ppm to <1250 ppm (Jalas et al., 2000).

Gunnarsen (2000) reported on a historically poorly maintained Danish school and the remediation of its mechanical ventilation system, windows, temperature controls, and ceiling heights. The interventions resulted in some IEQ improvements due to enhanced user controls. Hunter (1990) reported on interventions in a windowless secondary school in Toronto, Canada to improve the mechanical HVAC system-- increasing outdoor air intake and air circulation, new humidification system and heat exchangers. The result was quantitative compliance with thermal comfort guidelines.

*Indoor air temperature and relative humidity, thermal comfort*

Ventilation, mechanical and/or natural through windows, 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, ASHRAE Standard 55 (1992) was developed for adults, typically in the office environment, and it is not known how well these conditions apply to children in school environments. Furthermore, the Standard 55 guidelines may not always be appropriate for tropical climates such as Hawaii (Kwok, 1997, 1998). Indoor air T and RH are also influenced by occupants through occupant density and their activity levels, i.e., respiration and perspiration. School studies in Las Vegas (Shaughnessy et al., 1997), Santa Fe, NM (Turk et al., 1997), Los Angeles (Shendell, 2003; Shendell et al., 2003b), Copenhagen, Denmark (Thorstensen et al., 1990) and Uppsala, Sweden (Smedje and Norback, 1999a; Sahlberg et al., 2002) reported measured AER, T, and RH.

The recently completed LBNL relocatable classroom (RC) study (Apte et al., 2002, 2003) suggested mechanical ventilation, natural ventilation as desired and possible, and appropriate teacher T set points could allow RCs to achieve both good IEQ and compliance with acceptable seasonal T and RH ranges in ASHRAE Standard 55 (1992). In the LBNL study, though there was negligible vertical T stratification when HVAC systems operated, when ASHRAE Standard 55 was not met it was usually due to measured indoor air RH. In the LBNL and UCLA school studies (Shendell et al., 2002b, 2003b; Shendell, 2003), 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. These included afternoon cooling and morning heating demands on mechanical HVAC system operation; attributes of the mechanical HVAC system technologies; occupants; ambient conditions; and, teacher T set point preferences.

Measures of indoor air RH can also serve as indicators of condensation build-up on interior surfaces, and thus potential moisture damage of materials and subsequent mold growth. For example, Bates and Mahaffy (1996) investigated 13 classrooms in six schools in Florida. Indoor air and carpet concentrations of dust mite allergens and airborne culturable fungi, relative to outdoors, were low. Nevertheless, reported occupant health complaints and musty odors, and visible mold, were associated with higher (> 70%) average indoor air RH.

*A-weighted Noise Levels*

Noise is any unwanted, extraneous sound. People can detect minute changes in sound level; an increase of three A-weighted decibels (dB (A)) is just noticeable, five dB (A) is clearly noticeable, and 10 dB (A) is considered twice as loud (ASHRAE, 1989). At birth, the human inner ear has completely developed; hair cells and nerve fibers cannot regenerate once destroyed by noise (Lancet, 1991; Clark and Bohne, 1999; WHO, 2001b). Children, during their formative years of academic development, require better acoustic quality than adults in classrooms, especially given good speech recognition is necessary for optimal comprehension and learning during the processes of language and reading acquisition (WHO, 2001a-b). Children are ineffective listeners to speech (i.e., cannot hear and understand) in noise until adolescence (Nelson, 2003). Children with hearing impairments, and learning and/or attention disorders, are especially susceptible and have unique needs, as do those learning in a second language (Nelson, 2003).

Typical classroom sources of noise are listed below.

1. Noise from the outdoors, such as playgrounds, construction, and nearby traffic.
2. Mechanical noise, for example, when the HVAC system and adjacent classroom surfaces vibrate to produce airborne noise. A survey by Parker (1992) found the unit ventilator was the most popular HVAC system in U.S. schools, but noise and operating limitations-- the fan must always be on to effectively provide adequate ventilation-- have reduced its popularity.
3. Noise from other indoor sources. These include occupants, TV/VCR, and lighting ballasts and dimmers (transformer humming), including reverberation.

