

SCHOOLS



FOR HEALTH

FOUNDATIONS FOR STUDENT SUCCESS

HOW SCHOOL BUILDINGS INFLUENCE
STUDENT HEALTH, THINKING AND PERFORMANCE



SCHOOL OF PUBLIC HEALTH
Center for Health and the
Global Environment

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This report, *Schools for Health: Foundations for Student Success* was researched and produced by the Healthy Buildings program at the Harvard T.H. Chan School of Public Health under the direction of Dr. Joseph Allen. Our goal is to improve the lives of all people, in all buildings, everywhere, every day. The Schools for Health program is a platform to discuss, research, and disseminate information on how school buildings affect the health and productivity of students, teachers, and staff every day. Our team works to answer critical questions related to the environmental and contextual factors that influence chronic absenteeism, academic performance, and short- and long-term health performance indicators. *Schools for Health: Foundations for Student Success* is intended to serve as an evidence-based decision-making tool for key school stakeholders.

SCHOOLS + FOR HEALTH

The Questions We Ask About Schools

We ask about student:teacher ratios. We ask about test scores. We ask about the curriculum. We ask about start and end times, drop-off and pick-up routines, and bus schedules. We ask about lunch, art and music programs, and the principal. We visit a classroom to meet a teacher or two. But has anyone, ever, asked about the school building?

Building Foundations for Student Success

This report makes the scientific case that the school building is foundational to student success, and is as important as all of these other factors we consider.

- + **The evidence is unambiguous** - the school building impacts student health, thinking and performance.
- + Investing in school buildings is an **investment in our collective future**.
- + It is time for action. It is time for **Schools for Health**.





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I. EXECUTIVE SUMMARY

In the decade after the release of the landmark National Research Council report *Green Schools: Attributes for Health and Learning* (National Research Council, 2007), the global research community has gathered extensive information and evidence to demonstrate that the school building is foundational to student success — enough evidence to know that we can not afford to neglect the conditions of our schools. In recent years, numerous studies have emerged that show that the school environment can adversely or positively affect students’ well-being in multifaceted ways, both in the short term and over the course of their academic career. This report, *Schools for Health: Foundations for Student Success*, reviews findings from more than 200 scientific studies and identifies more than 70 Health Performance Indicators.

These findings provide robust public health evidence that environmental exposures in school buildings can impact student health, student thinking and student performance. Studies show that environmental factors within and around the school building can interact with each other in complex ways. Thus, the school building itself, where students spend a significant portion of their childhood, represents a prime opportunity to intervene and protect the health of children, our most vulnerable citizens.



Despite growing recognition of the importance of environmental health in schools, the national investment in public school facilities in the United States continues to fall short by \$46 billion a year. Consequently, many schools are left underfunded and unable to make much-needed upgrades to deteriorating buildings. Millions of K–12 students in America spend several hours a day learning in schools that are more than 50 years old and in need of extensive repair and where children may be exposed to mold, poor ventilation, uncomfortable temperatures, inadequate lighting, and overcrowded, excessively noisy conditions. These adverse circumstances can disadvantage students who already struggle on a daily basis.

Children are not little adults. They have unique needs, sensitivities, and vulnerabilities, and it is becoming increasingly evident that current school building conditions may not be sufficiently protective of our students’ developing bodies and minds. A large body of research has demonstrated that the school building influences their success as much as any other factor. Now it is time to act on behalf of our children and teachers, who deserve to develop, learn, and thrive in a healthy environment that optimizes their potential to succeed.

The scientific literature provides overwhelming evidence of the benefits of healthy school buildings. And evidence that when we act, we see an immediate difference. In this report we make two recommendations. First, we make a call for standardized Health Performance Indicators so that we can continue to understand the key drivers of health and performance in schools. Second, recognizing that school facilities represent the second largest sector of U.S. public infrastructure spending after highways, we call for a National Director of School Infrastructure and a National School Infrastructure Assessment.



II. INTRODUCTION

The Importance of the School Building

The quality and characteristics of our schools have an outsized impact on the health of students. By the time a student graduates from high school, she or he has spent 15,600 hours inside a school, an amount of time second only to that spent at home. For more than 50 million K–12 students in the United States, the time spent in school is also a time of rapid physical growth, hormonal changes, intense learning, and critical neurological and social development. Unfortunately, many aspects of the health and performance of students can be negatively affected by chronic exposures to common environmental factors in school buildings, including indoor air pollution, mold, pests, pesticides, radon, asbestos, lead, inadequate lighting, and elevated noise levels. The U.S. EPA (2011) has estimated that more than 60,000 schools (i.e., 46% of U.S. public schools) have environmental conditions that contribute to poor IEQ, including many of these factors.

For more than 50 million K–12 students in the United States, the time spent in school is also a time of rapid physical growth, hormonal changes, intense learning, and critical neurological and social development.

Although there is growing recognition that children’s health is foundational to their ongoing success in the classroom and beyond, increasing numbers of American students are burdened with ailments that challenge their ability to be present and fully engaged at school. Childhood asthma is a leading cause of student absenteeism and accounts for 13.8 million missed schools days each year, according to the latest estimates from the Centers for Disease Control and Prevention (2015). With increased absences, a student’s test scores may begin to reflect less about how much was studied and more about his or her health and ability to focus on learning.

13.8 million missed schools days each year due to asthma

Safe and healthy school environments are those that promote rather than hinder students’ learning (Wargocki et al., 2015). Keeping children in school is essential to their education, and educational attainment has a larger impact on long-term health than childhood socioeconomic status. Increased educational attainment has been shown to reduce gaps in health and life expectancy associated with disparate socioeconomic status (Montez & Hayward, 2014). It has been estimated that addressing inadequacies in education, which exacerbate disparities in health and rates of mortality, could save eight times as many lives as would be saved by medical advances alone in the same period (Woolf et al., 2007). In the United States, students are experiencing an increasing number of health burdens: one in three children exceed a normal, healthy body weight (National Collaborative on Education and Health, 2015), and visual health and levels of physical activity are declining as students increase their screen time (Centers for Disease Control and Prevention, 2014b). These pressing health concerns merit greater attention when designing school buildings precisely because this is the place where children spend most of their time outside the home.

21st Century Learning in 20th Century Schools

In the past 80 years, 250,000 public schools were consolidated into approximately 98,000 (National Center for Educational Statistics, 2016). According to the U.S. EPA, schools have four times more occupants than office buildings in the same amount of floor space. Public funds are strained and building capacity



is stretched to accommodate new students. This can often result in the use of spaces not intended for children or for proper educational delivery, as is the case in the 31% of schools that use portable classrooms, which are temporary, quickly assembled structures to accommodate increased numbers of students (Alexander et al., 2014).

Because many schools in the United States were constructed 50 or more years ago, students do not fully benefit from more recent critical research advances. Children regularly face adverse environmental exposures associated with building decay, such as water damage, mold growth, poor plumbing, and legacy pollutants that persist in the environment. An example is windowless classrooms, the result of a design trend that began with the 1973 energy crisis. Energy codes and buildings regulations enacted as a result of the energy crisis drove a trend toward reducing or altogether eliminating windows in classrooms (Baker & Bernstein, 2012). Despite occupant complaints, windowless classrooms were considered a viable option and gained popularity in the 1970s because the work of multiple researchers found that windowless classrooms were not associated with any significant difference in students' performance at school (Baker &

School is the place where children spend most of their time outside the home

Bernstein, 2012). However subsequent studies have shown that access to views of nature can be restorative (Li & Sullivan, 2016).

Simultaneously, our nation's water infrastructure — water pipes and mains that in many instances are more than 100 years old — has significantly deteriorated as it approaches the end of its useful life. A 2013 assessment by the American Civil Society of Engineers found America's water infrastructure to be in "poor to fair condition and mostly below standard" with "strong risk of failure" (American Society of Civil Engineers, 2013). Wear and tear on service pipes can exacerbate corrosion, which is the dissolving of metals that arises from chemical reactions between water and plumbing fixtures. This corrosion influences the extent to which lead, copper, and other metals can contaminate drinking water (U.S. EPA, 2016f).

Our aging school building infrastructure illustrates the need for reinvestment and renovations for the health and well-being of school occupants. From the air they breathe to the water they drink, there is an opportunity for the school to leave lasting health impacts on our students, teachers, and staff.

Lessons from Recent History

National attention recently put the public schools of Detroit in the spotlight after a series of teacher protests against poor school building conditions, but Detroit is only one of many districts grappling with these issues. Media reports within the past two years revealed that there have been numerous documented cases of school facility closures in the United States that were associated with concerns over environmental quality and potential health hazards in and around schools.

- In March 2015, a Dallas elementary school closed for several days after an environmental team found elevated carbon monoxide levels in the boiler room. The day before, nearly a dozen students had fallen ill and visited the school nurse, with many others reporting symptoms of headache before the school building was evacuated. Parents were alarmed to discover that the school did not even have a carbon monoxide detector on site (Hernandez, 2015).



