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COMMENTARY

Significance of the School Physical Environment - A Commentary

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In their article ''Critical Connections: Health and Academics,'' Michael et al[1] summarize research syntheses about the effects on academic achievement of each of the 10 components of the Whole School, Whole Community, Whole Child framework (WSCC).[2] We were particularly interested in the summary about effects of the school physical environment, because this component often seems comparatively neglected. Indeed, a National Research Council (NRC) examination of the criteria used in green schools[3] concluded that a school with the following attributes would support student and teacher health, learning, and productivity: a dry building with good indoor air quality and thermal comfort, that is clean, quiet, and well maintained.

This commentary summarizes some additional important evidence about the effects of the school's indoor environmental quality on academic achievement. Much of this evidence has been developed since completion of the NRC review. Due to space constraints, we describe only key findings and papers. We do not review other risks to occupant health and/or achievement, such as asbestos, polychlorinated biphenyls (PCBs), lead in paint or drinking water, radon, renovation of occupied school facilities, pesticides and other hazardous supplies; moreover, we do not discuss the potential impacts of environment on students with special needs.

Michael et al[1] briefly mention the importance of classroom ventilation rate (VR) which is the rate of outdoor air supply. Here we elaborate more on the role of lower classroom VRs, ie, lower rates of outdoor air supply that are associated with increases in student absence in 2 of 3 US studies.[4-6] In the strongest of these studies, Mendell et al[5] tracked VRs and illness absence over 2 years in 162 classrooms within 28 urban schools in 3 California school districts. After controlling for potential confounders, for each 1 liter per second (L/s) per student increase in VR, on average, illness absence of students decreased by 1.6%. A substantial body of literature finds that lower VRs also reduce student performance. For example, 2 of 3 studies in US schools[7-9] found that increases in VRs are associated with statistically significant improvements in performance in standard tests of academic achievement. Haverinen-Shaughnessey et al[8] found that scores in math, reading, and science increase approximately 0.5% for each 1 L/s per person increase in VR. Their prior study[7] found that pass rates in math and reading tests increased 2.9% and 2.7%, respectively, per each 1 L/s per student increase in VR within the 87 of 100 classrooms that had VRs less than specified in the applicable standard. A third study[9] from California found small increases in test scores with increased VRs that were mostly not statistically significant. Other research, including blinded controlled intervention studies,[10-12] found that higher VRs are associated with improved student performance on special tests inserted into the curricula, for example tests of reading comprehension

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or addition. In general, work speed, but not accuracy, improves with increased VR.

The evidence of the importance of classroom VRs needs to be considered together with the extensive data showing that VRs in classrooms routinely fail to meet the minimum requirements specified in standards, often by a wide margin. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) minimum VR for classrooms[13] with standard occupant density is approximately 7.1 L/s per person. The median or mean measured VRs in various US studies are typically about 50% of this minimum requirement.[5,7,8,14,15] Consequently, the potential improvements in attendance and absence are several times larger than the improvements per 1 L/s per student listed above. Mendell et al[5] estimate that increasing the average VR in California's classrooms to the minimum requirement in standards would decrease illness absence by 3.6%. They further estimate that increasing the average VR to a higher value, 9.4 L/s per student, would decrease illness absence by 7% to 10%. They also estimate that the increased revenue provided to school districts, which is linked to attendance, far exceed the energy costs associated with increases in VR.

Several studies have investigated associations of microbial pollutants and their sources in classrooms with asthma and respiratory outcomes. Table 1 lists related studies and summarizes their key findings. Higher airborne concentrations of total or specific types of airborne molds are associated with asthma or respiratory outcomes in 5 listed studies. There is a sizable body of literature documenting frequent visible dampness and mold in classrooms.[27] With high consistency, visible dampness and mold in homes has been associated with increases in respiratory and asthma symptoms[28] and with respiratory infections,[29] suggesting a similar association for classrooms. However, the direct documentation of the adverse effects of visible dampness and mold in the classroom is considerably more limited. Fewer, and generally, smaller studies have been performed in schools. The reduced time spent at school, relative to at home, also may be a factor.