There have been to our knowledge, however, few published scientific studies on quantitative exposure to noise levels in American school classrooms due to indoor and outdoor sources, although non-regulatory guidelines have been established (see Appendix I). One study was conducted in New Zealand (Blake and Busby, 1994). A study conducted by the University of Florida at Gainsville suggested noisy classrooms may hinder student learning ability; students had difficulty hearing the teacher when > 12 feet away and noise levels exceeded the average background of 50 dB (A), even though normal conversation is about 60 dB (A) (Wakefield, 2002). Braganza et al. (2000) reported on one of the USEPA school IEQ demonstration studies. One set of measurements Tuesday-Thursday during occupied hours at four indoor sites and one outdoor location per school were conducted at eight public schools across the U.S. prior to energy efficiency retrofits and interventions, e.g., implementation of USEPA *Tools for Schools*. Across the eight schools, mean sound levels ranged 45-62 dB (A) and the maximum five-minute sound levels ranged 70-81 dB (A). These data were consistent with the recent study of new California RCs by LBNL (Apte et al., 2002, 2003; Shendell et al., 2002b-c)-- mean school day $L_{eq}$ across classrooms and wall-mount HVAC systems were approximately 56 dB (A). There was one previous study in California schools in traditional buildings (CDE, 1986).

The acoustic design goal for a mechanical HVAC system, where specific noise control techniques are a function of space-use requirements, is usually a low-level background sound

(ASHRAE, 1989). Measurements in dB (A) compensate for the human ear's lower sensitivity to lower frequency and very high frequency sounds (ASHRAE, 1989). Thus, though dB (A) correlates well with human judgment of relative loudness, the metric does not correlate as well with human judgment of relative noisiness or subjective sound quality, i.e., comparing sounds with distinct spectral or tonal characteristics including frequency (ASHRAE, 1989). High-frequency sounds may be relatively more hazardous to human hearing, and high-frequency, intermittent, and impulsive sounds may be more annoying due to their temporal unpredictability. A large proportion of low-frequency components in noise may have adverse effects (WHO, 2001a).

Scientific evidence has suggested chronic noise exposure in communities near air, road, and/or rail traffic, as a stress and distracting stimulus, can lead to noise-induced hearing loss, annoyance, sleep disturbance, stress, mental health and behavior problems, and decreased school performance and cognitive delays. These include trouble with word discrimination, reading, problem solving, memorization, and interference with speech communication. There was also evidence of elevated blood pressure and heart disease in adults and children. (Slater, 1968; Wyon, 1970; McLean and Tarnopolsky, 1977; Ising et. al, 1980, 1990; Gunn et. al, 1981; Cohen and Weinstein, 1981; Westman and Walters, 1981; DeJoy, 1984; Siebert, 1989; Clark, 1991; Duncan et. al, 1993; Powers, 1993; Sanz et. al, 1993; Bond, 1996; Soli and Sullivan, 1997; Evans et. al, 1998, 2001; Lercher et. al, 1998, 2002; Maxwell and Evans, 2000; Passchier-Vermeer and Passchier, 2000; Booker, 2001; Haines et. al, 2001a-c, 2002a-b, 2003; Manlove et. al, 2001; WHO, 2001 a-b; Van Kamp et al., 2002, 2003; van Kempen et. al, 2002; Wakefield, 2002; Jovanovic, 2003).

*Fluorescent lighting and daylighting*

Lighting and daylighting through windows and skylights have recently been studied in relation to physical development and academic performance (Hathaway, 1995; Heschong Mahone Group, 1999). In addition, the study by Sahlberg et al. (2002) of SBS among Swedish school staff reported several relevant findings. Illumination (per 100 lux increase) and lighting effect (per 10 $W m^{-2}$ increase) were significantly associated with decreased fatigue, a general symptom (adjusted OR (95% CI) of 0.90 (0.84-0.99) and 0.59 (0.38-0.90), respectively, $p<0.05$). Lighting effect (per 10 $W m^{-2}$ increase) was also significantly associated with fewer eye symptoms (adjusted OR (95% CI) 0.43 (0.21-0.90), $p<0.05$). The daylight factor, which was based on each 10% increase in window area ($m^2$) per floor surface area ($m^2$), was significantly associated with fewer headaches, a general symptom (adjusted OR (95% CI) 0.62 (0.39-0.99), $p<0.05$).

