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A Summary of Scientific Findings on Adverse Effects of Indoor Environments on Students' Health, Academic Performance and Attendance

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Executive Summary

Background–This paper summarizes the current state of scientific knowledge about the adverse impacts of indoor environments in schools on health and performance. Key gaps in knowledge and critical outstanding research questions are also summarized. The U.S. Department of Education commissioned this paper in order to meet the Section 5414 requirements of the Elementary and Secondary Education Act, as amended by the No Child Left Behind Act of 2001.

Approach–This summary is based on a recent and more comprehensive literature review that examined the relationships between indoor environmental quality (IEQ) in schools and the academic performance, attendance, and health of students. Because of the limited scientific information available specifically from studies in schools, the review also considered relevant literature from studies of children or adults in other types of buildings. The review was based primarily on papers published in refereed scientific journals and conference proceedings. To draw conclusions, the review considered the quality of scientific methods and the consistency of findings among studies. This paper, in addition to summarizing the previous review, provides appendixes with details of the scientific literature on two topics–the relationship between IEQ and health and the relationship between academic absence and student learning.

Results and conclusions–There is persuasive evidence that higher indoor concentrations of nitrogen dioxide–a combustion product–and higher outdoor concentrations of several air pollutants are related to reduced school attendance. There is also persuasive evidence, primarily from studies in homes, that indoor dampness and microbiological pollutants are associated with asthma exacerbation and respiratory infections, health effects that in turn are related to reduced school performance and attendance. Dampness problems, microbiological pollutants, and inadequate ventilation are known to occur in significant numbers of schools. A substantial body of scientific literature links specific aspects of poor IEQ (e.g., low ventilation rate, presence of moisture, or even slightly elevated concentrations of formaldehyde) with respiratory and other health effects in children and adults, although a minority of the studies have been performed in schools.

The overall evidence strongly suggests that poor environments in schools, due primarily to effects of indoor pollutants, adversely influence the health, performance, and attendance of students. However, overall inadequacies in the IEQ of U.S. schools have not yet been systematically characterized. Nevertheless, the well-documented conditions of inadequate ventilation and dampness in many schools merit public concern and additional research.

Background

The U.S. Department of Education commissioned this paper on the health and learning impacts of environmentally unhealthy public school buildings on students and teachers in order to meet the Section 5414 requirements of the Elementary and Secondary Education Act, as amended by the No Child Left Behind Act of 2001. This paper briefly summarizes the current state of scientific knowledge about the adverse impacts of indoor environments on health and performance more generally, describes key gaps in this knowledge with respect to schools, and specifies outstanding research questions related to adverse impacts of school environments.

This summary is based on a recent and more comprehensive literature review (Mendell and Heath 2003) that examined the relationships between indoor environments in schools and the academic performance and attendance of students. Because of the limited scientific information available specifically on these relationships, the review included a broader range of research findings on the relationships of indoor environments to human performance and attendance. The review critically evaluated evidence for *direct* relationships between indoor environmental quality (IEQ) and the performance or attendance of occupants. The review also briefly summarized, as *indirect* links, reported relationships among aspects of IEQ, health, performance, and attendance. The available evidence was mostly from offices and schools. This report also provides, as appendixes, more detailed summaries of the available scientific literature on two topics–IEQ and health, and academic absence and performance–not included in the previous review.

Current Knowledge Related to Adverse Effects of IEQ in Schools

The term "indoor environments" refers to indoor, nonindustrial, nonagricultural environments. These environments have been assumed to be free of the long-recognized pollutant sources in industrial and agricultural work environments. The specific term "indoor environmental quality" (IEQ) refers to indoor pollutants (including biological, chemical, or particulate pollutants), thermal conditions, moisture conditions, and also other factors not covered here such as noise, light, and odor. The field of research on human effects of IEQ is still in an early phase. On the one hand, a substantial body of scientific evidence, and a larger body of experience, suggest that exposures and conditions in indoor environments, including offices, homes, and schools, can have important and widespread adverse effects on the occupants of buildings (Mendell et al. 2002a). On the other hand, there are substantial limitations in the completeness and scientific documentation of this knowledge and even in the tools for conducting research.

Sufficient information is not yet available to set health-protective *exposure* standards for most measurable indoor contaminants in schools and other nonindustrial environments. While exposure standards have been developed to protect healthy workers from substances that have known adverse health effects and that may occur at high levels in industrial occupational environments, these standards are not designed for protection of the general population, including children and others with a potentially broad range of susceptibility, and with exposure periods often exceeding the typical workweek. Children have greater susceptibility to some environmental pollutants than adults, because they breathe higher volumes of air relative to their body weights and their tissues and organs are actively growing (Landrigan 1998; Faustman et al. 2000). Thus, while occupational exposure standards are rarely exceeded in homes, schools, and other nonindustrial indoor environments, these regulated substances (i.e., those for which there are occupational standards) might still contribute to the health effects associated with poor IEQ in nonindustrial indoor settings.

Aside from the lack of documented safe levels for indoor environmental exposures, many of the key indoor exposures that are considered responsible for apparent adverse effects on health and performance (including both chemical and biological exposures) cannot yet be quantified, and some have not even been identified (Mendell et al. 2002a). Also, some health outcomes linked to poor IEQ, such as the nonspecific symptoms sometimes called sick building syndrome, cannot yet be measured objectively, making them difficult to document and study.

At present, evaluation of good IEQ is based not on specific indoor exposure limits (other than for a few specific substances such as formaldehyde), but on good *practices* of design, maintenance, and operation of buildings that are considered to provide conditions of acceptable IEQ. These practices, for instance, include the provision of adequate outdoor air ventilation, control of temperature and humidity within accepted comfort boundaries, provision of good maintenance and housekeeping practices, control of excess moisture and visible mold, and control of the sources of indoor pollutants. Whether such practices are sufficient to prevent adverse effects of IEQ on health and performance has not been documented.

There are many ways, direct and indirect, in which aspects of IEQ might influence the health and performance of occupants in school buildings. Figure 1 (adapted from Mendell and Heath (2003)) shows a variety of hypothesized causal links through which poor IEQ could impair the health or performance of occupants in schools. IEQ factors such as indoor pollutants and thermal conditions can influence health outcomes and also cause discomfort or other physiological effects. Health outcomes in turn can influence performance directly or could do so indirectly through effects on attendance. IEQ factors could also influence performance indirectly through discomfort or other physiologic processes. Adverse effects of indoor environments on the health or performance of teachers could add to the direct adverse effects of IEQ on the learning of their students. Some students, such as asthmatics, have increased susceptibilities to environmental exposures in schools.

Inadequate indoor environments in schools may decrease performance by causing health effects that either directly impair concentration or memory or indirectly affect learning. For instance, indoor pollutants might cause adverse neurologic effects or might exacerbate diseases such as asthma or allergy that produce symptoms or absenteeism that in turn reduce learning. Indoor environments can also cause discomfort or distraction through thermal, visual, acoustic, or olfactory effects, which can reduce performance.