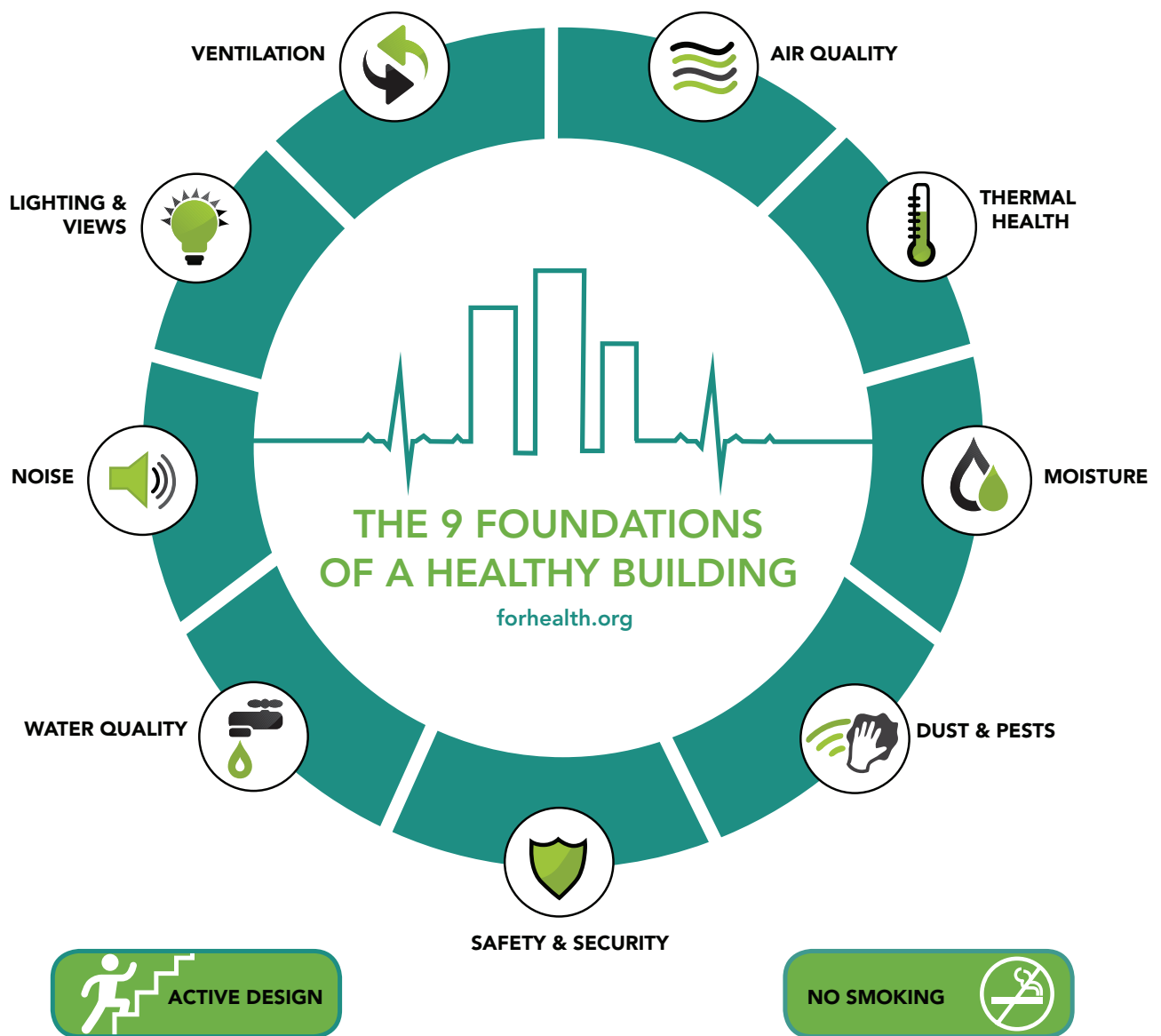
- After receiving complaints of odors and mold in February 2016, a 62-year-old elementary school in Millis, Massachusetts, temporarily closed when air quality testing results found elevated levels of trichloroethylene and tetrachloroethylene, which at acute, high-level exposures can cause eye irritation, respiratory symptoms, and neurophysiologic effects (such as dizziness and headache) (Harris, 2016).
- In California, more than 1,000 students were affected by the closure of the entire Klamath Trinity Unified School District for several days in February 2016 after mold was found in cafeterias, kitchens, administrative offices, libraries, boiler rooms, and classrooms throughout several buildings. Extensive repairs that include removal and replacements of roofs, walls, and ceiling tiles could cost the district an estimated \$17.5 million (Creswell, 2016).
- In May 2016, a K–12 school in Midwest, Wyoming, closed its doors after school staff reported a gaseous odor and some students complained of symptoms, including headaches, rashes, and hives. Indoor air quality testing revealed abnormal levels of volatile organic compounds (VOCs). Previously, in 2014, one of the school’s kitchen staff had fallen ill after smelling an unidentified odor and had to be flown to a hospital for medical treatment (Storrow & Schrock, 2016).
- In June 2016, the cafeteria and main office of a K–8 school and high school in Portland, Oregon, were closed after dangerously high levels of radon gas were detected. Several classrooms also showed radon test levels above the federal action limit. Radon is a naturally occurring radioactive gas that is invisible and odorless and that when inhaled at high levels is associated with increased risk of lung cancer (Hammond, 2016a,b).
- In 2016, elevated lead levels were detected in the drinking water in many public school buildings across the country (Ludden, 2016) including 30 public schools buildings in Atlanta (Bloom, 2016), 26 buildings in Chicago (Nitkin, 2016), and 19 of the 62 public school buildings in Detroit (Chambers & Lynch, 2016); the presence of elevated lead in water is just part of a larger ongoing issue across the nation’s aging school infrastructure (Wines et al., 2016).

These are just a few of the cases that exemplify the struggles encountered in many of America’s K–12 schools and the need for quick action as well as evidence-based decision-making and interventions to protect the health and education of our youngest Americans. The chronic impacts of a poor school environment often do not get the same type of attention as cases like these, because the links between building quality and health are subtler and less overt. As a nation, we have an obligation to provide nurturing, supportive, and healthy learning environments that address both acute and chronic impacts help to ensure that all students thrive and achieve their fullest potential. Educational reforms often focus on strengthening curriculum and teacher quality but give little or no consideration to the adequacy of school facilities.



THE 9 FOUNDATIONS OF A HEALTHY BUILDING

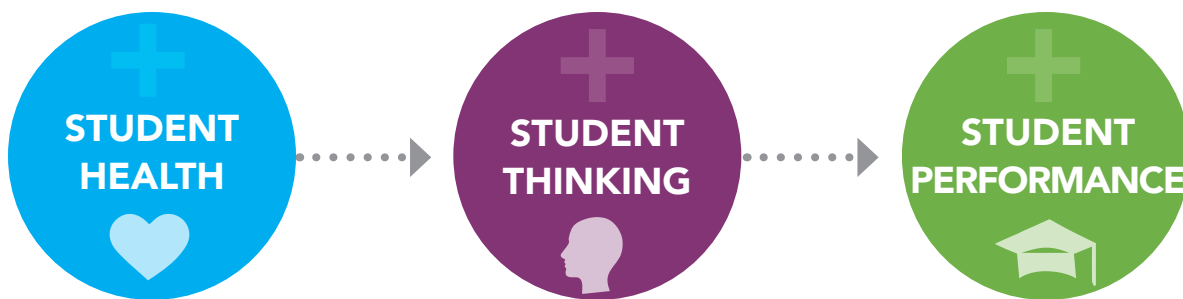
What constitutes a “healthy building”? In 2016, the Healthy Buildings team at Harvard released The 9 Foundations of a Healthy Building, which synthesized 30 years of scientific evidence into the nine fundamental building factors that influence health and performance. The 9 Foundations provides a valuable framework for thinking about school facilities in the United States and other developed nations. More at: 9Foundations.ForHealth.org





III. EXAMINING THE EVIDENCE

More than 40 years of scientific research has led to many insights about how the indoor environment influences student health, well-being, and productivity. School building conditions such as ventilation, indoor air quality (IAQ), thermal comfort, lighting and views, and acoustics and noise play an important role in a student’s ability to focus, process new information, and feel engaged at school. These environmental factors can have both detrimental and positive impacts on student health and performance. This report examines when and how these various building conditions affect a student and pays special attention to articulating the nuanced effects these parameters have on how our students feel, think, and perform.



+ STUDENT HEALTH captures the overall physical and biological health of a school building occupant. For example, allergies, common cold, and other noncommunicable and communicable diseases can prevent students from feeling well throughout the academic year and may affect attendance.

+ STUDENT THINKING encompasses short-term (i.e., hourly, daily, or weekly) impacts on cognitive function and mental well-being and includes attention, comprehension, annoyance, and irritability.

+ STUDENT PERFORMANCE refers to the successful long-term academic performance of students.