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, there is little peer-reviewed published data for conclusions on health and performance in schools due to relative advantages or disadvantages of artificial versus natural light. However, work emerging on this topic suggests benefits to daylighting. We can thus support some comments. First, glare from incident sunlight on to or reflecting off surfaces (e.g., desks, computer screens) should be reduced to the extent practical. Second, there is a guideline regarding quantity of light to be provided indoors to students (IENSA, 2000 discussed in Shendell et al., 2002b): 50 foot-candles for low contrast materials, 30 foot-candles for high contrast materials.  Third, student desks should not be placed directly in front of windows due to the potential negative impact on learning (reading) and thermal comfort.  Finally, when indirect natural light through windows or skylights is sufficient, fluorescent lights should be turned off. This will save energy and money and assist school occupants whose health and learning are affected by artificial light, a condition termed Irlen Syndrome or Scotopic Sensitivity Syndrome. The condition is caused by hypersensitivity to the physical properties within light sources (spectrum of colors, wavelengths).  Several medical studies have examined this class of learning disabilities in school children, which includes reading disorders and attention deficits (Lehmkuhle et al., 1993; Robinson et al., 1995).  Other medical studies have examined the practicality and short and long-term efficacy of interventions for children, e.g., Irlen tinted lenses, colored versus clear plastic transparencies on books (Robinson and Miles, 1987; Saint-John and White, 1988; Whiting et al., 1988; Cotton and Evans, 1990; O'Connor et al., 1990; Robinson and Conway, 1990, 1994; Williams et al., 1992; Menaker et al., 1993; Tyrrell et al., 1995; Jeanes et al., 1997).

***Persistent organic pollutants and possible endocrine-disrupting chemicals: Present concerns possibly present in older schools***

Polychlorinated biphenyls (PCBs) are likely present in schools with fluorescent light fixtures not replaced after 1979.  PCBs, with low electrical conductivity, had been used in the small magnetic capacitors and in the insulating potting material (USEPA, 2001).  Newer, more energy-efficient, and higher quality light producing T-8 or T-5 electronic capacitor-based ballasts, which are generally recommended for "green," sustainable design, do not contain PCBs.  U.S. production of PCBs stopped in 1978 under the Toxic Substances Control Act of 1976.  Older ballasts breakdown and become susceptible to leaks and fires, hence accidental exposures to PCBs.

PCBs and other persistent organic pollutants, especially endocrine-disrupting chemicals, have been shown in ecotoxicology and laboratory toxicology studies to mimic hormones across gender and disrupt the endocrine system.  These changes might lead to other adverse health consequences, e.g., child neurobehavioral and physical development, reproductive health of young female teachers (Gabrio et al., 2000; Heindel, 2000; Suk et al., 2003).  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 residues of such chemicals.  The present concerns include pesticide residues, fertilizers on grounds, and plasticizers including phthalates. Phthalates can be found in foods, consumer products, and certain interior finish materials (Jaakkola et al., 1999, 2000; Simoneau, 2003; Suk et al., 2003).

The phthalates of high present concern in the media and to governments in Europe, Japan, and the U.S. are di-2-ethylhexyl phthalate (DEHP), dibutylphthlate (DBP), diethylphthlate (DEP), and diisononyl phthlate (DINP).  DEHP was recently listed (October 24, 2003) by the California Office of Environmental Health Hazard Assessment, under Proposition 65 (Safe Drinking Water and Toxic Enforcement Act of 1986), as a known toxicant for developmental and male reproductive endpoints based on laboratory toxicology studies (OEHHA, 2003).  In 1986, the U.S. started a voluntary agreement with manufacturers to remove or limit phthalates in plastic, soft flexible toys.  The European Union and Japan recently established bans on DINP and/or DEHP to protect pre-school children (<3 and <6, respectively).

Polyvinyl chloride (PVC) flooring contains plasticizers like phthalates, and because it is of low cost and easy to maintain and to clean, it has been used in school classrooms and other areas around sinks and lab benches. Koch et al. (2003) reported, based on first morning urine samples of 36 German kindergarten children ages 2-6 and 19 adult staff and parents, widespread exposure to DEHP, with levels of metabolites in urine higher in children than in adults tested. Jaakkola et al. (1999), in a matched case-control study of newborns (n=251 pairs) followed for two years, reported a significant elevated risk of bronchial obstruction when PVC flooring was present compared to wood or parquet flooring (adjusted OR 1.89, 95% CI 1.14-3.14). In a population-based cross-sectional study of 2553 Finnish children, though only about 3% reported the presence of plastic wall materials at home, there were statistically significant relationships between this crude exposure variable and lower respiratory tract symptoms (wheezing, coughing, phlegm production), but not asthma or pneumonia (Jaakkola et al., 2000). Nevertheless, overall, Longnecker et al.(2003), who led a conference seminar in 2000 on endocrine disruption for a group assisting initial planning of a proposed U.S. National Children's Study, reported present evidence is not strong for endocrine disruption in humans with background-level exposures.