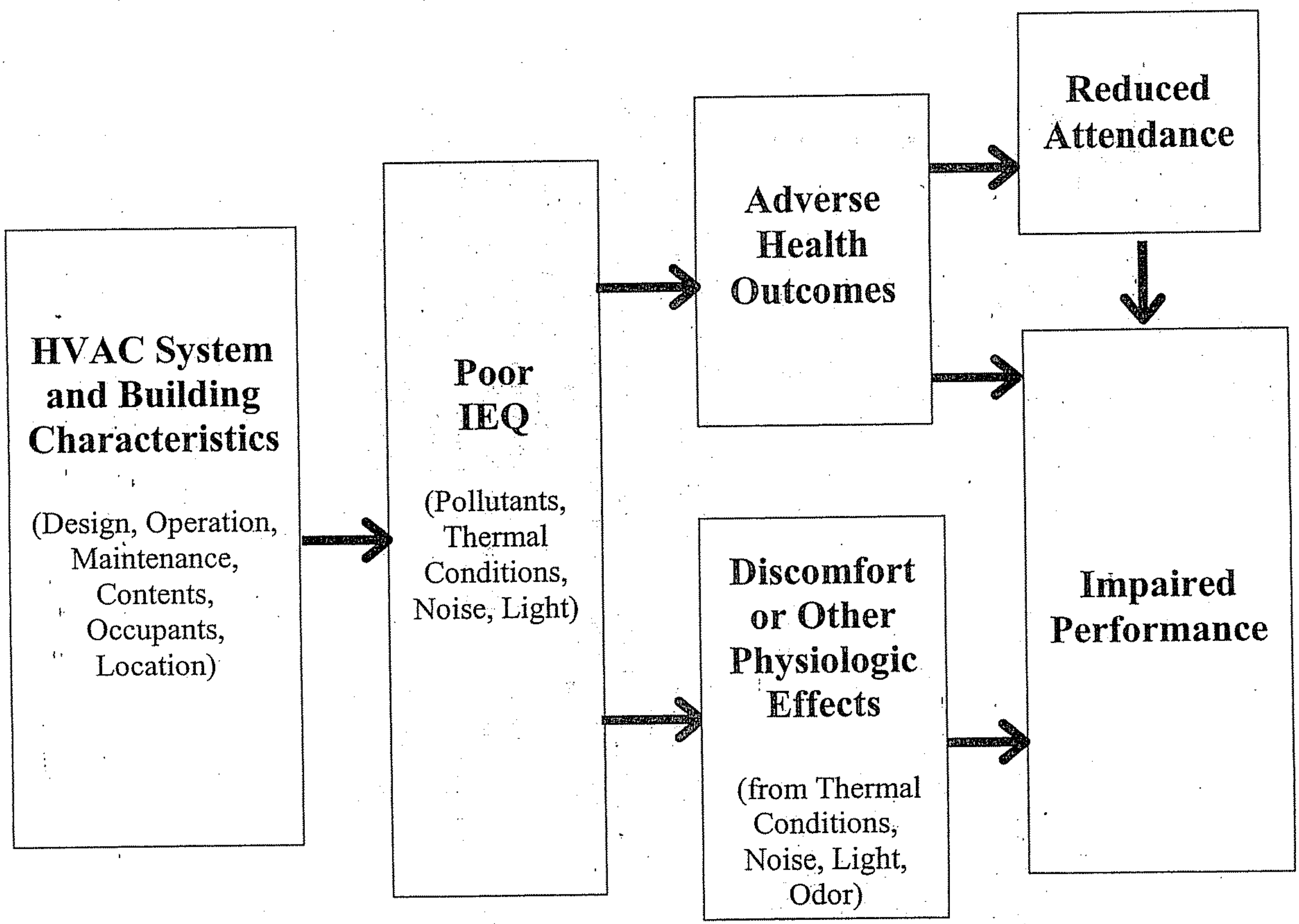

Figure 1. Hypothesized causal links from indoor environmental quality (IEQ) in schools to attendance and performance of students
(Arrows signify hypothesized direction of causality.)
HVAC = heating, ventilating, and air-conditioning; IEQ = indoor environmental quality

Current Knowledge about the Influence of IEQ or Building Characteristics on the Health, Performance, or Attendance of Occupants in Schools

Current knowledge about IEQ suggests that adverse effects on the health of occupants are caused by biological, chemical, or particulate pollutant exposures or through thermal conditions such as temperature or humidity. These exposures are associated with indoor environmental factors such as ventilation rate, characteristics of buildings and ventilation systems, and conditions of excess moisture. The observed adverse effects of IEQ on performance are likely to be at least partially mediated by adverse health effects from IEQ exposures. For example, respiratory infections and asthma, linked in some scientific studies to IEQ, are known to decrease school attendance, and reduced attendance has been linked to decreased school performance (Mendell and Heath 2003).

Current knowledge about the effects of IEQ in buildings on health, performance, or attendance is summarized below, *by type of environmental risk factor or exposure*. (For an expanded summary, with citations, of the scientific literature on IEQ and health, see Appendix 1. Appendix 2 provides an alternate summary by *type of health effect* rather than by type of risk factor or exposure. Appendix 3 provides a critical review and summary of the scientific literature on the relationship between attendance and academic performance in schools. Appendix 4 lists suggested additional readings.)

- *Ventilation Rate* – Rates of outdoor air ventilation below current standards have been very consistently associated in scientific studies with increased frequency of irritant and respiratory symptoms among occupants of office buildings. In many reported studies, increasing ventilation rates *above* the levels specified in current codes and standards resulted in further benefits. Evidence also has suggested that lower outdoor air ventilation of buildings may be associated with decreased performance or attendance in offices and in schools. These findings suggest that dilution, through outdoor air ventilation, of the indoor air pollutants found in buildings reduces indoor exposures that otherwise would cause adverse effects among occupants. This dilution may reduce pollutant-related inflammation of mucosal membranes. Furthermore, by reducing indoor airborne concentrations of infectious agents originating from occupants, ventilation may reduce transmission of infectious respiratory disease such as colds and influenza. Almost all scientific evidence on adverse effects of inadequate ventilation comes from studies of offices and homes, with little available from school environments specifically. Thus, current school ventilation standards are not based on health data relevant for children and school environments.

- *Building Characteristics* – Visible moisture or mold has been consistently associated with substantial increases in asthma or respiratory symptoms in a large, diverse, and persuasive body of research conducted in both homes and schools. These findings suggest a widespread and important problem. A variety of indoor surface materials, including carpet, fleecy or fabric surfaces, and plastic materials, have been found in a number of studies to be related to health effects such as neurologic and other symptoms, bronchial obstruction, asthma severity, and release of inflammatory mediators. Less frequent cleaning in schools has been found to be associated with nasal congestion and inflammation, although vacuuming with a standard vacuum cleaner (e.g., without high-efficiency filtration) can increase air concentrations of settled particles and allergens, at least temporarily. Location of buildings in areas of high outdoor air pollution will increase indoor exposures to outdoor pollutants that enter buildings.

- *Ventilation System Characteristics* – The presence of central air-conditioning systems has been consistently associated in many studies with the higher prevalence of symptoms among office workers, compared to buildings without central ventilation systems. This suggests that ventilation systems, especially those involving water, may pose a risk of producing and disseminating pollutants in buildings, despite their advantage of providing enhanced thermal control. Central humidification systems have been associated with increased symptoms in some studies, but with reduced rates of respiratory infections or absenteeism in other studies. In a number of documented cases, contaminated humidification systems have caused serious health effects. Enhanced air filtration that more effectively removes particles from indoor air in residences has in some but not all studies been associated with reduced allergy or asthma symptoms. Poor design, operation, or maintenance of ventilation systems, particularly if related to potential microbiological contamination, has been shown in some studies to be related to increased risk of lower respiratory or asthma-like symptoms. Some studies have shown that older air filters become contaminated with microbial growth more quickly than has been conventionally assumed and are related to mucous membrane irritation and congestion.

- *Biological Pollutants* – Many studies have found relationships between moisture and visible mold in residential buildings and various respiratory health effects, including asthma and respiratory infections. Although historically, conventional metrics of indoor airborne microbiological organisms have usually not been associated with health effects, recent studies have found some measured indoor levels of airborne microbiological contaminants to be associated with allergic, immunologic, or inflammatory health effects, as well as neurological effects including headache or concentration problems. Too little is now known to set safe levels of microbiological exposures or even to specify the appropriate environmental measurements or health measurements to use for setting safe levels. The most consistently identified indoor risk factors for respiratory health effects are visible moisture and mold, which presumably act as crude indicators for as yet poorly characterized microbiological exposures. Concentrations of cat and dog allergens on surfaces in schools, transported there on clothes of pet-owning children, have been shown to be sufficiently high to cause symptoms among sensitized children with asthma. Although exposure to dust mite allergens in homes has been clearly related to allergic sensitization and to allergy and asthma symptoms, it is not known whether harmful exposures to dust mite allergens occur often in schools.