VENTILATION AND INDOOR AIR QUALITY

Ventilation is a key determinant of health in buildings. Ventilation rate is the flow of outside air into a building per unit of time. The aim of good ventilation is to ensure a comfortable, healthy, and productive indoor environment throughout the day and to respond to the number of occupants in a space. Existing guidelines for *acceptable* IAQ, defined by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), in schools recommend a minimum classroom ventilation rate of 15 cubic feet of outside air per person, or five liters per second, per person to keep indoor carbon dioxide (CO₂) concentrations at or below 1000 ppm (ASHRAE, 2016).

INDOOR ENVIRONMENTAL QUALITY (IEQ) v. INDOOR AIR QUALITY (IAQ)

IAQ is commonly used to describe environmental conditions in buildings, but our health depends on much more than just the air. As such, we prefer the term indoor environmental quality (IEQ) because it encompasses a wider range of factors, including contaminants found in air, dust and water.

A useful indicator of ventilation is the concentration of CO₂, continuously exhaled by building occupants. High CO₂ levels suggest that there is poor ventilation and movement of air in a space, which could lead to increased concentrations of a variety of irritants. Studies of IAQ in schools have repeatedly found CO₂ levels in excess of the ASHRAE threshold (Corsi et al., 2002; Dorizas et al., 2015a; Haverinen-Shaughnessy et al., 2011; Muscatiello et al., 2015; Shendell et al., 2004; Toftum et al., 2015). An assessment of 120 classrooms in Texas (Corsi et al., 2002) found that time-averaged CO₂ concentrations exceeded 1000 ppm in 66% of classrooms and that peak CO₂ concentrations surpassed 3000 ppm in 21% of classrooms surveyed. Shendell and colleague (2004) measured CO₂ concentrations greater than 1000 ppm in 45% of the 435 classrooms they surveyed in Washington and Idaho. A study in the southwest United States found that 87 of 100 classrooms assessed had ventilation rates below the ASHRAE standard 62.1-2004, which recommended a minimum of 7.1 liters per second per person (L/s/p) (Haverinen-Shaughnessy et al., 2011). In the state of New York, a study of 64 classrooms reported that 20% of measured CO₂ concentrations exceeded 1000 ppm (Muscatiello et al., 2015).

Children have developing lungs with narrow airways and, compared with adults, they breathe larger volumes of air relative to their body size (Annesi-Maesano et al., 2013; Schwartz, 2011). More than 25 million children — nearly 50% of America's students — attend schools that have not yet adopted an IEQ management plan, a strategy used to identify and remediate poor air quality in schools (U.S. EPA, 2014). These plans are not mandatory for schools but are considered best practices. According to the Centers for Disease Control and Prevention's School Health Policies and Practices Study, the number of schools reporting implementation of IAQ management programs dropped from 47.7% in 2012 to 46.1% in 2014.

In that same time frame, the percentage of U.S. public schools requiring students to receive health instruction on asthma also declined at the elementary, middle, and high school levels (Centers for Disease Control and Prevention, 2012; 2014a). IEQ management plans, such as the frameworks provided in the U.S. EPA's *IAQ Tools for Schools* action kit, empower schools to benefit from best practices and proven approaches and strategies that advance environmental health in schools (Environmental Law Institute, 2015). After implementing an IAQ management program based on the *IAQ Tools for Schools* checklist, the Omaha Public School District observed a decrease in the frequency and severity of asthma attacks (Bengston, 2012). In Connecticut, adoption of a program based on the *IAQ Tools for Schools* has helped address IAQ problems in more than 850 schools. In Waterford, 9 out of 13 schools reported 66% fewer IAQ-related complaints. In the North Haven school district, school nurse visits were reduced by 11% and reported respiratory cases declined by 48%. In Hartford the school district saw a 21.2% decrease in asthma cases within a single year, and in Hamden, absenteeism rates fell by more than half (Connecticut Education Association, 2011).



+ STUDENT HEALTH

Common indoor air pollutants in schools have been observed at levels two to five times higher than outdoor concentrations, including VOCs, which have been associated with acute chronic health effects including asthma, allergies, mucous membrane irritation, and impacts on the central nervous system functioning (Alves et al., 2013; De Gennaro et al., 2013). Indoor exposure to VOCs such as formaldehyde (present in many adhesives, glues, polyurethane, foam insulation, particle board, plywood, pressed wood, fiberboard, carpet backing, and fabrics) has been associated with asthma-like symptoms in schoolchildren (Annesi-Maesano et al., 2013) as well as with eye, nose, and throat irritation; headaches; nausea; and more (U.S. EPA, 2016e).

Adverse effects have been reported for elevated CO₂ levels in classrooms, including increased student absence (Gaihre et al., 2014; Simons et al., 2010), decreased satisfaction with IAQ (Chatzidiakou et al., 2014), and symptoms of wheezing among children in daycare centers (Carreiro-Martins et al., 2014). Lower ventilation rates have been linked to more missed school days caused by respiratory infections (Toyinbo et al., 2016a); greater prevalence and incidence of symptoms of sick building syndrome (Chatzidiakou et al., 2015a); greater mean number of school nurse visits caused by respiratory symptoms (Haverinen-Shaughnessy et al., 2015a); increased asthmatic symptoms, nasal patency, and risk for viral infections (Chatzidiakou et al., 2012); and the transmission of airborne infectious diseases such as chickenpox, measles, and influenza (Li et al., 2007; Luongo et al., 2015).

+ STUDENT THINKING

Improving IEQ can positively affect cognitive function outcomes, such as decision-making, attention, concentration, and memory. In recent studies, the short-term effect of air quality on health was captured through the use of computerized tests that assessed problem solving and memory. These tests have been helpful tools for researchers to show the effects of air quality on a day-to-day basis in students and office workers. Studies have found that higher ventilation rates and low CO₂ levels can positively affect cognitive function (Allen et al., 2015; Mendell et al. 2015; Satish et al., 2012). For example, a controlled exposure study of office workers found that when ventilation rates were doubled from the “acceptable”

Asthma and Chronic Absenteeism

Nearly one in 13 children of school age has asthma, the leading cause of school absenteeism related to chronic illness. There is substantial evidence that indoor environmental exposure to allergens, such as dust mites, pests, and molds, plays a role in triggering asthma symptoms. These allergens are common in schools and can affect student attendance, comfort, and performance and reduce teacher and staff performance (U.S. EPA, 2016b).

- ✓ Elementary school students are more likely to be absent because of health reasons or circumstances beyond their control (i.e., asthma, transportation, or unstable housing), rather than oppositional or defiant behavior that would cause them to drop out. Chronic absenteeism (missing 10 or more days of school) is often used as a proxy for health information at the school level because specific health data cannot be released to researchers because of privacy legislation (Ready, 2010).
- ✓ In 2013–2014, more than 6 million students were absent 15 days or more, putting them at increased risk of dropping out or falling behind. As of June 2016, the U.S. Department of Education launched a new initiative, “Every Student, Every Day National Conference: Eliminating Chronic Absenteeism by Implementing and Strengthening Cross-Sector Systems of Support for All Students.” The main goal of the initiative is to support state and local efforts to address and eliminate chronic absenteeism among our nation’s most vulnerable students, particularly those attending low-performing schools (U.S. Department of Education, 2016). Addressing poor IEQ may be one of the many solutions needed to reduce this epidemic.



minimum and CO₂ concentrations were lowered from 1400 to 950 or 550 ppm, study participants had higher cognitive function scores (Allen et al., 2015). These same improved conditions were also related to participants' perceptions of better IEQ and better self-reported health, suggesting that the effects of IEQ in cognitive function and health can move through both psychological and physiological pathways (MacNaughton et al., 2016a).

Similar results have been reported in a computerized assessment of primary schoolchildren's cognitive function. Students' attention processes are significantly slower in classrooms with high CO₂ levels and low ventilation rates. Researchers observed a 5% decrement in "power of attention" in poorly ventilated classrooms, roughly equivalent to the impact that a student might feel from skipping breakfast (Coley et al., 2007). With similarly poor CO₂ levels and ventilation rates in school buildings, students have been observed to experience greater fatigue, impaired attention span, and loss of concentration (Chatzidiakou et al., 2012); poorer performance on tests of concentration (Dorizas et al., 2015a); and lower levels of focus among university students during lectures (Uzelac et al., 2015).

+ STUDENT PERFORMANCE

Multiple studies have shown that when steps to mitigate poor IEQ are taken, students' academic performance improves (Basch, 2011; Centers for Disease Control and Prevention, 2009a; La Salle & Sanetti, 2016; Michael et al., 2015). A study of fifth-grade students in 54 U.S. classrooms reported evidence of an association between ventilation rates and pupils' performance on standardized mathematics tests (Shaughnessy et al., 2006). Similarly, in a study of 100 U.S. elementary classrooms, positive associations

IEQ and School Staff

Adults who work in schools are also vulnerable to impacts from the environmental conditions presented in this document, and their health and wellbeing is essential to the day-to-day function of the school, both inside the classroom and out. Teachers and custodians are examples of school staff influenced by quality and composition of indoor air.