***Asbestos, radon, and specific heavy metals of concern***

*Asbestos*

Exposure to asbestos through inhalation of loose fibers of this naturally occurring mineral substance, which can be found in ceilings and walls (e.g., fire retarding insulation on structural beams, soundproofing materials), has been shown to cause lung disease in humans and animals. Federal requirements for schools for inspection, notification, and containment in bound form or for the 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 (USEPA, 2003c).

*Radon*

Radon is an inert, colorless, odorless, radioactive gas. Epidemiological studies have demonstrated a causal association between radon and lung cancer. Radon derives from uranium, which is present in soils and rock. The USEPA has published several reports with data and suggestions for the mitigation of radon gas entry into schools in geographically susceptible areas, due to known geology and soil conditions (USEPA, 1989, 1994; Chmelynski and Leovic, 1992; Leovic and Craig, 1994). These included discussions of design and construction of foundations and ventilation systems, and ventilation system installation, operations and maintenance issues. The California Department of Health Services conducted a statewide survey in elementary school classrooms in 1991-92 (Zhou et al., 1998). Schools were grouped by zip codes in three geographical regions based on bedrock geology uranium potential. Adjusted analyses suggested about 5% of California elementary schools had at least one classroom with average annual indoor air radon concentrations above the USEPA intervention action level, 4 picocuries $L^{-1}$.

*Specific heavy metals*

<u>Arsenic</u>

Arsenic can be found inside schools if it is tracked into the classroom in soil on shoes or clothing, especially after recess on playgrounds and in sandboxes near equipment constructed with wood treated with certain preservatives, e.g., chromated copper arsenate (CCA). In addition, portable classrooms are usually sited on prepared areas, which include the use of CCA-treated wood to raise the modules above ground level to allow cross-ventilation. Certain pesticides used on school grounds may also contain arsenic (CARB, 2003c). The California Portable Classrooms Study reported some classrooms had levels of arsenic in settled floor dust above the MDL, and in relatively more portables than traditional classrooms (CARB, 2003c). The USEPA enacted a voluntary phase-out of CCA, and CCA is no longer on the approved list of chemical pesticides. New York State has banned new installations of CCA playground equipment and requires mitigating old equipment and playground surfaces.

Lead

One of the American public health goals, as stated in the environmental health focus area of "Healthy People 2010" (USCDC, 2003), was to eliminate the incidence of elevated blood lead levels in children ages 6 and under (current guideline defined as > 10 $\mu g\ dL^{-1}$). Likely sources of lead in school classrooms, as exhibited in some classroom settled floor dust samples from the California Portable Classrooms Study (CARB, 2003c) and samples of interior paint chips collected from older school buildings during a previous California survey (CDHS, 1998), were:

1. peeling or chipping paint applied prior to 1970, which contaminates dust on indoor surfaces or adjacent outdoor soil, since soil can be tracked in on shoes or enter through natural ventilation; and,
2. poorly contained and monitored renovation activities in the classroom or an adjacent area.

Nielsen et al. (2003) conducted an intervention case study in Denmark of children's exposure to lead in contaminated soil following adjacent outdoor playground activities (dermal, hand-to-mouth). There were two kindergartens with interventions and one reference kindergarten classroom, at different schools. Measurements in the soil and from child hand wipes before and 5-7 weeks post-intervention were in agreement and suggested the reduction of potential exposure to lead. Variations in the amount of lead on children's hands, however, also suggested variability introduced within and between individuals due to behaviors and playing patterns.