- *Chemical Pollutants* – Studies have consistently identified formaldehyde as an important indoor pollutant causing irritation of eyes, nose, and throat at concentrations found in many types of indoor environments. Irritation by other specific indoor chemicals, while strongly suspected, has not been documented. The apparent irritant effects of chemical emissions in indoor environments may be explained by one or more of the following: the effects of compounds not now measured or recognized; the effects of mixtures of many compounds at low concentrations; the creation, through chemical reactions in indoor environments, of highly irritant but short-lived compounds not identified or readily measured; inflammatory effects of chemicals like formaldehyde or nitrogen dioxide at levels conventionally considered too low to cause health effects; and previously unrecognized pulmonary sensitizing effects of chemicals at low levels from cleaning activities. An emerging body of evidence suggests that common indoor chemical pollutants can cause respiratory health effects: three studies have found increased respiratory symptoms among children in homes with larger amounts of plastic floor and wall coverings, which emit chemical pollutants. Strongly suggestive evidence has linked higher concentrations of indoor nitrogen dioxide from unvented combustion sources to decreased school attendance.

- *Particulate Pollutants* – Field and laboratory studies have found that indoor airborne or settled dust can produce nasal inflammation, upper respiratory and mucous membrane irritation, and neuropsychological effects. The nature of the inflammatory substances in dust has not been identified, nor is it known if these substances result from chemical emissions or reactions or from microorganisms.

- *Lead* - Lead is a toxic heavy metal that adversely affects nearly every organ system in the body, particularly in young children (and fetuses). Lead can have profound impacts on learning and performance, since the primary adverse effects are neurological deficits and behavioral problems, including both attention deficit disorder and lowered IQ. Childhood lead poisoning results in significant medical and special education costs and reduces the lifetime earning potential of poisoned children. Although most documented single cases of childhood lead poisoning are traced to homes, schools have similar levels of lead in paint and outside soil as houses of the same age; drinking water in schools can also be contaminated with lead.

- *Pollutants from Outdoor Sources* – Relationships of outdoor gaseous and particulate pollutants to a variety of lower respiratory and other health effects are well documented. Many of these pollutants are documented to enter readily into buildings, becoming indoor pollutants. Strongly suggestive evidence links higher outdoor ozone and carbon monoxide to decreased school attendance. One study has shown that higher traffic levels near a school were associated with increases in allergic sensitization. If, as seems plausible, indoor exposures in schools to pollutants produced outdoors cause adverse health effects, altered characteristics of buildings or ventilation systems (or the location of schools away from outdoor pollutant sources) could substantially reduce exposures among students and teachers to these pollutants during the school week.

- *Temperature and Humidity* – Higher indoor temperatures, above or even within the generally accepted range of thermal comfort, have been associated fairly consistently in studies with increased symptoms among occupants. Some evidence, although less consistent, associates moderately elevated temperatures that are common indoors with reduced performance in schools and other work settings. Evidence on relative humidity levels is more limited and less consistent.

Findings from the studies summarized above come from a variety of indoor environments, including offices, homes, and schools. Although most are from non-school environments, available findings have tended to be consistent across building environments. Assuming that the variety of relevant indoor pollutant sources and exposures is similar across building types and that children are at least as sensitive to indoor pollutants as adults, it is reasonable to further assume that the findings in non-school environments, such as adverse effects associated with low ventilation rates and with moisture, apply to schools as well. As has been previously mentioned, children breathe higher volumes of air relative to their body weights and are more susceptible to some environmental pollutants than adults. Overall, the link between IEQ and a variety of adverse effects in children and adults suggests a public health problem exists in an unknown number of U.S. schools with inadequate IEQ.

School Absence and Academic Performance
Most studies reviewed, including the two most strongly designed, found increased school absences to be correlated with reductions in measured levels of short-term learning in school. However, these two studies were conducted with college students, so their findings may not apply directly to primary and secondary school students, with differences in both educational processes and developmental levels. Much of the reported correlation between attendance and performance may not be causal but may result from statistical confounding by factors such as motivation or personal factors associated with both attendance and performance. Still, based on findings of the stronger available studies, some of the association is likely to be causal. Even if a direct relationship between increased absence and decreased short-term learning in school is assumed, however, it is not clear how much reductions in short-term learning from absences aggregate to reduce long-term learning or to what extent these effects, demonstrated most strongly in studies of college classes, occur in primary and secondary school classes.

Current IEQ in U.S. Schools
Little representative information is available to characterize the current IEQ that children in U.S. schools experience. An exception is outdoor air ventilation rates, one of the best-documented risk factors for adverse effects on health and performance in buildings. Measurements in a broad range of scientific surveys has found that ventilation rates in many schools are below recommended levels in both U.S. and European schools. In a representative national school survey by the U.S. General Accounting Office (1995),

almost 30 percent of U.S. schools reported unsatisfactory or very unsatisfactory ventilation. This suggests that substantial but preventable adverse effects from inadequate classroom ventilation on health and performance may be occurring among U.S. school children.

Little information is available on current indoor exposures and conditions in U.S. schools with respect to concentrations of biological, chemical, or particulate pollutants or thermal conditions. The presence of water leaks and unsatisfactory ventilation systems in many U.S. schools (U.S. General Accounting Office 1995) may produce interior moisture and other sources of microbiological growth. Poorly ventilated classrooms also are likely to increase exposures to chemicals emitted from building materials.

A recent California study provides some data regarding lead in schools. It has been estimated that 96 percent of California schools have paint with detectable lead, and over 70 percent contain lead-based paint by the U.S. EPA definition–greater than 5,000 parts per million (ppm) lead. Lead paint was found in a similar proportion of California schools as in California homes of similar age. About 6 percent of California public elementary schools have lead levels in bare soil that exceed the U.S. EPA reference value (400 ppm) for soil in areas where children play. An estimated 18 percent of California schools are likely to have lead in drinking water at or above the U.S. EPA action level of 15 ppb.

Key Knowledge Gaps

Available scientific findings have documented that various aspects of IEQ in specific environments, such as ventilation in offices and visible moisture and mold in residences and schools, are associated with adverse effects on the health or performance of building occupants. It is also likely that inadequate IEQ conditions are common in U.S. schools and lead to adverse effects on students and teachers in those schools. For many of the adverse effects of IEQ summarized above, however, scientific studies have not yet confirmed the applicability of findings from nonschool buildings and adults to schools and schoolchildren. Research has not yet taken the following necessary steps: (1) identifying the specific indoor exposures or conditions causing health or performance effects in schools, (2) quantifying the strength of the adverse effects, (3) documenting measured levels below which adverse effects do not occur, and (4) demonstrating the effectiveness of specific prevention or remediation strategies. Furthermore, measurement tools for the health and performance effects of concern are not yet fully developed for either adults or children. These knowledge gaps limit our ability to define optimally protective strategies for the occupants of schools and to estimate the costs and benefits of implementing such strategies.

Key Research Questions

The following list presents current key research questions. The list includes an additional type of research not traditionally included in environmental health research agendas but important for improving actual environments–research on improving the *implementation* of available environmental health knowledge in school facilities. While organized in a logical scientific sequence, the third item is the most urgent and important from a *public* *health perspective*. This involves identifying effective preventive or remedial actions that could be undertaken immediately to reduce current adverse effects of IEQ on the health, performance, or attendance of school occupants.