✓ **TEACHERS** Educational employees report the highest proportions of work-related asthma cases in the United States. Teachers have a higher prevalence of asthma compared with other non-industrial occupational groups (Angelon-Gaetz et al., 2016). A recent survey of 500 teachers in New York State found that teachers experiencing multiple symptoms such as sinus problems, headache, allergies, congestion, or throat irritation were more likely to report having classrooms with dust, dust reservoirs, paint odors, mold, or moldy odors. The strength of the association increased with greater numbers of classroom characteristics related to poor IAQ (Kielb et al., 2015). Elevated classroom CO₂ concentrations have also been associated with increased self-reported neurophysiological symptoms among teachers, including headache, fatigue, and difficulty with concentration, even after controlling for classroom age, ventilation factors, and potential indoor allergens and irritant sources (Muscatiello et al., 2015).

✓ **CUSTODIANS** A school free of dust, pests, and other allergens is essential for healthy building occupants. In the course of custodians' daily tasks to ensure a clean environment, they can be chronically exposed to harsh chemicals that may result in injury or illness if products are not properly used. Detergents, bleaches, caustic chemicals, and other cleaning products are often inhaled, accidentally ingested, or absorbed through the skin. Ingredients found in common cleaning products may exacerbate asthma and rhinitis (Liu et al., 2016; Vizcaya et al., 2015) and cause custodial chemical injuries, which collectively result in \$25 million in lost time and worker compensation each year in the United States (Regional Asthma Management & Prevention).



were observed between ventilation rates and performance on standardized tests in math and reading, with researchers estimating that each 1-L/s/p increase in ventilation rate was associated with an expected increase of 2.9% and 2.7% in math and reading scores, respectively (Haverinen-Shaughnessy et al., 2011). The link between ventilation and achievement was substantiated in another study in which students in schools that failed to meet a minimum ventilation rate of at least 6 L/s/p were found to be more likely to perform poorly on mathematics tests (Toyinbo et al., 2016b). Likewise, researchers in California who analyzed longitudinal data collected over two years from 150 classrooms found that higher ventilation rates in the preceding 30 days were associated with a district-wide increase of 0.6 points on English tests and a similar (though not statistically significant) increase in math test scores (Mendell et al., 2015).



WATER QUALITY

The U.S. Environmental Protection Agency controls the National Primary Drinking Water Regulations (NPDWR) which sets water testing schedules and legal limits for more than 90 contaminants in drinking water (EPA, 2015). Limits are set for the following classes of potential contaminants: microorganisms, disinfectants, disinfection byproducts, inorganic chemicals, organic chemicals and radionuclides. For each, EPA sets a Maximum Contaminant Level Goal (MCLG) and a Maximum Contaminant Level (MCL), of which the latter is the legally enforceable limit. Occasionally these limits are not met. An investigation and analysis of over 20 million tap water quality test results from 2004-2009 found that even among regulated contaminants, 87 chemicals were detected at least once at levels above recommended guidelines (EWG, 2009).

For schools impacted by lead in water, strategies that involve fixing tap water are more economical in the long-run compared to providing bottled water

(Cradock et al., 2012).

Drinking water quality can be impacted from improper treatment; poor maintenance of distribution systems; malfunctioning wastewater treatment systems; accidental sewage releases; pesticides, fertilizers, and livestock waste from agricultural runoff; and heavy metals from manufacturing processes (Centers for Disease Control and Prevention, 2009b). Water quality is also affected by the amount of time that water is stored in a system before being used. Storage for long periods can damage plumbing materials and compromise the safety of drinking water by diminishing the efficacy of disinfecting agents (such as chlorine) and contributing to the growth of microorganisms that pose a risk to human health (Rhoads et al., 2015). Likewise, changes in disinfection practices in lead service lines can increase the levels of lead in drinking water (U.S. EPA, 2007; Miranda et al., 2007; Brown et al., 2012).

+ STUDENT HEALTH

Providing access to safe drinking water is critical to student health. There are state and federal policies for access to safe, clean drinking water that are often not being met (Kenney et al., 2016). And the evidence shows that when appropriate access to water is provided, water intake increases (Jasper et al., 2012).

In many cities and schools our nation's water infrastructure is significantly deteriorated and approaching the end of its useful life as many water pipes and mains are more than 100 years old (ASCE, 2013), brought to national attention by the Flint water crisis in Michigan, which exposed thousands of children to unsafe levels of lead (Hanna-Attisha et al., 2015).

Microbial contamination is by far the largest contributor to the global burden of waterborne disease, and although the United States has one of the safest public drinking water supplies in the world (USDA, 2011), outbreaks of waterborne illnesses continue to occur. Surveillance data from the CDC revealed that in 2011-2012, 32 drinking water related outbreaks were reported across the nation, contributing to 431 cases of illness, 102 hospitalizations, and 14 deaths (Beer et al., 2015). More than 78% of these outbreaks were associated with community water systems. When adequate water and sanitation facilities are available there is a reported decrease in both diarrheal and gastrointestinal diseases (Jasper et al., 2002).



+ STUDENT THINKING

Lead in drinking water is of primary concern in schools. A significant body of evidence has established that lead can affect children's cognitive development (Brown & Margolis, 2012) even at low levels (Earl et al., 2015) and that the effects of lead can persist into young adulthood. Children exposed to lead are more likely to have cognitive deficits (Mazumdar et al., 2011), reduced attention span, and behavioral problems (Daneshparvar et al., 2016). Lead service lines and higher levels of lead in water have been significantly associated with elevated blood lead levels in young children (Brown et al., 2012; Edwards et al., 2009). Because children are especially vulnerable to lead exposures, the U.S. EPA has stated that there is "no known safe level of lead in a child's blood" (U.S. EPA, 2016f).

Lead, Mercury and Neurotoxic Chemicals

The hazards of exposure to lead go beyond that of finding it in drinking water — exposure to lead-based paints, lead dust, and contaminated soils are also common hazards. Exposure to lead contributes to adverse impacts on neurodevelopment including intellectual and cognitive deficits, long-term brain development, attention, memory, language skills, and IQ decrements (Lanphear et al., 2015; Mason et al., 2014). Mercury, another neurotoxic metal, can still be found in some schools in thermostats, thermometers, switches, fluorescent bulbs, and other electrical devices. Mercury found in schools has been associated with poor performance on tests of mental function and reduced IQ (Liu & Lewis, 2014). Like lead and mercury, PCBs are risk factors for cognitive impairment. International studies have reported negative associations between prenatal PCB exposures and measures of cognitive function in childhood (Lanphear, 2015; Schantz et al., 2003). Flame retardants also affect neurological function (Roze et al., 2009). For example, in a study of 515 adolescents, a significant association was found between concentrations of flame retardants in the body and poorer performance on a standard neurobehavioral test (Kiciński et al., 2012). See 'Chemicals of Concern' for more information.

+ STUDENT PERFORMANCE

Nearly 40 years ago, Needleman et al. (1979) examined lead levels in first and second graders shed teeth since teeth provide a history of metal exposure over time. Students with higher lead-levels (>17.2 ppm dentine lead) appeared to be highly distractible, more dependent, frustrated, hyperactive unable to follow simple directions and sequences, and had low overall functioning compared to students with lower lead level (<5.1 ppm dentine lead). In the same group of students, it appeared that full scale IQ was significantly lower in high lead students compared to low lead students with specific deficits in information, vocabulary and overall verbal IQ. This finding has since been affirmed in more recent studies which show impacts on IQ and cognitive performance at lower levels of lead exposure (Schwartz, 1994; Lanphear et al., 2005).



DUST, PESTS, MOLD & MOISTURE

Dust acts as a reservoir for a variety of harmful agents – outdoor particles that penetrate indoors, viruses, bacteria, chemicals, allergens (pets, mites, mold spores, pollen), building materials, dander, fabric fibers, and flakes of paint with lead. The primary concern from pests and domestic animals is that they introduce allergens to the indoor environment which can cause an immune response in adults and children. The most relevant allergens for many indoor locations are: dust mites, cockroaches, mice, rats, cats and dogs. Entrance of water into damaged, poorly designed, and improperly maintained buildings has been identified as the main source of building-related illness from mold exposure in a review of over 120,000 indoor air quality documents published between 1994 and 2001 (OSHA, 2006).

+ STUDENT HEALTH

Mold and pests respond to increased indoor relative humidity levels and moisture, and the presence of mold and pests may signal improper design, maintenance, or operation of buildings. Students and school occupants can come in contact with mold by breathing mold spores that become airborne and by touching mold on surfaces. Indoor building dampness and mold have been found to increase respiratory symptoms significantly in multiple epidemiological studies and meta-analyses (Baldacci et al., 2015). These building conditions have been linked to higher prevalence of asthma (Kuehn, 2009), greater number of self-reported upper respiratory symptoms (i.e., wheeze, congestion and phlegm, nocturnal dry cough, and allergic rhinitis) (Jacobs et al., 2014; Toyinbo et al., 2016a), as well as respiratory-related absenteeism, nocturnal dry cough, wheeze, and nasal symptoms (Borràs-Santos et al., 2013). Visible mold, higher bacterial counts, and classroom mean fungal spore concentrations have also been significantly associated with higher odds of cough episodes (Madureira et al., 2015), student absenteeism (Simons et al., 2010), and greater prevalence of physician-diagnosed asthma (Chen et al., 2014).