The documentation of associations between student health and specific pollutants or classes of pollutants that are nonmicrobial in nature is more limited but remains significant, with most of the research from outside of the US. Table 2 lists related studies and summarizes their findings. Higher levels of nitrogen dioxide (NO_2), formaldehyde, sulfur dioxide, and particles are associated with asthma or respiratory health in 2 or more listed studies. China-based studies from Zhang et al[35] and Zhao et al[36] may not apply well to locations with much lower concentrations of outdoor air pollutants. For many of the specific nonmicrobial air pollutants, with the exception of NO_2,[28] the available data are too limited for firm conclusions; however, the current findings are sufficient to justify precautionary measures and performance of further research.

There is also literature relating nonmicrobial pollutants or their sources with measures of student absence, cognition, or test scores. Growth in cognitive development was diminished in children in schools in Barcelona, Spain, with higher levels of traffic-related pollutants in the classroom and outdoors.[37] Forns et al[38] found that higher levels of traffic-related pollutants in classrooms in Barcelona were associated with lower child behavior development based on a survey completed by parents. Average levels of outdoor air pollutants in Barcelona are higher than levels in most US cities; thus, these findings from studies in Barcelona might not apply to US locations. Mohai et al[39] report associations of decreased attendance and lower test scores in English and math with an increase in air pollutant sources near schools in Michigan.

Relatively few published papers address the effects of temperature in classrooms on the health or performance of students, other than studies from about 50 years ago that involved relatively extreme temperatures. In an intervention study in Denmark,[10] speed in tests of subtraction, addition, and reading were statistically significantly improved at 20°C relative to 25°C; however, there were no effects on errors. Error rates in an acoustic proofreading test, involving listening to recorded text, were diminished at 20°C, but speed was not affected. There were no statistically significant associations of temperature with performance in tests of multiplication and logical thinking. Improvements in performance at 20°C versus 25°C, when statistically significant, were generally less than 10% but in one case the improvement was as high as 37%. In a cross-sectional study from the US[8] that employed data from standard academic achievement testing, scores in the math test increased about 0.5% per each 1°C decrease in temperature in the 25°C to 20°C range. Scores in reading and science were affected similarly by temperature, but the associations were not statistically significant. In a study of university-level computer classrooms,[40] there were statistically significant increases in ocular, nasal, and throat symptoms, headache, and tiredness with increased temperature. These outcomes increased about 1.5% per each 1°C increase in temperature. Few systematic data on temperatures in US classrooms were identified. In a large survey of elementary-level classrooms in California,[41] temperatures were less than 17°C 4.3% of the time, exceeded 26°C 4.4% of the time, and exceeded 29°C 2.3% of the time.

When classrooms and other parts of school buildings are noisy, it becomes difficult for students to comprehend spoken information from the teacher

Table 1. **Studies of Associations of Asthma and Respiratory Outcomes With Microbial Pollutants and Their Sources**

Study	Key Findings
Cai et al[16]	Some positive and some negative associations of types of fungal DNA in dust in Malaysia with respiratory symptoms and doctor reported asthma, cat allergen not associated with health
Chen et al[17]	Airborne fungal spores of some types were associated with current asthma and with having fewer asthma symptoms on holidays
Lai et al[18]	Air endotoxin associated with asthma symptoms in nonatopic children, but not in atopic children
Meklin et al[19]	In Finland, moisture damage associated with respiratory symptoms in concrete/brick schools but not in wood schools
Mi et al[20]	Observed molds associated with asthma exacerbation
Norback et al[21]	Lower nasal patency associated with increased airborne molds, aspergillus
Sahakian et al[22]	Employees of two damp schools had more respiratory symptoms than National Health and Nutrition Examination Survey (NHANES) reference population. Employees of one damp school had increased doctor-diagnosed asthma
Saijo et al[23]	Nasal symptoms and cough increased with various indications of dampness or mold in classrooms, but most associations not statistically significant
Simoni et al[24]	Total viable molds in air associated with cough and rhinitis; aspergillus/penicillium DNA associated with wheeze; *Aspergillus versicolor* DNA associated with wheeze, rhinitis, cough, and lung function
Smedje et al[25]	Current asthma associated with airborne viable molds and bacteria
Smedje and Norback [26]	In nonatopic children, airborne molds associated with new asthma diagnosis