- What are *harmful exposures or conditions in schools* with adverse effects on the health or performance of the occupants? What do we know now and can we learn more?
- *How common* is the occurrence of harmful exposures or conditions in schools, and what is the *magnitude* of their harmful effects in U.S. schools? What do we know now? How can we learn more?
- How can harmful exposures or conditions in schools be *prevented or remedied*? What do we understand sufficiently now to justify immediate actions? How can we improve future strategies?
- How can we *remove barriers to and create incentives for the implementation of available knowledge* about healthful school environments?

Cutting across and related to all these research questions is an additional key research question related to tools and technologies:

- What new *methods, technologies, or practices* are necessary to improve the measurement of indoor environments and related human responses, and to improve the ability to provide healthful indoor environments in cost-effective and energy-efficient ways?

(Note: References for citations in both the above report and the Appendices are provided after the Appendices.)

Appendix 1. Summary of findings on Indoor Environmental Quality and Health (organized by type of risk or exposure)

Many review articles or chapters have extensively reviewed aspects of relationships between IEQ and health (none focusing specifically on children in schools, although including articles on this topic). Reviews are available on the following topics:

- Respiratory infections and building environments (Fisk 2000).
- Dampness in buildings and health (Bornehag et al. 2001).
- Moisture and mold as risks for respiratory health effects (Peat et al. 1998).
- Indoor environments and asthma (Committee on the Assessment of Asthma and Indoor Air 2000), including a section on asthma and schools (pp. 321-323).
- Pets and asthma or allergies (Ahlbom 1998).
- HVAC system type and symptoms in buildings (Seppanen and Fisk 2002).
- Ventilation rates and health in buildings (Seppanen et al. 1999).
- Indoor environments and symptoms in offices (Mendell 1993).
- Many other IEQ and health relationships, including indoor chemical and biological pollutants, and effects including building-related illnesses, sensory irritation, eye irritation, and skin responses (Spengler et al. 2000).

The following text summarizes findings in the published scientific literature between aspects of IEQ and the health of occupants of buildings. Much of this research was conducted in office buildings rather than schools; it is unknown how such findings may apply across different types of buildings and occupants.

Measured IEQ factors and relationship to health

This section will summarize available evidence on relationships between measured IEQ factors and health outcomes among occupants. Measured IEQ factors here include specific pollutant exposures (biological, chemical, or particulate, measured indoors or outdoors), pollutant control processes (e.g., ventilation rate), and thermal parameters.

Indoor pollutants and relationship to health

- *Indoor Biological Pollutants*–In recent decades, researchers have rarely found relationships between conventionally measured indoor concentrations of culturable microorganisms and health outcomes (Mendell 1993). Only recently, mostly using new metrics of exposure and response, have researchers begun finding relationships between higher air or dust concentrations of microbiological organisms or related materials and health outcomes. Multiple studies have now reported relationships between concentrations in air or dust of culturable fungi and bacteria or their products or of other biological materials, and allergic, immunologic or inflammatory response, including asthma (Skov et al. 1990; Hodgson et al. 1991; Rylander et al. 1992; Mendell 1993; Gyntelberg et al. 1994; Li et al. 1997; Smedje et al. 1997; Garrett et al. 1998b; Meyer et al. 1999; Norback et al. 2000a; Seuri et al. 2000b). Concentrations of cat and dog allergens in schools, transported there on clothes of pet-owning children, are sufficiently high to cause perennial symptoms among sensitized children with asthma (Munir et al. 1993; Berge et al. 1998; Perzanowski et al. 1999; Elfman et al. 2000). Exposures to molds, bacteria, or their products such as spores or metabolites may cause a variety of health effects, through largely unknown mechanisms. Mold spores and toxins may cause inflammation of mucosal membranes and produce allergic reactions or otherwise influence the immune system, thereby facilitating viral and bacterial infection in the respiratory tract (Flannigan et al. 1991).

- *Indoor Chemical Pollutants*–Studies decades ago documented the presence of hundreds or thousands of chemical compounds in the air of typical indoor environments (e.g., the Total Exposure Assessment and Measurement (TEAM) study) (Wallace et al. 1987). These compounds have been widely suspected of causing the health complaints reported from many buildings during these decades. To document this, many studies have now assessed relationships between summary metrics of chemical compounds in indoor air and irritant or other symptoms among occupants. Few of these studies have found measured chemical exposures, when assessed with summary metrics such as total volatile organicic compounds (TVOC), to be related to symptoms (Mendell 1993), and some have even found inverse relationships (Bluyssen et al. 1996). Studies, however, have found evidence of other relationships and processes that may explain how VOCs can produce irritant responses that are not associated with conventional exposure assessment metrics. The explanations may include the effects of compounds not measured or recognized; the creation of highly irritant but short-lived compounds not identified or readily measured (Weschler and Shields 2000; Wolkoff et al. 2000); inflammatory effects of chemicals like formaldehyde or nitrogen dioxide at typical levels not thought to have health effects (Pazdrak et al. 1993; Wantke et al. 1996; Pilotto et al. 1997 Smedje et al. 1997; Garrett et al. 1999; Franklin et al. 2000; Norback et al. 2000a); and previously unrecognized pulmonary sensitizing effects of chemicals at low levels from cleaning activities (McCoach et al. 1999; Zock et al. 2001). In all these cases, inflammatory effects of exposures may promote sensitization to potential allergens present.

- *Indoor Particulate Pollutants*–Studies have found that airborne or settled indoor dust can produce nasal inflammation, upper-respiratory and mucus membrane irritation, and neuropsychologic effects (Walinder et al. 1999; Mølhave et al. 2000 Norback et al. 2000a).

- *Outdoor Pollutants*.– Higher concentrations of outdoor gaseous or particulate pollutants have been found to be related to diagnosed asthma (Guo et al. 1999), decreased peak expiratory flow (Steerenberg et al. 2001), markers of lung or nasal inflammation (Steerenberg et al. 2001), and asthmatic symptoms (Ramadour et al. 2000) but not atopy as defined by skin prick tests (Charpin et al. 1999). Because many pollutants originating outdoors enter readily into buildings and become indoor pollutants, and people spend most of their time (greater than 90 percent) indoors, primary human exposures to many outdoor pollutants may occur indoors. For example, nitrogen oxides and particulate matter generated by nearby traffic penetrated indoors readily at a day-care center (Partti-Pellinen et al. 2000). Traffic count on streets near schools showed a dose-response relation with sensitization to pollen, determined by skin prick tests and serologic examination, among occupants of schools, suggesting increased allergic sensitization from vehicle exhaust generated outdoors (Wyler et al. 2000). Therefore, the epidemiologic relationships consistently found between outdoor concentrations of key pollutants and human responses *may* be due largely to indoor exposures, with measured outdoor concentrations in available studies having served largely as proxies for unmeasured indoor levels. If this were true, altered characteristics of buildings or ventilation systems might substantially reduce exposures to pollutants originating outdoors.

Control of indoor pollutants and relationship to health

Available findings document that increased outdoor air ventilation rates in buildings are associated with decreased building-related symptoms among occupants, up till at least 20 cubic feet per minute (cfm) per person and possibly up to 30, 40, or more cfm per person (Mendell 1993; Seppanen et al. 1999). Exposures in specific buildings depend on sources, source strengths, pollutant removal, and other factors. These findings therefore suggest that dilution, through outdoor air ventilation, of the indoor air pollutants found in buildings in general, reduces currently uncharacterized indoor exposures that otherwise would cause acute symptoms among occupants. This dilution has been shown to reduce pollutant-related inflammation of mucosal membranes (Walinder et al. 1997; Walinder et al. 1998). Outdoor air ventilation rate *per person* in these studies (Walinder et al. 1997; Walinder et al. 1998) was not associated with the assessed outcomes, suggesting that pollutants produced by the building or its interior rather than those produced by occupants were critical for human health responses. On the other hand, ventilation may also, by reducing indoor concentrations of infectious agents originating from occupants, reduce infectious respiratory disease (Seppanen et al. 1999; Fisk 2000; Menzies et al. 2000; Milton et al. 2000; Mendell et al. 2002a).