Additionally, cockroach allergen is ubiquitous in cities and may be an important driver of asthma because of its highly allergenic nature. Cockroach and mouse allergens are released into the air or dust through pest droppings, saliva, and body shedding. There is mounting evidence that airborne allergens and pollutants aggravate asthma and allergy symptoms in both sensitive and nonsensitive individuals (Baldacci et al., 2015; Kanchongkittiphon et al., 2015). Inner-city students from across the United States who were exposed to high levels of cockroach allergen and who had a cockroach allergy had significantly more days of wheezing, missed school days, and nights with lost sleep than students who were not exposed, and their parents or other caregivers were awakened during the night and changed their daytime plans more frequently because of the child's asthma (Rosenstreich et al., 1997). Analyses of schoolrooms in Detroit, Houston, Baltimore, and Birmingham, Alabama, found that each city had schoolrooms with levels of cockroach allergen exceeding proposed sensitization thresholds (Abramson et al., 2006; Amr et al., 2003; Sarpong et al., 1997; Sheehan et al., 2009). In several randomized controlled trials addressing cockroach allergen with HEPA filters and professional cleaning for one year, researchers found a reduction in school days missed, caretaker burden, sleep disruption, and daytime symptoms (e.g., wheezing) after the intervention (Eggleston et al., 2005; Morgan et al., 2004; Pongracic et al., 2008).

+ STUDENT THINKING

In a study of over 1000 students, the concentration of molds in floor dust was associated with concentration problems, headache and dizziness (Kim et al., 2007). Similar impacts were observed in studies of teachers. In a study of 500 New York State teachers, the most commonly reported allergens and irritants were dust and dust reservoirs, followed by moisture problems, construction during school hours, and roaches or



CHEMICALS OF CONCERN

Along with traditional IEQ concerns, increasing attention is being paid to “chemicals of concern.” Many of these chemicals are semi-volatile and can be found in both air and dust.

Flame Retardant Chemicals

Flame retardant chemicals can be found in many common furnishings and building materials used in schools. These chemicals don't stay put — they migrate out of products into the air and dust (Allen et al., 2008) and accumulate in our bodies. Many flame-retardant chemicals are endocrine disruptors that interfere with the reproductive system (Johnson et al., 2013; Meeker et al., 2010) and are associated with thyroid disease (Allen et al., 2016).

Stain Repellent Chemicals

Stain-repellent chemicals are widely used in many products because they confer resistance to water, oil, and greases. These classes of chemicals, called polyfluorinated alkyl substances (PFASs) or polyfluorinated chemicals (PFCs), are used in furnishings, carpets, clothing, nonstick cookware, paints, and other objects. People are exposed to these chemicals through air, dust, and drinking water (Trudel et al., 2008). A study published in 2016 found that, for more than 6 million U.S. residents, the concentration of PFASs in their drinking water is over the limit set by the U.S. EPA (Hu et al., 2016). PFASs are associated with cancer (Vaughn et al., 2013), thyroid disease (Melzer et al., 2010), and immunotoxicity; in a study of young children (age 5–7), higher PFAS in blood was associated with reduced immune response to childhood immunizations (Grandjean et al., 2012).

Phthalates

Phthalates are a class of chemicals that are used as plasticizers to make products soft and flexible. They can be found in many products in schools — such as vinyl tile, PVC piping, school supplies, and artificial leather (phthalates are also commonly found in personal care products such as nail polish, hair spray, and skin lotions) (Lowell Center for Sustainable Production, 2011). As is the case with flame-retardant and stain-repellent chemicals, phthalates can leach out of their original product or medium and enter the air and dust in our homes, offices, and schools. A primary health concern related to phthalates is concern over their association with asthma and allergies. In one large study of several hundred children, researchers found that phthalates in dust were associated with allergic symptoms in children when present at levels that are commonly found indoors (Bornehag et al., 2004).

Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) — an environmentally persistent pollutant, endocrine disruptor, and “probable carcinogen” (U.S. EPA, 2016a) — is still commonly found in school building caulk and lighting ballasts and at documented airborne concentrations that frequently exceed recommended health guidelines. Although PCBs are no longer produced or used in the United States (U.S. EPA, 2016a), it is estimated that PCBs in building caulk still remain as an important legacy pollutant in more than 25,000 U.S. schools (Herrick et al., 2015). PCBs can disrupt thyroid hormone receptors, which are critical for normal brain development and immune system function. Prenatal exposure to PCBs may affect height, weight, head circumference, and body size at puberty, which may be a concern for pregnant teachers and staff members (Dallaire et al., 2014; Rogan & Ragan, 2003).



rodents (Kielb et al., 2003). Over 10% of teachers reported headaches, fatigue or drowsiness, eye or throat irritation, and allergies/congestion, which impacted their ability to attend or teach class effectively (Kielb et al., 2003). Also, in the Copenhagen School Study, a higher prevalence of building related symptoms (nose and eye irritation, headache, fatigue, and concentration difficulties) were associated with high inflammatory potential of school dust samples compared to schools with a lower prevalence of symptoms (Allermann et al., 2003).

+ STUDENT PERFORMANCE

Students cannot perform well if they are not present physically. The presence of visible mold, humidity and poor ventilation were all independently associated with absenteeism in a study of schools in New York State (Simons et al., 2010). There are also indirect effects, as noted in a review by Mendell et al., where many studies link molds and moisture to effects on asthma and respiratory infections, which are themselves associated with absenteeism and lower performance in school (Mendell and Heath, 2005).



THERMAL HEALTH

Thermal health is a term proposed by the ForHealth team to replace the more commonly used and narrow term “thermal comfort”. The term thermal health encompasses all of the impacts of thermal conditions on health, cognitive function and performance, that go beyond just “comfort”. Traditionally, the focus in the built environment has been on thermal comfort, which is defined as “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.” (ASHRAE, 2013). Thermal health is largely a function of humidity and temperature and is influenced by individual factors such as clothing, physical activity, metabolic rate, and personal preference. It is also influenced by building-mediated factors, including air temperature, air speed, and humidity. Humidity encompasses absolute humidity — the water vapor content of the air — and relative humidity, which is expressed as a percentage and is relative to the temperature of the air. When the humidity level is 100%, indoor air is completely saturated with water vapor (Byber et al., 2016). Indoor temperatures can be influenced by characteristics of a classroom’s operation, including occupant density and ventilation strategies (Chatzidiakou et al., 2015a) as well as building structure and mode of ventilation used (Salthammer et al., 2016).

In a recent study examining Regents exam test scores in 75,000 high school students in New York City, Park (2016) found that for every increase of 1°F, test scores fell by 0.2%; for the average student, the likelihood of failing an exam taken on a 90°F day versus a 75°F day would be 12.3% higher.

Thermal health can be highly subjective because it includes individual expectations, metabolic rate, and clothing insulation (Zomorodian et al., 2016). Existing thermal comfort models are based on studies done with adult subjects and have often been found to predict students’ thermal comfort levels inaccurately (Teli et al., 2012; Van Hoof, 2008; Zomorodian et al., 2016). Although young children may not yet have the vocabulary to express their thermal sensations or the difference between temperature and heating, they do show awareness of these basic concepts and the notion of comfort (Fabbri, 2013). Young children have higher metabolic rates, higher core body temperature, less developed thermoregulation capabilities (Garcia-Souto & Dabnichki, 2016; Liu et al., 2015; Zomorodian et al., 2016), and a wider range of thermal responses. Children are more vulnerable to the effects of heat stress and appear more uncomfortable at higher temperatures than those of adults. They have also been found to prefer cooler environments (Nam et al., 2015; Vanos et al., 2016; Zomorodian et al., 2016). Additionally, children’s clothing and activity levels are distinct from adults (Havenith et al., 2007) and are likely to have a significant influence on students’ thermal preferences. Pre-K and kindergarten students, who may still require assistance with getting dressed, are less able to adapt by adding or shedding extra layers of clothing when they feel uncomfortable.

+ STUDENT HEALTH

Thermal health characteristics including humidity have been associated with the development and exacerbation of respiratory symptoms in adults and children in schools. Low absolute humidity has been associated with increased influenza virus survival and transmissibility and the onset of seasonal influenza outbreaks (Koep et al., 2013; Myatt et al. 2010). Evidence of the effects of humidity on student health have been observed in a study of more than 1,000 13- to 16-year-olds from 11 public schools in Poland. Researchers investigated how indoor environmental conditions in school gymnasiums might influence students’ health during physical education classes. In addition to collecting dust samples to assess potential allergen exposure, they measured air temperature, air pressure, and humidity and administered pulmonary-function tests to students before and after attending a 45-minute physical education class. They observed that although higher temperature itself did not appear to be a risk factor, exposure to higher humidity independently increased students’ risk of clinical symptoms, including exercise-related cough or bronchoconstriction, reported during or after class (Stelmach et al. 2016).