Mercury

Exposure to mercury, in its elemental or bioaccumulative organic (methylated) forms, has human and ecological health effects. In schools, older fluorescent bulbs contained mercury, but many new, energy efficient bulbs, which also produce higher quality light, do not. Some states like Vermont have banned mercury from light bulbs and required labeling. In addition, mercury may be present in secondary schools with chemistry laboratories, and in general in health clinics (thermometers) and thermostat and computer hardware. If potential sources are identified as present, they should be carefully contained and their use managed until replaced with alternatives and properly disposed of as hazardous waste. Also, new sources should not be introduced. To date, there are no clean up standards for spills inside schools. The USEPA and the University of Wisconsin have developed Internet sites on these topics (see Appendix I.1).

**Practical science-based recommendations for short and long-term actions**

A few conference papers (Bakke, 1999; Kumar, 1999; Sävenstrand et al., 1999), a university-based Region 10 initiative (WSU, 2002), and USEPA Internet sites ("IAQ Tools for Schools," "IAQ Design Tools for Schools," (see Appendix II.1) presented general and specific common sense, voluntary advice for schools regarding good IEQ in school facilities. We applaud these efforts, and information should be used as applicable. We present practical recommendations, for short and long-term actions, for school stakeholders based directly on the available science reviewed and summarized here on a broad range of IEQ topics (Tables 1-2).

Numerous studies in the Nordic countries of Denmark, Finland and Sweden, which documented observed positive effects of renovation of moisture damaged school buildings on measured IEQ parameters and occupant health complaints, were referenced. In summary, before renovations, there was a higher prevalence of reported respiratory and general symptoms among students and teachers responding to self-administered questionnaires in damaged compared to reference schools. After repairs, those differences did not exist or were not statistically significant. Thus, leaks and subsequent moisture damage of building and interior finish materials, including furnishings, should be prevented to avoid fungal and bacterial growth. Also, similarly, schools should replace wet, damaged materials, and completely dry out the underlying surface as soon as possible.

Frequently washing floors and other surfaces like desks would maintain good general hygiene and help minimize levels of airborne culturable bacteria and pet allergens transported to school classrooms on clothing. This recommendation, in effect, would protect children who are highly susceptible to such agents, especially pet allergens, and otherwise avoid exposure to them. Local policies can prohibit pets kept at school or cared for in classrooms.

It would be prudent to use non-toxic or least-toxic cleaners in school facilities, during unoccupied hours but not right before the start of school or near the end of lunch break, as well as non-toxic or least toxic teaching supplies. Implementation of this recommendation would minimize potential exposures and risks from toxic and odorous VOCs, including byproducts of their reactions on surfaces in the presence of ozone from outdoors. A related recommendation to minimize occupant exposure to these chemical compounds would be to allow sufficient time for mechanical and natural ventilation to air out classrooms after being painted or receiving new furniture or teaching materials, e.g., those made of exposed particleboard, a HCHO source.

The following recommendations relate to ventilation. Many studies discussed in this paper provided evidence on the potential multiple IEQ, comfort, and health benefits of providing fresh, filtered outdoor air to occupied classrooms. Schools should ensure compliance with ASHRAE Standard 62, monitored over time with biannual or annual HVAC system inspections and more frequent inspections and replacements of filters. The goal should be to provide enhanced or at least adequate ventilation with filtration of particles and pollen allergens of outdoor origin. It is also known ambient ozone is destroyed on surfaces of HVAC systems when they are operational. Operable windows will enhance natural ventilation and should be available and used, depending on local weather conditions, local safety policies, and potential adjacent outdoor sources of pollution and noise. In addition, the design, installation, and commissioning of whole building or portable classroom wall or ceiling-mounted mechanical HVAC systems must consider year-round ambient conditions. Such precautions could prevent potential scenarios when water condensation builds up on interior surfaces, leading to moisture damage and subsequent microbial growth. Finally, during inspections, current classroom enrollment data should be consulted so damper settings allow provision of sufficient fresh outdoor air (at least 15 $ft^3$ $min^{-1}$ per occupant).

In future revisions to Standard 55 on occupant thermal comfort in buildings, ASHRAE could consider criteria more specific to children and schools. 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 the HVAC technology either cannot dehumidify air or cools air using water vapor.

Given noise-induced hearing loss has no physical symptoms, the key to prevention is education (see Bahadori et. al (1993), Clark and Bohne (1999)) and reduction of noise at the source with engineering controls or improved HVAC system technologies (ASHA, 1995; Seep et al., 2000). The recommendations below are indirectly related to mechanical HVAC systems or new construction.