Indoor physical parameters and health

Physical parameters in indoor environments that have been related to the health of building occupants include thermal parameters such as temperature, humidity, light, and noise, of which only the first two are reviewed here.

Lower temperatures within the conventional thermal comfort envelope has been associated fairly consistently, in a substantial number of studies, with health benefits such as reduced symptoms (Jaakkola and Heinonen 1989; Skov et al. 1990; Jaakkola et al. 1991b; Wyon 1992; Menzies et al. 1993; Meyer et al. 1999; Reinikainen and Jaakkola 2001; Mendell et al. 2002b), improved performance-related mental states (Mendell et al. 2002b), and reduced nasal congestion and inflammation (Walinder et al. 1998), and rarely with adverse effects such as increased prevalence of asthma (Smedje et al. 1997).

Evidence on humidity, more limited and less consistent, suggests that higher relative humidity within a moderate range may reduce symptoms (Reinikainen et al. 1992; Nagda and Hodgson 2001; Mendell et al. 2002b), whereas lower relative humidities may have benefits such as reduced prevalence of asthma (Smedje et al. 1997) or reduced transmission of common respiratory infections (Milton et al. 2000). However, disagreement exists about the indoor humidity levels best for indirect effects on health of occupants, with respect to survival of infectious organisms, growth of fungi, formation or release of toxic chemicals, and so on (Arundel et al. 1986; Baughman 1996; Milton et al. 2000). (For additional discussion of humidity as related to humidification, see below.)

IEQ-related characteristics of buildings and relationship to health

- *HVAC characteristics and relationship to health*

Research findings on relationships between ventilation systems and health consistently show associations between more complex mechanical ventilation systems and increases in prevalence of various symptoms among occupants, relative to naturally ventilated buildings without ventilation systems. Among mechanically ventilated buildings, an even higher prevalence of symptoms has been found in association with air-conditioned or humidified buildings, with differences between types of humidification systems not clearly evident (Mendell and Smith 1990; Mendell 1993; Seppanen and Fisk 2002). Sufficient information on the nonspecific symptoms assessed is generally not available in these studies to suggest biological mechanisms. One study, however, found mechanical ventilation to be associated not only with nasal congestion but also with objectively measured swelling of nasal mucosal and biomarkers of nasal inflammation (Walinder et al. 1998), suggesting increased exposures to inflammatory substances, either biological or chemical. Overall, findings on this question suggest increased risk of adverse exposures associated with complex ventilation systems, particularly if they involve water. However, some buildings of each kind of ventilation system have prevalence of symptoms as low as naturally ventilated buildings, suggesting that increased risk is not inherent in ventilation systems but may be related to aspects of design, operation, or maintenance.

As mentioned in the section on HVAC characteristics and absenteeism, the findings of Milton et al. (Milton et al. 2000) that suggest increased illness-related absenteeism in offices in relation to humidification contrast with those of several studies that have found humidification of school buildings to be associated with lower rates of respiratory infections or absenteeism (Sale 1972; Green 1974). Humidification of buildings and indoor relative humidity may confound each other's relationships to health and absenteeism among occupants in many reported field studies. Adverse effects of potential microbiological exposures from contaminated humidifiers may diminish any positive effects of higher humidity, or increase apparent positive effects of low humidity. Studies reporting positive effects of humidification or of higher relative humidity may be seeing underestimated net benefits resulting from true positive effects of higher indoor relative humidity lessened by negative effects of microbiologically contaminated humidification systems. Nevertheless, humidification systems have been documented to cause adverse health effects, some serious, and the effective prevention of this risk by use of biocides or of specific types of humidification has not been documented.

Some evidence is available to document health benefits of air filtration in ventilation systems to remove particles or gases from indoor air (Kemp et al. 1998; Mendell et al. 2002b). Relationships have been found between poor design, operation, or maintenance of HVAC systems, particularly those related to potential microbiological contamination, and increased risk of respiratory symptoms or disease (Sieber et al. 1996; Mendell et al. 2003).

- *Building and occupied space characteristics and relationship to health*

Numerous studies have associated dampness, water-damage, mold damage, or related indicators with respiratory, atopic, immunologic, or inflammatory effects (Thörn et al. 1996; Li et al. 1997; Peat et al. 1998; Rudblad et al. 1999; Committee on the Assessment of Asthma and Indoor Air 2000; Taskinen et al. 2000; Bornehag et al. 2001; Walinder et al. 2001a; Meklin et al. 2002; Taskinen et al. 2002). Schools located near high-traffic roads had higher atopic sensitization to pollen among students, with a dose-response relation between traffic count and sensitization (Wyler et al. 2000).

Studies have found relationships between a variety of indoor surface types, including carpet (Hansen 1987; Norback and Torgen 1989; Norback et al. 1990; Skov et al. 1990; Dybendal and Elsayed 1992; Wargocki et al. 1999; Lagercrantz et al. 2000), plastic surface materials (Jaakkola et al. 1999; Oie et al. 1999; Jaakkola et al. 2000b; Jaakkola et al. 2000a), fleecy or fabric surfaces (Skov et al. 1990; Jaakkola et al. 1999), and health effects including bronchial obstruction, asthma severity, release of inflammatory mediators, and neurologic and other symptoms. Also, less frequent cleaning of surfaces and wet mopping of floors were associated with nasal congestion and inflammation (Walinder et al. 1999)

Appendix 2. Brief summary of scientific findings on relationships between IEQ and health (organized by type of health effect) (from Mendell and Heath (2003))

This appendix includes studies on relationships between health and a broad range of IEQ factors, from HVAC or building characteristics to measured pollutants or thermal conditions. The section cites articles, grouped by type of health effect, reporting primary research on IEQ and health.

Respiratory Health Effects

Many recent studies have found objectively measurable upper or lower respiratory effects, some serious, associated with indoor pollutants or risk factors. In contrast, only a few years earlier, subjective symptoms were essentially the only health outcomes measured in IEQ studies (Mendell 1993). Among the indoor exposures or risk factors now most frequently and consistently associated with respiratory health effects are: the presence of moisture, water damage, and microbiological pollutants (Committee on the Assessment of Asthma and Indoor Air 2000; Bornehag et al. 2001), combustion products (Burr 2000), and animal and other biological allergens (Platts-Mills 2000). Other risk factors for respiratory health effects demonstrated in relatively few studies but important because of potentially widespread exposures and serious outcomes include: formaldehyde (Pazdrak et al. 1993; Wantke et al. 1996; Smedje et al. 1997; Garrett et al. 1999; Franklin et al. 2000; Norback et al. 2000a), plastics or plasticizers (Oie 1997; Jaakkola et al. 1999; Jaakkola et al. 2000b), nitrogen dioxide (Pilotto et al. 1997; Norback et al. 2000a); low or even recommended rates of ventilation (Menzies et al. 2000; Milton et al. 2000); chemicals in cleaning compounds (McCoach et al. 1999; Zock et al. 2001), outdoor pollutants or vehicle exhaust (Guo et al. 1999; Wyler et al. 2000; Steerenberg et al. 2001), and moisture or dirt in HVAC systems (Sieber et al. 1996; Mendell et al. 2003).

Risk factors found in buildings for respiratory infections include nitrogen dioxide (Pilotto et al. 1997), low ventilation rate (Fisk 2000; Menzies et al. 2000; Milton et al. 2000), humidification (Milton et al. 2000), and also lack of humidification (Green 1985).

Regarding specific health outcomes, identified risk factors for either asthma, increased pulmonary function variability, pulmonary hyperresponsiveness, or decreased pulmonary function include fungi and bacteria (Hoffman et al. 1993; Smedje et al. 1997; Garrett et al. 1998a; Garrett et al. 1998b; Seuri et al. 2000a), endotoxin (Michel et al. 1996; Michel et al. 2001), dust mites (Platts-Mills 2000), animal dander (Smedje et al. 1997; Platts-Mills 2000), formaldehyde (Smedje et al. 1997), chemicals in cleaning compounds (McCoach et al. 1999; Zock et al. 2001), outdoor pollutants (Guo et al. 1999; Steerenberg et al. 2001), dampness or water damage (Taskinen et al. 2000), carpets (Hansen 1987), and open shelves (Smedje et al. 1997).