Although objective measurement of symptoms and environmental conditions can provide stronger evidence, useful insights can also be gained from school occupants' subjective perceptions. A survey of more than 4,200 students and 134 principals representing 297 schools in Finland investigated associations between school building attributes, IEQ, and self-reported upper respiratory symptoms. The researchers noted that during the heating season, students' reports of upper respiratory symptoms were significantly associated with principals' reports of unsatisfactory (too hot or too cold) classroom temperatures (Toyinbo et al., 2016a). Warmer classroom temperatures have also been associated with student perceptions of poor air quality; self-reported symptoms of stuffiness; headache; and eye, nose, and throat symptoms (Norbäck & Nordström, 2008; Turunen et al., 2014); as well as fatigue and difficulty breathing (Bidassey-Manilal et al., 2016).

+ STUDENT THINKING

Thermal conditions can distract occupants of school buildings from their ability to stay focused in the classroom. When temperatures are too warm, teachers and students are in general slower to react and process information from their surroundings. Although direct studies of children remain limited, studies of adults and the effects of occupational heat stress have shown that heat stress may increase mental fatigue during performance of sustained-attention tasks that demand greater cognitive resources (Qian et al., 2015). Cold stress, such as reductions in ambient temperature to around 50°F, may have a negative effect on cognitive function by increasing distractibility (Muller et al., 2012).

Research on university students and adults, while not K–12 students, can help to elucidate the effects of heat and cold stress on cognitive function. Among university students, complex tasks such as working memory, reasoning, and planning skills appear particularly vulnerable to extreme heat stress, whereas simpler tasks were less affected by this condition (Zhang & de Dear, 2016). In a study focused on cold stress, Taylor and colleagues (2015) found that both simple and complex task performance were negatively affected. Studies of university students have found that cognitive performance scores were 5% higher in self-reported acceptable (thermally neutral) conditions than in unacceptable thermal conditions (Zhang & de Dear, 2016), whereas exposure to a slightly warmer temperature (82.4°F) was associated with significantly more self-reported difficulties in concentration (Maula et al., 2015). Office workers scored 5.4% higher on cognitive function tests when they were in a thermally acceptable environment, compared to colleagues who were not (MacNaughton et al., 2017).

+ STUDENT PERFORMANCE

Several large studies show thermal health can influence academic performance — specifically test scores. In a recent study examining high-stakes exam test scores in 75,000 high school students in New York City, Park (2016) found that for every increase of 1°F, test scores fell by 0.2%; for the average student, the likelihood of failing an exam taken on a 90°F day versus a 75°F day would be 12.3% higher. In a survey of more than 4,000 6th-graders, students who reported they had never experienced high indoor temperatures achieved 4% more correct answers on a national mathematics test compared with students who experienced high temperatures daily (Haverinen-Shaughnessy et al., 2012). Another study of 10- to 12-year-old children observed that reducing classrooms temperatures from 25 to 20°C (77 to 68°F) during warm weather was associated with significant improvements in students' speed on arithmetic and language-based tests. The children reported experiencing the indoor air as much fresher. Based on these findings, the researchers calculated a dose–response relationship indicating that each 1°C (1.8°F) reduction in temperature could translate to a 4% improvement in students' performance speed (Wargocki and Wyon, 2013). A study of more than 3,000 schoolchildren in 140 classrooms of fifth-graders in the southwestern United States also reported that each 1°C decrease in temperature within the range of 20–25°C (68–77°F) was associated with an additional increase of 12–13 points in students' average test scores in mathematics. Science and reading test scores showed effects of a similar magnitude but with higher variability. The researchers concluded that students' academic performance could significantly benefit from adequately maintaining thermal comfort in classrooms (Haverinen-Shaughnessy & Shaughnessy, 2015b).



LIGHTING & VIEWS

Good-quality lighting in schools creates optimal viewing conditions for students to see the blackboard and to read and write during classroom learning activities. Lighting plays an important role in the school environment; it has evolved over time with the advent of new lighting technologies and changes in the size and presence of windows, which have influenced the quality of light inside the classroom. Lighting exposures primarily come from electric lighting and natural daylight. Two main attributes of light are its illuminance and color temperature. Illuminance over a given area is determined by the luminous flux per square meter and is measured in units of lux. In a classroom, the recommended illuminance is 500–2000 lux, which allows students to perform visual tasks with low or medium contrast and small sized font and detail, including activities such as reading, typing, or attending lectures. Correlated color temperature (CCT) describes the thermal temperature of a light source and is measured in units of Kelvin (K). Lights of low color temperature appear warm (red to yellow), whereas lights of high color temperature appear cold (white to blue). Daylight has a CCT of about 6500K and peaks in the blue spectrum.

Lighting, energy, visual comfort, and thermal comfort parameters interact as a delicate balance between light quality, heat from lighting sources, and solar heat gain from windows. Window shadings, such as blinds or curtains, are adaptive solutions to enhance thermal comfort and minimize glare from direct sunlight, but they reduce daylight penetration and can increase energy consumption from the use of artificial lights indoors (Zomorodian et al., 2016). Traditionally the main type of electric lighting used in schools has been fluorescent lighting, which emits infrared heat and can increase the temperature of a room. Over the past two decades, the desire for increased energy efficiency has driven widespread adoption of light-emitting diodes (LEDs) because they emit minimal heat and have potentially significant cost-saving benefits.

+ STUDENT HEALTH

Although studies of lighting impacts in school environments are limited, we do know that children are more sensitive to light exposure than adults because they have larger pupils and have significantly greater light-induced melatonin suppression, with young adolescents having greater circadian-system sensitivity to light exposures than older adolescents (Crowley et al., 2015; Higuchi et al., 2016; International Commission on Illumination, 2012; O’Hagan et al., 2016).

Low levels of light indoors in combination with less time spent outdoors have been associated with increased risk for nearsightedness (myopia) (Kocak & Sherwin, 2015). Conversely, studies have shown that increasing children’s time spent outdoors may reduce the risk of developing myopia or slow its progression (Kocak & Sherwin, 2015; Ramamurthy et al., 2015; Sherwin et al., 2012). In a randomized controlled

VISUAL AND NON-VISUAL IMPACTS OF LIGHTING

The visual and non-visual impacts of lighting are in constant interaction because light not only aids vision, but also synchronizes the biological clock that governs our sleep–wake cycles. The timing, intensity, and spectral power distribution of light exposure can alter these patterns because lighting cues from the environment signal the body to suppress levels of the sleep-related hormone melatonin in order to increase our feelings of alertness (Figueiro, 2013). The human eye has evolved to be attuned to light that peaks in the blue spectrum (such as the midday sun), meaning that electrical light sources with a similar color temperature can also stimulate the body’s circadian system. The circadian system is different from the visual system in that it is stimulated by higher levels of illuminance and its spectral sensitivity peaks at shorter (i.e., blue spectrum) wavelengths of light (Lockley, 2009). Furthermore, the circadian system is exquisitely sensitive — the same light stimulus can affect it in different ways at various stages of the day, advancing the circadian clock in the morning for example or delaying it in the evening (Bellia et al., 2013; Rodriguez et al., 2015).



clinical trial of 1,983 Chinese children, outdoor play time was increased to 40 minutes per day to assess its efficacy in preventing myopia over a three-year period. Baseline myopia incidence in the case and control groups was less than 2%, but at the end of three years, the cumulative incidence of myopia in the outdoor playgroup was observed to be 9.1% lower (He et al., 2015). Based on these findings, other researchers investigated whether increasing light levels indoors could provide a similar protective benefit against myopia onset. In their prospective study of 317 children from 6 to 14 years old in four schools, researchers introduced a lighting intervention that included rebuilt elevated lighting systems (suspension-mounted fluorescent tubes of 6500K) that significantly improved the average illuminance of desks (from less than 100 lux to more than 500 lux) and the uniformity of desk lighting. After one year, a comparison of students learning in classrooms with brighter ambient light levels and students learning in control (non-intervention) conditions revealed that the prevalence of new onset myopia (measured as a decrease in refractive error and smaller increase in axial elongation) in the intervention group was significantly lower than in the control group (4% vs. 10%) (Hua et al., 2015).