1. Future case studies and surveys of school facilities should assess average occupant exposure to noise from present sources during school hours and, as resources allow, contract an acoustics specialist to determine spectral characteristics (e.g., frequency range) of potential sources and to ensure proper reverberation times.
2. In the LBNL study of new relocatable classrooms (Shendell et al., 2002b-c, Apte et al., 2002, 2003), examination of the minimum measured six-minute dB (A) data suggested alternate interior finish material classrooms had lower background noise levels than standard material classrooms. This may have been evidence of a secondary benefit from the alternative ceiling tiles, their higher noise reduction coefficient rating (NRC) (Shendell et al., 2002c). They were originally chosen since in laboratory environmental chamber experiments they were not HCHO sources (Hodgson et. al, 2001, 2002, 2003). As time and financial resources permit, interior finish material NRCs should be considered, especially for large surface areas. Reverberation time, the persistence of sound after the source itself stops or is removed from an unoccupied classroom, may also decrease (Knecht et al., 2002, Nelson, 2003).
3. Follow the example of a California policy, SB 352 (M. Escutia, October 2003), which stated not to build new schools near freeways due to health concerns from air pollution and noise.

With respect to persistent organic pollutants like PCBs and phthalates, few quantitative data from school environment studies exist. Thus, the appropriate recommendation appears to be to encourage primary prevention of exposure in classrooms. Reported guidelines and regulations for radon, asbestos, arsenic, lead and mercury are similar. Schools should remove and substitute potential sources of natural and/or synthetic chemicals known to be, or which may prove to be, hormonally active and of human health concern.

To date, even with federal Executive Order 13101, no federal program has strongly promoted or enforced pollution prevention policies (also called environmentally preferable) for the purchasing of school construction and interior finish materials or classroom teaching, maintenance, and cleaning supplies (APHA, 2001). In addition, a recent national survey (Jones et al., 2003) reported no local school policies related to HVAC systems, including supply air ducting, or IEQ except for environmental tobacco smoke. Nevertheless, limited case studies presented in this paper have demonstrated the institution of indoor air pollutant source controls and interventions to increase outdoor air ventilation in primary schools improved IEQ and lowered the prevalence of reported respiratory symptoms and sensory irritation. Thus, such policies and more programs like the USEPA *Design Tools for Schools* internet site and the California Collaborative for High Performance Schools *Best Practices Manuals Volumes I-IV* (see Appendix II.1) are needed at federal and state levels to drive change in local school districts. Furthermore, for future school studies and general environmental public health tracking, programs with sustained funding are needed to record and monitor student illnesses as well as unintentional injuries incurred on school grounds.

According to a public health goal in the environmental health focus area of "Healthy People 2010" (USCDC, 2003), our recommendations could contribute towards a new reality. The goal stated, "increase the proportion of the nation's primary and secondary schools that have official school policies ensuring the safety of students and staff from environmental hazards, such as chemicals in special classrooms, poor indoor air quality, asbestos, and exposure to pesticides."

**Table 1**: School IEQ studies and highly related references identified and cited in the review, by type of reference and IEQ category used for (*NOTE: an individual reference could be used more than once*)

| **IEQ category** or the *IEQ 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 theses |
|---|---|---|---|---|---|
| **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 and 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 |
| No. times references used in total | 156 | 130 | 47 | 13 | 6 |
| No. unique references (301 total) | 147 | 98 | 42 (26+13+3) | 13 | 2 |
| No. references used for multiple topics | 9 | 32 | 5 | 0 | 1 |

**Table 2**: Summary of recommendations for schools to improve indoor air and environmental quality in classrooms and other areas based on available science