Indoor environmental risk factors for lung inflammation include endotoxins (Michel et al. 2001), formaldehyde (Franklin et al. 2000), and outdoor pollutants (Steerenberg et al. 2001). Risk factors for bronchial obstruction include PVC flooring (Jaakkola et al. 1999), textile wall materials (Jaakkola et al. 1999), and plasticizer-emitting materials (Oie 1997). Risk factors for asthmatic symptoms include moisture or dirt in HVAC systems (Mendell et al.), plastic wall materials (Jaakkola et al. 2000b), and outdoor pollutants (Ramadour et al. 2000). Risk factors for atopy include fungi (Garrett et al. 1998a), formaldehyde (Garrett et al. 1999), dampness or mold (Taskinen et al. 2000), and vehicle exhaust (Wyler et al. 2000). Indoor risk factors for allergic alveolitis include dampness, water damage, or mold, in buildings or HVAC systems (Hodgson et al. 1987; Woodard et al. 1988; Kreiss 1989; Thörn et al. 1996; Seuri et al. 2000a).

Neurologic Symptoms

Risk factors for neurologic symptoms, such as headache, confusion, difficulty thinking, difficulty concentrating, or fatigue, include dust (Mølhave et al. 2000), VOCs (Mølhave et al. 1985; Otto et al. 1992), a used carpet taken from a complaint building (Wargocki et al. 1999; Lagercrantz et al. 2000), small particles (Mendell et al. 2002a), and higher temperatures within the comfort envelope (Mendell et al. 2002a).

Other Health Effects

A variety of IEQ risk factors have been identified for other health outcomes: nasal swelling, congestion, or inflammation (Pazdrak et al. 1993; Walinder et al. 1998; Walinder et al. 1999; Norback et al. 2000a; Norback et al. 2000b; Steerenberg et al. 2001; Walinder et al. 2001b); irritant symptoms of nose, throat, eye, or skin (Ten Brinke et al. 1998; Walinder et al. 1998; Rudblad et al. 1999; Mølhave et al. 2000; Nagda and Hodgson 2001); and nonspecific symptoms (Jaakkola and Heinonen 1989; Norback and Torgen 1989; Mendell and Smith 1990; Norback et al. 1990; Skov et al. 1990; Hodgson et al. 1991; Jaakkola et al. 1991a; Reinikainen et al. 1992; Rylander et al. 1992; Wyon 1992; Mendell 1993; Menzies et al. 1993; Gyntelberg et al. 1994; Sieber et al. 1996; Wantke et al. 1996; Li et al. 1997; Garrett et al. 1998a; Kemp et al. 1998; Meyer et al. 1999; Seppanen et al. 1999; Meklin 2000; Taskinen et al. 2000; Seppanen and Fisk).

Appendix 3. Effects of Student and Teacher Absenteeism on Academic Performance of Elementary and Secondary School Students: A Review

This appendix summarizes the available scientific findings in the educational, social science, and health research literature on the effects of student and teacher absenteeism (from health and other causes) on learning and academic performance among elementary and secondary school students.

Methods

We searched three electronic databases for articles published up till mid-2002: Medline PubMed, Educational Resources Information Center (ERIC), and Current Contents all editions. We also included selected articles cited in the articles identified from the electronic databases, and articles included in the previous broader review (Mendell and Heath 2003).

We review and discuss here articles reporting primary scientific research findings or reviews of the scientific literature, published either in peer-reviewed journals or in proceedings of scientific conferences. We also summarized findings for several journal articles for which abstracts but not the full text were obtained within the time available for this review.

This review covers findings on three relationships discussed in the scientific literature: between *student absenteeism* and *student performance* in school, *teacher absenteeism* and *student performance* in school, and *teacher absenteeism* and *student absenteeism* from school. For each of these topics, available studies were evaluated for the strength of their design and analyses. Studies considered stronger were those with experimental or prospective designs, good measurement methods, and effective control of key potential confounding factors through either study design or multivariate analysis methods. Research on absenteeism and school performance is made difficult by the many mutually related confounding factors that are likely to cause correlations between absence and performance that do not represent causality. These factors, such as poor motivation, chronically poor health, and other personal, familial, or social factors such as socioeconomic status, are likely to cause *both* increased absence and reduced performance in school. Articles reviewed here will be evaluated with attention to how well their design and analyses protect against such potential strong confounding influences.

Even if absenteeism were shown to cause reduced school performance, causes and means of reducing the absenteeism would be diverse and complex. Of special interest here is absence due to illness, particularly illness that may be caused by deficiencies in school environments. Performance decrements caused by such absence might be reduced by improving school environments. Other non-illness-related absence due to a poor school environment (sometimes called "motivational absenteeism") might also be reduced by improved school environments. Such absenteeism, however, cannot be identified in a study as easily as illness-related absence. A number of studies have associated indoor environmental factors such as lower ventilation rate and outdoor pollutants with increased absenteeism in either workers or students (Mendell and Heath 2003). Because effects of absences from different causes were not distinguished in available research, their independent impacts could not be considered in this report.

Results

We identified 16 articles meeting our criteria from electronic databases: six from Medline PubMed, seven from ERIC, and three from Current Contents, plus additional articles cited within the initially identified articles.

It is usually assumed that a student must be present in school to benefit from the instructional relationship between the teacher and the students, and that absence from class by the student (or the regular teacher) diminishes the achieved learning. Student absenteeism may involve non-sick leave (e.g., religious occasions, family illness, bereavement, truancy) or sick leave (true or feigned illness). Teacher absenteeism may involve non-sick leave (e.g., religious leave, family illness leave, bereavement leave, or training/professional/conference/visitation leave) or sick leave (Ehrenberg et al. 1991). Teachers use sick leave for illness and, in some cases, for covert "paid vacation" unrelated to illness (Ehrenberg et al. 1991). Factors influencing the amount of absenteeism among students or teachers have been discussed elsewhere (Elliott 1979; Norton 1998). A number of studies have associated certain indoor or outdoor pollutants with increased absenteeism in students (Mendell and Heath 2003).

Effects of student absenteeism on student performance in school

Prospective observational studies

Rodgers (2001) reported findings from a follow-up study of Australian university students in a statistics class. The authors used within-person analyses to control for unobserved characteristics of students that were likely to affect both attendance and performance, in both fixed-effects and random-effects models adjusted for a variety of measured individual confounding factors. Each 1 percent increase in attendance resulted in a small but statistically significant increase of 0.05-0.13 points out of 100 possible points accumulated during testing during the study period. A student with the average attendance level of 74 percent would have scored about 1.3-3.4 percentage points lower than an identical student with perfect attendance. The availability of complete lecture notes for all students, facilitating private study after absences, may have caused downward bias in the effects seen (compared to expected effects for conventional classes without such notes available). Also, in order to adjust for individual ability and motivation, the analysis controlled for grades in other simultaneous classes; however, as these were also likely to be affected by attendance, this also would have biased the estimates downward toward no apparent effect. This was the most strongly designed and thoroughly reported study of relationships between attendance and short-term learning as assessed by testing, with potential flaws tending to reduce apparent relationships seen between attendance and performance.

Marburger (2001) reported a carefully designed study of attendance and test performance among university students. Students were significantly more likely to answer incorrectly those test questions covering material taught during days on which the students were absent. This was true even though most students reported reading the class notes of others after absences. The individual-level design of this study effectively canceled out differences between students in various prior influences. This test is a straightforward and valid assessment of the direct causal link between school absenteeism and short-term learning at the college level.