Many studies on the health impacts of daylight have reported evidence for benefits, including improvement of vision, better sleep quality, and reduced symptoms of nearsightedness, eyestrain, headache, and depression. In children, higher levels of average daily daylight exposure have been associated with reduced weekday and weekend sedentary time and with increased levels of physical activity on the weekends (Aggio et al., 2015). Studies examining the impact of daylight productivity are strongest in research on office workers. Daylight exposure and access to windows at work have been linked to improved sleep duration and mood, reduced sleepiness, lower blood pressure, and increased physical activity, whereas lack of natural light has been associated with depressive symptoms, physiological and sleep disturbances (Aries et al., 2015; Boubekri et al., 2014; Harb et al., 2015; Zadeh et al., 2014). Office workers exposed to electric lighting and natural lighting conditions have reported experiencing less glare and less sleepiness earlier in the day under natural lighting compared with when they were under exclusively electric lighting (Borisuit et al., 2014).

+ STUDENT THINKING

Bright light with high illuminance — and blue-light exposure in particular — have been associated with decreased daytime and higher nighttime melatonin concentrations, reduced daytime sleepiness, improved sleep duration, improved sleep efficiency, lower self-reported sleepiness, greater subjective well-being, and higher levels of alertness (Bellia et al., 2013; Cho et al., 2015; Keis et al., 2014; Liu & Wojtysiak, 2013). High school students exposed to blue-enriched white light (300 lux, 5500K) in the early morning during winter have shown faster cognitive processing speed and better concentration performance than students in standard lighting conditions (300 lux, 3000–3500K)(Keis et al., 2014).

Cortisol, a hormone influenced by light exposure, reaches peak levels in the morning upon waking, a process known as the cortisol activation response. In a study of sleep-restricted 12–17-year-old students,

BIOPHILIC DESIGN

Researchers in the field of environmental psychology have become increasingly interested in the restorative effects of visual access to natural environments. Students in classrooms with access to green views through their windows have been observed to experience significantly faster recovery from stress and mental fatigue and performed significantly higher on tests of attentional functioning, compared to students in classrooms with no windows or windows looking out onto other buildings facades (Li & Sullivan, 2016). This research supports the biophilia hypothesis posited by E.O. Wilson – that there is an innate connection between humans and nature (Wilson, E.O., 1984). Buildings can bring nature in through biophilic design, which aims at improving indoor environments by incorporating natural elements into the design of the building (Browning et al., 2014).



students who were exposed to 40 lux of short-wavelength (blue spectrum) LED light in the morning showed a significantly enhanced cortisol activation response compared with students exposed to dim light (<5 lux from an incandescent light), indicating that short-wavelength morning light could stimulate students and help them feel more alert at school (Figueiro & Rea, 2012; Keis et al., 2014).

Color temperature is another aspect of light that can affect building occupants' levels of alertness. For example, dim warm-colored light has been shown to induce a calming effect in children. In a nine-month study of 110 students in primary (grade 3) and secondary school (grade 10) and 11 teachers, researchers found that a "relax" setting (325 lux, 3500K) was significantly associated with reduced restless behavior compared with children in "standard" program lighting classrooms (Wessolowski et al., 2014). Additionally, a laboratory controlled study of 47 university students found that participants in artificial daylight (correlated color temperature 6500K) reported significantly higher levels of alertness, performed significantly better on a computerized test, and made fewer typing errors compared with when they were under cool white light (4000K) or warm white light (3000K) (Shamsul et al., 2013).

+ STUDENT PERFORMANCE

Access to good-quality and task-appropriate lighting at school is important because many classroom activities — like reading and writing — are visually oriented and form the basis of student learning. Oral reading fluency (measured as words read correctly per minute) is an important precursor in the development of reading comprehension. A study of 172 U.S. third-grade students tested the effect of high-intensity (1000 lux, 6500K) glare-free "focus" lighting on students' oral reading fluency performance for a full academic year. By midsemester, students in the "focus" lighting showed a higher percentage increase in oral reading fluency performance compared with students in "standard" lighting (500 lux, 3500K) classrooms (36% vs. 17%). The same researchers conducted a follow-up study among students from low socioeconomic backgrounds and found that by the end of the academic year, students in the "focus" lighting group showed larger gains in oral reading fluency performance than the non-focus lighting group and their oral reading fluency improvement trajectory more closely aligned with national trends (Mott et al., 2012; Mott et al., 2014).

CIRCADIAN RHYTHM

Keeping the circadian sleep-wake cycle in proper alignment in order to obtain adequate levels of sleep is essential to maintaining good cognitive function. Circadian rhythms influence basic cognitive processes such as attention, working memory, and executive function. In teenagers, these processes operate at lower levels in the early morning (before 11:00 a.m.). Adolescents are also more likely to suffer from "social jet lag," the discrepancy between circadian and social clocks, which contributes to chronic sleep loss (Keis et al., 2014; Roennenberg et al, 2012; Valdez et al., 2014).

Current lighting standards are designed to meet the needs of the visual system without accounting for the nonvisual, biological impacts of light. Yet being able to see in a space does not ensure that the circadian system is being adequately stimulated. Furthermore, even when a building is designed to bring more daylight indoors, occupants may not receive sufficient amounts to stimulate their circadian systems, especially in winter months (Lockley, 2009). Researchers have observed seasonal differences in the amount of daylight exposure received by building occupants, indicating the need to consider supplementing natural light with circadian-stimulating artificial light indoors (Bellia et al., 2013; Figueiro & Rea, 2014). An accumulating body of evidence suggests that learning and memory can be impaired when the sleep-wake cycle is disrupted (Collwell, 2015; Keis et al., 2014; Wright Jr. et al., 2006). Thus it is important to consider how circadian-stimulating electrical lighting can be combined with daylighting strategies to optimize the well-being of children in school.



ACOUSTICS AND NOISE

Ensuring appropriate noise levels and listening conditions at school is essential to maintaining the ability of teachers to deliver instruction in the classroom effectively so that students can clearly and easily hear and understand what is being said. Two important aspects of hearing well in a classroom are background noise and reverberation time. Background noise is any “unwanted sound that interferes with what you want to hear” and has many sources both in and outside the classroom, from air conditioning systems and other students to traffic (Acoustical Society of America, 2010). The amount of background noise that enters a classroom depends in part on the walls’ sound-transmission class, that is, their ability to block or carry noise. Reverberation time is the length of time sound lingers in a room; when a room has a long reverberation time, sound will echo and interfere with speech. It is important to have low background noise and short reverberation time in a classroom (Acoustical Society of America, 2010). The Acoustical Society of America recommends maximum background noise exposure levels of 35 dB for unoccupied core-learning spaces in permanent school buildings, as well as a maximum reverberation time of 0.6–0.7 seconds (depending on classroom volume) (Acoustical Society of America, 2010). However, a growing body of evidence shows that noise and reverberation conditions in classrooms vary and often fail to meet these recommended standards (Lewis et al., 2014).

+ STUDENT HEALTH

Noise has both auditory effects, such as hearing loss, and non-auditory effects, such as annoyance, sleep disturbance, stress, hypertension, and effects on performance. International studies of the effects of noise show diverse health outcomes in students, including increased levels of fatigue, stress, and irritability (Seabi et al., 2015). Windows in high-noise environments may be kept closed to reduce a variety of external noises and drafts (Zomorodian et al., 2016), which can contribute to excess buildup of heat and thermal discomfort in the classroom. In recent years, evidence of the negative impacts of noise has strengthened in the case of aircraft noise (Correia et al., 2013) and road traffic noise. Road traffic noise was associated with hypertension, a risk factor for cardiovascular disease (van Kempen & Babisch, 2012), as well as emotional symptoms, behavioral conduct problems, and increased hyperactivity in children (Dreger et al., 2015; Tiesler et al., 2013).

Studies of the non-auditory effects of noise exposure have found that increased noise levels are associated with higher systolic and diastolic blood pressure and changes in heart rate (Basner et al., 2014). In children in particular, environmental noise exposure has been associated with higher blood pressure (Belojevic et al., 2015; Liu et al., 2014; Paunović et al., 2011), decreased well-being, and stress responses, including increased levels of hormones such as adrenaline and noradrenaline (Stansfeld & Clark, 2015).

+ STUDENT THINKING

Children under age 15 are more sensitive to difficult listening conditions because they are still developing mature language skills (Nelson et al., n.d.), and, compared with adults, children have more difficulty with complex listening tasks (Sullivan et al., 2015). Noise interference in the classroom can impair children’s speech and listening comprehension (Klatte et al., 2013) as well as their concentration, understanding of verbal information (Seabi et al., 2015), reading comprehension, and memory (Stansfeld & Clark, 2015). In noisy conditions, children require a greater signal-to-noise ratio or less distortion from background noise to perform on par with adults in speech recognition tasks. Young children in particular need shorter reverberation times to attain speech perception abilities similar to those of older children and adults (Lewis et al., 2014).