| |
|---|
| Prevent leaks and subsequent moisture damage of building and interior finish materials, including furnishings. |
| Similarly, replace wet, damaged materials, including completely drying out the underlying surface, as soon as possible. |
| Frequently wash floors and other surfaces like desks, which occupants come into frequent contact with, to maintain good general hygiene and help minimize levels of airborne culturable bacteria and pet allergens. |
| Use non-toxic or least toxic cleaners in school facilities, during unoccupied hours but not right before the start of school or near the end of lunch break. |
| Use non-toxic or least toxic teaching supplies and materials. |
| Allow sufficient time for mechanical and natural ventilation to air out classrooms after being painted or receiving new furniture or teaching materials, e.g., those made of exposed particleboard, a formaldehyde source. |
| Ensure compliance with ASHRAE Standard 62, monitored over time with biannual or annual HVAC system inspections and more frequent inspections and replacements of filters. The goal should be to provide enhanced or at least adequate ventilation with filtration of particles and pollen allergens of outdoor origin. As possible, given weather conditions, local safety policies, and potential adjacent outdoor sources of pollution or noise, operable windows to add natural ventilation can also be used. |
| Design, installation, and commissioning of mechanical HVAC systems must consider year-round ambient conditions. Such precautions could prevent potential scenarios when water condensation builds up on interior surfaces, leading to moisture damage and subsequent microbial growth |
| During inspections, current classroom enrollment data should be consulted so damper settings allow provision of sufficient fresh outdoor air (at least 15 $ft^3$ $min^{-1}$ per occupant). |
| In future revisions to Standard 55 on occupant thermal comfort in buildings, ASHRAE could consider criteria more specific to children and schools. |
| Future case studies and surveys of school facilities should assess average occupant exposure to noise from present sources during school hours and, as resources allow, contract an acoustics specialist to determine spectral characteristics (e.g., frequency range) of potential sources and to ensure proper reverberation times. |
| As time and financial resources permit, noise reduction coefficients of interior finish materials should be considered, especially for large surface areas (e.g., ceiling tiles). Reverberation time may also decrease. |
| Do not build new schools near freeways due to health concerns from air pollution and noise. |
| For persistent organic pollutants like PCBs and phthalates, as well as radon, asbestos, arsenic, lead and mercury, encourage primary prevention of exposure in classrooms through source control and proper removal and disposal. |
| Promote strong, monitored programs for pollution prevention in environmentally preferable purchasing of school construction and interior finish materials, and classroom teaching, maintenance, and cleaning supplies. Policies are needed at federal and state levels to drive change in local school districts. |
| Neither buses nor trucks powered by diesel fuel should be allowed to remain idling near school facility outdoor air intake vents (assuming dampers open). Such a policy would reduce indoor concentrations of carbon monoxide, particles, and other vehicle-related combustion pollutants such as polycyclic aromatic hydrocarbons and nitrogen oxides. |
| Glare from incident sunlight on to or reflecting off surfaces (e.g., desks, computer screens) should be reduced to the extent practical. This includes not placing student desks directly in front of windows. |
| When indirect natural light through windows or skylights is sufficient, fluorescent lights can be turned off, which also saves energy and money. |

## Conclusion

This manuscript provided a concise school indoor air and environmental quality (IEQ) literature review followed by practical recommendations to prevent or reduce potential occupant exposures to biological, chemical, and physical agents of potential concern in American school facilities, in particular classrooms. These recommendations were based on about 300 scientific citations directly involving or highly related to school IEQ. This manuscript can inform various school stakeholders and policy makers at federal and state levels to drive change in local school districts. The goal is to improve and promote good school IEQ, occupant attendance and health, and academic achievement. Timelines and costs of implementation will inherently vary, but most of the proposed recommendations are initially low-cost or can result in long-term savings.

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## APPENDIX I

Existing noise guidelines for school environments at local, state and international levels

(Washington State Department of Health (WADOH), 2000; WHO, 1999; 2001a-b; ASA, 2002; Wakefield, 2002; Nelson, 2003)

| Specific Microenvironment | Leq, dB(A) | Time | Reference |
|---|---|---|---|
| School classrooms and pre-schools, indoors | 35 | During school hours | WHO, 1999; WHO, 2001a-b |
| School, playground, outdoors | 55 | During recess or physical education | WHO, 2001a-b |
| Industrial arts, vocational education and trade classrooms, chemistry fume hoods and/or dust exhaust systems operational when unoccupied, indoors | 65 | During class hours | WADOH, 2000 |
| Vocational education and music areas, indoors | 115 | One second or longer | WADOH, 2000 |
| School classrooms, unoccupied, indoors<br>NOTE: also included 0.6 second max. unoccupied reverberation time | 35 (*in 2003, due to Americans with Disabilities Act*) | During school hours | ASA, 2002; Wakefield, 2002 |

APPENDIX II.1

List of some state and federal government sponsored Internet sites on school IEQ and energy