While both these studies are strongly designed, their findings in college students may not apply to primary and secondary students because of the differences in the structure of these different levels of education and in the developmental levels of the students.

O'Brien et al. (1985) reported results of a carefully designed prospective study of achievement in sixth- to eighth-grade students. Although absenteeism was correlated with final achievement test scores, after multivariate adjustment no significant correlation remained. The primary multivariate-adjusted predictors of achievement were the two pretest achievement tests (which in turn were both correlated with student absence during the study). This apparent confounding provides a possible explanation for some of the associations reported in other less carefully designed studies, in which measured performance may not have been independent of prior achievement tests of subjects.

Port (1979) followed Hawaiian students from kindergarten through 10th grade, and, in a carefully designed study, assessed the correlation of various background and school-related factors with scores on standardized tests of achieved skills. The instrument used, the Hawaii State Test of Essential Competencies (HSTEC), tests competencies achieved during an 11-year school career. Absenteeism, although having unadjusted negative correlations with test scores, in a multivariate analysis added essentially nothing to the explanation of variation in HSTEC scores. Most of the explained variation could be accounted for by scores on two tests taken eight years earlier, in second grade.

Summers and Wokfe (1977) reported findings from a large and well-designed study of factors influencing achievement scores over three years among elementary school students. The analysis controlled for previous grades and many socioeconomic factors. The attendance variable studied–unexcused absences (considered an indicator of students' motivation)–was significantly related to changed scores in the achievement tests, particularly in middle- and higher-income students. This finding, however, while it may test the targeted relationship of motivation at school to achievement, does not test the relationship between absences *per se* and performance, independent of the effects of motivation or other potential confounding factors. In particular, illness-related absence, an outcome of key interest with respect to environmental prevention, would generally be *excluded* from the unexcused absences studied. Thus these findings on unexcused absences, concerning only the subset of absenteeism most influenced by current motivation and unrelated to illness, are not likely to be relevant to adverse health effects caused by school environments. They would be relevant, however, to the potential effects of poor quality of *perceived* school environments (e.g., schools perceived as unhealthy or dangerous) in increasing what is called "motivational absence." But the findings cannot distinguish between the effects on performance of poor motivation and of motivational absence.

Other observational studies

Ziomek and Schoenberger (1983) studied educationally disadvantaged students in grades two through six Title I programs, comparing end-of-year achievement tests per student with attendance at both school and Title I programs, adjusting for beginning-of-year achievement scores. They reported statistically significant but small correlations, ranging for each grade from 0.00 to 0.22, with stronger correlations for Title I attendance than for school attendance. No multivariate adjustment for other potential confounders such as gender was included. The study suggests possible weak associations between attendance and achievement but failed to adjust for potential confounders other than prior achievement levels.

Data in a cohort study in Minnesota of asthmatic children and age- and sex-matched controls by Silverstein (2001) show, although the author did not explicitly report it, that greater absenteeism was significantly associated with lower grade point average and, in some analyses, with lower standardized test scores.

Douglas and Ross (1965) studied absence among British primary school students aged 6 to 11 and their mental ability and school performance scores years later. From retrospective analyses of national data, the authors determined that in all social classes but the upper middle, greater absence from school was associated with lower scores for mental ability and school performance, particularly in the lower socioeconomic levels. The researchers, however, suggested that detrimental effects of past absenteeism in primary school might not persist if attendance improves (Douglas and Ross 1965). The analysis did not include multivariate adjustment for prior potential confounding factors.

Ehrenberg et al. (1991) reported findings from a large study of absenteeism among students and teachers in all school districts of New York State (excluding New York City), analyzed with data on pass rates for standardized state tests. Statistical models were adjusted for a wide variety of potential influences including, for teachers, teaching experience, tenure status, class size, and class quality, as well as for sociodemographic characteristics of the districts and communities from which students came (Ehrenberg et al. 1991). Higher levels of student absenteeism were related to a lower percentage of students passing standardized tests (each three additional days of average student absence was related to a 1 to 2.5 percentage point decrease in the proportion of students passing the test (Ehrenberg et al. 1991). However, the authors cautioned that these conclusions apply only to pass rates of students at the lower end of the range of academic talent, not to the relative performance of students well above the passing level, or to aspects of learning not measured by these exams. Furthermore, prior personal factors among students, related to both increased absenteeism and decreased performance, were not considered or ruled out in the analysis.

Safer (1986) performed a case-control comparison of multi-suspended junior high school students with non-multi-suspended, age- and sex-matched junior high school students. The study found that excessive absenteeism (over 16 days per year) in elementary school did not predict non-promotion in elementary school. Excessive absence in junior high school, in contrast, did predict non-promotion in junior high school–excessive absenteeism was associated with 10 times as much non-promotion; however, causality could not be established for this link. The authors point out that the high levels of absence studied might indicate a variety of disruptive personal, familial, and societal factors. For instance, non-promotion in elementary school strongly predicted later excessive absence in junior high school, making it unclear how much the statistical correlation between early excessive absence and later non-promotion in junior high school simply reflected the confounding effects of earlier academic failure. The study could not identify possible confounding factors statistically, due to the lack of multivariate analysis.

O'Neil et al. (1985) reported that increased absenteeism in public school (K-12) students in Connecticut was associated with lower grades, but not with lower scores on achievement tests (which were related to IQ scores).

Gutstadt et al. (1989), in a study of asthmatic children aged 9 to 17 attending an asthma clinic, found no relation of absenteeism to decreased performance on academic tests. Their analysis adjusted for emotional and behavioral problems but not prior performance, motivation, or other such potential confounding factors.

Other peer-reviewed reports, all of cross-sectional studies and not obtained in full nor reviewed here, found strong inverse relationships between absenteeism and class performance (Schmidt 1983; Park and Kerr 1990; Romer 1993; Durden and Ellis 1995). Other non-peer-reviewed reports, not reviewed here, also found at least some relationships between increased student absenteeism and decreased performance on school grades or standardized tests, although these correlations may not have been adjusted for potential confounding by outside factors.

Summary of findings

Overall, findings were mixed. The two strongest studies (Marburger 2001; Rodgers 2001) both found statistically significant inverse relations between absence and performance. Of the next strongest, which were cross-sectional studies adjusting for potential confounding factors including previous performance, two found a correlation (Ziomeck and Schoenberger 1983), while two did not (Port 1979; O'Brien et al. 1985). Among the remaining studies, which used multivariate adjustments but not for prior performance, or used no multivariate adjustment at all, four findings showed inverse correlations, one was mixed, and one showed positive correlations.

No available studies used experimental or quasi-experimental designs. The strongest available studies (Marburger 2001; Rodgers 2001), however, did control for the most important potential confounders–the social, family, and motivational factors that are difficult to control in observational studies–by design and analyses using within-person comparisons. (A within-person analysis assesses changes over time for each person separately, preventing distortion in the analysis due to differences between individuals.) This creative approach may be as close as is feasible to experimental approaches to study of relationships between absence and academic performance. The findings of correlations in four of five well-designed studies that controlled for key potential confounders, including both of the most strongly designed studies (Marburger 2001; Rodgers 2001), suggests a direct relationship between increased absence and decreased learning in school, and that this relationship may be causal. The strongest two of these studies, however, were conducted in college classes and may not apply to primary and secondary school students. Another of these studies (Summers and Wokfe 1977) excluded illness-related absence and thus provides evidence only on motivation-related absence. The inverse absence-learning correlations reported by less well-designed studies are only suggestive of causal relationships, because the studies failed to protect the findings, in the design or analysis, from effects on the tested performance of *previous* poor performance or attendance, which might also be strongly related to tested attendance. These less well-designed studies do not add to the persuasiveness of the findings from the strongest five studies. The overall picture is of a clear correlation between school absenteeism and performance, much of which may be due to mutually associated factors such as motivation or personal factors, but some of which, best assessed by Rodgers (2001) and Marburger (2001), is likely to be causal.