Table 2. **Studies of Associations of Asthma and Respiratory Outcomes With Nonmicrobial Pollutants or Unvented Combustion Heaters**

Study	Key Findings
Annesi-Maesano et al[30]	Higher levels of particles, acrolein, NO_2 associated with increased past year asthma, although the association with NO_2 was not quite statistically significant
Kim et al[31]	Increased plasticizers associated with asthma symptoms
Marks et al[32]	Unflued gas heaters associated with cough and wheeze, but not lung function
Mi et al[20]	Higher CO_2 and NO_2 associated with current asthma and asthma medication, nonsignificant association of formaldehyde with asthma outcomes
Simoni et al[33]	Higher concentrations of particles less than 10 μm in diameter were not significantly associated with wheeze, dry cough at night, and rhinitis but were associated with reduced nasal patency
Smedje et al[25]	Current asthma associated with open shelves, lower temperature, higher relative humidity, higher formaldehyde, higher volatile organic compounds
Wallner et al[34]	Reduced lung function associated with higher formaldehyde, ethyl benzene, and xylenes in air and with benzylbutly phthalate, and polybrominated diphenylethers in dust[34]
Zhang et al[35]	Nonspecific health symptoms, often called sick building syndrome symptoms associated with higher concentrations of particles, sulfur dioxide, and ozone
Zhao et al[36]	Higher SO_2 associated with wheeze and nocturnal breathlessness, higher NO_2 and formaldehyde associated with nocturnal breathlessness, although results varied somewhat depending on analysis model

or engage in classroom dialogue; it is also fatiguing for teachers to speak over a noisy background. Academic achievement and behavior are compromised.[42-45] For example, in a cross-national study of aircraft noise, ''a 5 dB difference in aircraft noise was equivalent to a 2-month reading delay in the United Kingdom and a 1-month reading delay in the Netherlands.''[45] There were also adverse impacts on recognition memory and annoyance. Some research indicates that noise interferes more with complex tasks than simpler tasks.[44]

Clearly, environmental conditions in schools can have a significant effect on student health and academic achievement. Environmental conditions in the home and community will also affect students' health. Thus, efforts to improve indoor environmental conditions deserve more attention and fit well within the WSCC framework. Examples of actions to improve school environmental conditions that are supported by this brief review include:

- maintaining ventilation rates at or above the minimum rates specified in applicable standards;
- implementing school building maintenance and operational practices that prevent dampness and mold problems, together with rapid remediation of any problems that occur;
- locating schools away from major roads and industrial pollutant sources;
- minimizing indoor sources of air pollutants, especially combustion pollutants and formaldehyde;
- maintaining temperatures within established comfort zones; and
- avoiding noisy heating and cooling systems and siting of schools near strong sources of noise.

As explained in a Healthy Schools Network report[46] based on a facilitated workshop of key stakeholders, our nation's children deserve better national, state, and local efforts to improve school physical environments. We will need purposeful collaboration across

health, environmental, and educational agencies and other responsible governmental and nongovernmental entities to strengthen school physical environment policies, programs, and indicators, including, but necessarily limited to the national Healthy People 2020 School Environment Health Objectives;[47] EPA Healthy Schools, Healthy Kids and related EPA programs;[48] US Centers for Disease Control School Health Policies and Programs;[49] Healthy Schools Network and the national Coalition for Healthier Schools.[50]

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