California Collaborative for High Performance Schools, *Best Practices Manuals* (Vol. 1-4)
http://www.chps.net/
National Center for Education Statistics, United States Department of Education (USDoEd)
http://nces.ed.gov/pubsearch
National Clearing House for Educational Facilities
http://www.edfacilities.org/rl
State of California Department of Energy,
"The Bright Schools Program: Energy-Efficient Schools for a Brighter Future"
http://www.energy.ca.gov/efficiency/brightschools/info.html
State of California, Division of the State Architect, "Sustainable Schools Website"
http://www.sustainableschools.dgs.ca.gov/sustainableschools/
*NOTE: Will include links to pages on "Environmentally Preferable Purchasing" of materials for school design and construction or modernization activities*
State of California Fire Marshall
http://www.fire.ca.gov/FireMarshal/PDF/class_more.pdf
State of California Interagency Working Group on Indoor Air Quality (IAQ)
(Department of Health Services, Environmental Health Laboratory Branch, IAQ Section),
"Advisory on Relocatable and Renovated Classrooms (12/1996)"
http://www.cal-iaq.org/
State of Minnesota Department of Health, children's environmental health issues,
including a page dedicated to schools
http://www.health.state.mn.us/divs/eh/children/schools.html
University of Wisconsin (USEPA funded, through Great Lakes National Program Office),
"Mercury in Schools Project"
http://www.mercuryinschools.uwex.edu/
USDoEd, information for school planning for natural disasters, violent incidents, terrorist attacks
http://www.ed.gov/emergencyplan
United States Department of Energy, "EnergySmart Schools Program Campaign"
http://www.eren.doe.gov/energysmartschools
USEPA "IAQ Design Tools for Schools"
http://www.epa.gov/iaq/schooldesign
USEPA "Healthy School Environments"
http://cfpub.epa.gov/schools/index.cfm
USEPA,"State Mercury School Programs"
http://www.epa.gov/mercury/index.html
USEPA "Tools for Schools" Program materials
http://www.epa.gov/iaq/schools/index.html

APPENDIX II.2

List of some public and not-for-profit institutions Internet sites on school environmental quality, and select private companies on IEQ-promoting classroom construction or finishing materials

AASA "Green School Project"
http://www.aasa.org
ACSA, "State Education Policy and Politics" column and list of articles
http://www.acsa.org/news
Alliance to Save Energy's (ASE) School Energy Efficiency Task Force
http://www.ase.org/greenschools
American Nurses Association,
"Safe Workplaces and Healthy Learning Places: Environmentally Healthy Schools"
http://nursingworld.org/mods/mod250/cesafull.htm
Association of Higher Education Facilities Officers (APPA)
http://www.appa.org/
Beyond Pesticides, information on state policies and programs on use of pesticides at schools
http://www.beyondpesticides.org
California Coalition for Adequate School Housing (CASH)
http://www.cashnet.org
California Healthy Schools Campaign, information for schools to eliminate pesticide use
http://www.calhealthyschools.org
Children's Health Environment Coalition (CHEC), "Healthy Schools: A Resource List"
wysiwyg://2/**http://www.checnet.org**/healtheducation/articles-detail.asp?Main_ID=487
Environment and Human Health, Inc. (CT), list of 12 steps to healthier schools
http://www.ehhi.org
Evans Consulting, "Irlen Syndrome accommodations at school or work"
http://www.evansconsult.org/is_accom.htm
Healthy Kids: The Key to Basics, information for children with asthma and other chronic conditions while at school and nurses who treat them
http://www.healthy-kids.info
Healthy Schools Network
http://www.healthyschools.org
National Education Association (NEA), links to programs and information on IEQ and asthma
http://www.nea.org/
National Parent-Teacher Association, information on different legislative categories on schools
http://www.pta.org/programs/legini.asp
Northwest Coalition for Alternatives to Pesticides, information to reduce pesticide use in schools
http://www.pesticide.org
Selected private sector companies with information on IEQ-promoting classroom materials:
http://www.carpet-rug.com/
"Selecting Carpets and Rugs: Carpet in Schools," "Indoor Air Quality: 'Green Label' Testing Program" (criteria for carpets, adhesives, cushion under carpet)
http://www.healthyflooring.org/Information.html
"Problems with Fitted Carpets and PVC Floors," "Suppliers" (list)
http://www.mbinet.org, Modular Building Institute