The full strength of this conclusion, however, holds only if the finding relating to college students applies to primary and secondary students in their classes. Furthermore, short-term reduced learning from individual absences may or may not aggregate over time so that chronically increased absenteeism would lead to reduced long-term learning. The summary effect on residual long-term learning of the short-term effects demonstrated by both Rodgers (2001) and Marburger (2001) might be more or less than additive. Demonstrating this, therefore, would be necessary to quantify the long-term effects. Also, the short- and long-term effects in college classes may be smaller or larger than those in primary and secondary school classes.

Effects of teacher absenteeism on student performance in school

Teacher absence has been reported to vary with factors such as day of week, month of year, age, gender, performance rating, school level taught, level of teaching license, years of teaching, degree held, school leave provisions, socioeconomic and ethnic mix of students, and level of student achievement (Norton 1998). We have not identified any studies on the relationship of teacher absenteeism to school environments, although a number of studies have associated indoor environmental factors such as lower ventilation rate with absenteeism in (adult) office workers (Mendell and Heath 2003). Teacher absenteeism causes a number of problems for schools, including the monetary costs for substitute teachers as well as the difficulty of finding qualified substitutes (Norton 1998).

Absenteeism of teachers may adversely affect student academic performance if less learning occurs with substitute teachers, or if teacher absenteeism increases student absenteeism, which in turn could decrease performance (Ehrenberg et al. 1991). A review by Elliot (1979) reports that in a study observing and rating teachers for classroom effectiveness, scores for substitute teachers were strikingly lower than the scores for regular teachers: in elementary school teachers the scores for substitutes were less than one third as high, and in secondary school teachers the scores were only one twentieth as high. Thus, teacher absenteeism could plausibly lower the quality of teaching and thus the environment in which students learn.

Few peer-reviewed studies were available on the relationship between teacher absence and student performance. Ehrenberg et al. (1991) reported that teacher absence at the levels observed did not influence student performance on most of the elementary and secondary school standardized tests assessed, with a negative effect on only one of the 7 tests. However, as previously mentioned, the researchers cautioned that these conclusions apply only to pass rates of students at the lower end of the range of academic talent, not to the relative performance of students well above the passing level, or to aspects of learning not measured by these exams.

Insufficient evidence is available to draw conclusions about the existence or causal nature of this relationship.

Effects of teacher absenteeism on student absence from school
Only one reported finding on this relationship was identified. Ehrenberg et al. (1991) reported that greater teacher absenteeism was positively associated with greater student absenteeism. The authors suggested that frequent absence of teachers may affect student motivation and attendance, or common factors in the school environment may simultaneously influence both teacher and student absenteeism. The authors reported statistical analyses suggesting that an influence operates between these variables (rather than their parallel changes being caused by some common outside influence), although the direction of influence was not determined.

Insufficient evidence is available to draw conclusions about the existence or causal nature of this relationship.

Discussion

Findings on relationships between absenteeism and impaired performance in schoolchildren have not been completely consistent, but the strongest available findings suggest a relationship that may be causal, at least for short-term-learning among college students. Evidence on the relationships between teacher absence and student performance, and between teacher absence and student absence, is insufficient for conclusions about the nature of these relationships.

Absenteeism from school by students or teachers may result from a variety of sociodemographic, family, or personal factors, including illnesses, or combinations of these factors. Of special interest to this review is to characterize the effects on performance of absenteeism that is *preventable by improving indoor school environments*. The consideration of illness-related and other specific categories of absence, rather than all absence, would better inform decisions about effective preventive strategies. However, the consideration of performance decrements in school caused by absence of specific causes was not possible with the available scientific findings.

Outstanding research questions

The nature and magnitude of any causal relationship between student absence and performance still needs clarification. We do not know if the short-term negative effects of absence on performance documented in college students correspond to long-term performance decrements in primary and secondary schoolchildren. We also do not know to what extent performance of students is diminished by absences resulting specifically from illness exacerbated by deficient indoor environments at schools. Whether increased teacher absenteeism also reduces student performance or attendance is also unknown. And finally, we do not know what effects deficient indoor environments in schools have on the attendance of students and teachers at school.

Suggested research

Additional carefully designed research is needed to replicate in primary and secondary schools the best available studies (conducted on college students) on relations between student absence and performance, and to extend these methods to measures of meaningful long-term performance. In particular, to strengthen their ability to assess potential causal relationships, study designs must effectively control for the effects of prior factors that may be strongly correlated with both current absence rates and current attendance. This latter consideration also applies to research on teacher absenteeism and the performance or absenteeism of students.

Appendix 4. Suggested additional reading materials, annotated

Mendell, M. J. and G. A. Heath (2003). "Do Indoor Environments in Schools Influence Student Performance? A Review of the Literature." Lawrence Berkeley National Laboratory, LBNL #51780.

This recent report critically reviews the scientific literature on relationships between indoor environments in schools and the performance or absenteeism of students. Because relatively little was available on this specific topic, the report was expanded to include the evidence on relationships between indoor environments in schools, offices, and laboratory settings and the performance, absenteeism and health of children and adults. This is apparently the most comprehensive such review available.

U.S. Environmental Protection Agency (2001), "Tools for Schools." EPA 402-k-95-001.

This set of documents and checklists is intended as a practical guide for schools and school districts to prevent and solve indoor air quality (IAQ) problems using available staff and expertise. It recommends establishing an IAQ coordinator in each school or school district to administer and coordinate IAQ-related activities by an IAQ team. Based on the best available knowledge at the time and designed to be user friendly, it has been widely used.

U.S. Environmental Protection Agency, National Institute for Occupational Safety and Health. "Building Air Quality: A Guide for Building Owners and Managers" (1991)

This document, developed with the contributions of a large number of experts in building science and building practice, is a practical guide for building owners and managers on preventing indoor air quality problems, and solving them when they occur. Based on the best available knowledge at the time and designed to be user friendly, it has been widely used.

Mendell, M. J., W. J. Fisk, et al. (2002a). "Improving health of workers in indoor environments: Priority research needs for the National Occupational Research Agenda." American Journal of Public Health 92(9): 1-12.

This peer-reviewed article, produced by a multidisciplinary team, recommends an agenda for priority research to allow improvements in the healthfulness of U.S. work environments. The major recommended topics of research include building-related health effects (communicable respiratory infections, allergy and asthma, and nonspecific building-related symptoms); science and technology of indoor environments; and strategies to reduce barriers and increase incentives for health-protective building practices.

California Department of Health Services (CDHS). Division of Environmental and Occupational Disease Control. Lead Hazards in California's Public Elementary Schools

and Child Care Facilities (1998). Report to the California State Legislature, http://www.dhs.ca.gov/ps/deodc/childlead/schools/opening.htm.

This document reports on the study performed as mandated by California's Lead-Safe Schools Protection Act which "required the California Department of Health Services (DHS) to conduct a study to determine the prevalence of lead and lead hazards in California's public elementary schools and childcare facilities, to report individual findings to participating schools, to develop environmental lead testing methods and standards, to make recommendations on the feasibility and necessity of conducting statewide lead testing in schools, to evaluate lead abatement technologies, and to work with the California Department of Education (CDE) to develop voluntary guidelines to minimize lead hazards in schools." This program, although designed for lead, an exposure with well-recognized adverse health and performance effects, would be a model for a survey of IEQ in schools.

U.S. Environmental Protection Agency (USEPA). Office of Water. "Lead in Drinking Water in Schools and Non-Residential Buildings." (1994). EPA 812-8-94-002. April 1994, http://www.epa.gov/safewater/consumer/leadinschools.html.

This document is a manual that demonstrates how drinking water in schools and nonresidential buildings can be tested for lead and how contamination problems can be corrected if found. It also discusses the importance of developing an overall communication strategy and examples of public notice materials.

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