Research has shown that cognitive processes in children such as memory and attention, which are critical elements of reading comprehension, develop slowly (Sullivan et al., 2015) and may be especially sensitive to chronic noise exposures (Seabi et al., 2015). A study of 8–10-year-old students' working memory and comprehension in association with noise conditions found that the children's performance on tests of auditory working memory and listening comprehension was significantly worse in noisy environments compared with quiet environments (Sullivan et al., 2015). Noise has also been found to affect reading and writing adversely; research suggests that chronic exposure to noise affects children's cognitive development (Klatte et al., 2013). Another study (Lewis et al., 2014) examined the ability of 50 8–12-year-old children with normal hearing to follow audiovisual instructions presented in varying conditions of noise or noise with long reverberation. The researchers found that students' performance on an audiovisual instruction test was significantly better when they were only exposed to noise without the addition of excessive reverberation. As of 2014, more than 20 studies have shown that environmental noise exposures were negatively correlated with children's learning outcomes and cognitive performance (Basner et al., 2014).

+ STUDENT PERFORMANCE

Chronic exposures to internal and external sources of noise can lead to deficits in test scores. Noise exposures are often determined by siting, such as proximity to major roadways or airports, but internal sources of noise can be equally important. For example, HVAC systems have been identified as a common source of background noise in classrooms (Nelson et al., n.d.). In a study of 73 elementary schools in Florida (Jaramillo, 2013), students in schools cooling with the noisiest types of HVAC systems were found to underperform on student achievement tests compared with students taking tests in schools with quieter systems. Furthermore, ambient noise annoyance has also been associated with poorer performance on mathematics tests among urban high school students (Zhang & Navejar, 2015).

In France, research using test scores has illuminated a direct relationship between noise and students' academic performance. A study of more than 500 8–9-year-old children in 35 primary schools examined whether chronic exposure to typical levels of urban residential area noise at home and school (average noise levels at school were 51.5 dB) affects students' academic performance. The researchers found that students' scores in national standardized tests in French and mathematics were independently and negatively associated with ambient noise exposures. Test scores were on average 5.5 points lower for each 10-dB increase in noise level (Pujol et al., 2014).

AIRPORT NOISE

Schools located near airports are a unique subset of schools because of the impacts of aircraft noise. Researchers study the students in these schools, with their proximity to airports and exposure to aircraft noise, in order to understand the impacts of noise on schoolchildren. Aircraft noise is a common source of noise annoyance; it can affect an individual's quality of life and causes irritation, discomfort, distress, or frustration (Seabi et al., 2013). A study of 1,058 second-graders in 29 German schools found that aircraft noise exposure at home was associated with small but significant increases in headaches and stomachaches. In schools exposed to large amounts of aircraft noise, 86% of teachers reported keeping the windows closed even in warmer weather and 38% indicated they undertook fewer outdoor activities with their students (Bergstrom et al., 2015).



SAFETY AND SECURITY

Maslow's Hierarchy of Needs tells us that safety and security are fundamental to our ability to thrive, coming only after the basic needs of food and water. We understand this in society and as individuals we see the role of security in our everyday lives through interactions with police, security lines, security cameras, and locking and unlocking the doors to our cars, homes and offices. We recognize the importance of these acts in keeping us safe from acute security events like robberies and crimes. What we may not recognize as clearly is that these feelings of safety and security directly influence our health, and buildings play a critical role in keeping us safe and secure.

+ STUDENT HEALTH

When our sense of security is threatened, it can trigger a cascade of biological "fight or flight" responses that alter our physical and psychological functioning (Schneiderman et al., 2005). Perceived threats to safety flood our bodies with stress-induced hormones like adrenaline and cortisol that elevate heart rate and increase blood pressure (Schneiderman et al., 2005). Children in unsafe neighborhoods have higher likelihoods of having poorly controlled asthma, increased dyspnea and rescue medication use, more limitation in activity, and higher night-time asthma symptoms (Kopel et al., 2015).

While individuals vary in their response, psychological stress can negatively affect immune function with onset of immune changes occurring in as little as five minutes (Marsland et al., 2002). Chronically elevated stress hormones suppress immunity which can exacerbate autoimmune diseases and other inflammatory conditions, while elevated blood pressure levels can eventually lead to damaged arteries and plaque formation, putting stressed individuals at greater risk of hypertension and cardiovascular disease (Schneiderman et al., 2005). Over time, these responses place wear and tear on the body that increases disease susceptibility (American Psychological Association, 2015).

+ STUDENT THINKING

Students' perceived sense of security within the school environment can impact their mental health, engagement in school activities, and academic achievement. Individuals with greater crime worry participate in fewer social activities, exercise less, are about 1.5 times as likely to have a common mental disorder, and nearly twice as likely to have depression compared to those reporting low fear of crime (Stafford et al., 2007). Being 'very worried' about crime has been significantly associated with higher levels of psychological distress (Roberts et al., 2010). Student can be negatively impacted even in the absence of personal victimization; victims and non-victims report suffering negative psychological effects from the fear of crime. For nonvictims, fear of crime contributes to feelings of anxiety and stress (65.1%), sleeping difficulties (27.4%), depression (10%), and panic attacks (8%) (Morrall et al., 2010).

+ STUDENT PERFORMANCE

While the impacts of safety and security on student health is well-understood, the impacts on student performance is largely underinvestigated. However, an individual's perceived sense of security in the school environment can affect students' test scores, engagement in school activities, and mental health. These can have direct effects on performance; exposure to school neighborhood violence is associated with lower test scores in English and math among elementary and middle school students (Chen, 2013).



IV. BEYOND THE 4 WALLS: CONTEXT MATTERS

We recognize that beyond the four walls of the school building there are many environmental and social contexts that can adversely affect students' well-being and undermine their academic potential. Inequities persist in the distribution of the social determinants of health, and students bring these influences with them every day when they walk through the doors of their school building. Although this report focuses on the school building itself, it is important to acknowledge the context in which these external variables affect student health and achievement outcomes to further underscore the contribution of targeting the school building as an intervention point.

Key factors to consider when thinking about the wider context of student health and performance include the following:

- **Disparities:** Early-childhood education programs and schools in poorer districts often have facilities and indoor environmental quality that are worse than those of other districts (Alexander et al., 2014; Earthman, 2004; Satterlee et al., 2015). Recent research suggests that schools that serve lower socioeconomic communities may also have a larger burden of asthma-related absences (Meng et al., 2012). And as the percentage of students who qualify for reduced-cost lunch increases, the quality of the school building decreases, and non-white and poorer student populations are disproportionately affected (Local 32BJ, 2013; Simons et al., 2010). Teachers working in schools in low-income neighborhoods have been found to report a higher prevalence of mental disorders, poorer psychosocial working conditions (Virtanen et al., 2007), higher rates of symptoms of occupational burnout (Vercambre et al., 2009) and to take more long-term sick leave (Virtanen et al., 2010).
- **Existing Health:** Students experiencing chronic health conditions such as obesity, attention-deficit hyperactivity disorder (ADHD), autism, and seizure disorders have been found to be at higher risk for poor academic performance on math and English tests (Crump et al., 2013), and for reduced cognitive functioning, concentration, attention, and general academic performance (Castelli et al., 2014; Michael et al., 2015; Singh et al., 2012).
- **Access to green space:** Green space surrounding a school has been positively associated with reductions in chronic absenteeism (MacNaughton et al., 2017), academic performance (Wu et al., 2014), restored attention capacity, decreased stress levels (Li & Sullivan, 2016), reduced mental fatigue and aggression, and improved coping with attention deficit disorder (Schulman & Peters, 2008). Students' working memory, superior working memory, and attentiveness have also been significantly positively associated with the surrounding greenness, partly mediated by reduced exposure to traffic-related air pollution (Dadvand et al., 2015). The amount and type of space available also influences health; researchers found that larger school campuses, school buildings, and play areas (per enrolled student) are associated with higher levels of physical activity in middle school students (Cradock et al., 2007).

MA SMART

Massachusetts' School Metrics And Research Tool

In order to understand the relationship between neighborhood environmental and social contexts and student performance, the Healthy Buildings program at the Harvard Center for Health and the Global Environment developed the Massachusetts' Schools Metrics and Research Tool (MA SMART). This database contains geographical, environmental, social, academic, and facilities information for nearly 1,900 schools in the state. In the first year of using MA SMART, researchers were able to find novel relationships between chronic absenteeism and outdoor air quality and surrounding green space (MacNaughton et al., 2017). This finding can inform policy, provide new strategies for overcoming chronic absenteeism, and promote evidence-based decision-making for both existing buildings and new building construction.



- **Air Pollution:** Higher outdoor air pollution levels around schools have been linked to increased rates of chronic absenteeism (MacNaughton et al., 2017) as well as poorer student health and poorer academic performance (Mohai et al., 2011), including lower individual student grade point averages (Grineski et al., 2016) and reductions in sustained attention (Kicinski et al., 2015). Additionally, exposure to diverse traffic-related fine particles (e.g., motor vehicle exhaust and road dust) were associated with an increased likelihood of wheezing, shortness of breath, inhaler use and asthma symptoms in children with asthma (Gent et al., 2009). Researchers have found that non-white children are more likely than white children to encounter airborne toxins near their schools (Chakraborty & Zandbergen, 2007).
- **Early Childhood Experiences:** Before a kindergartner enters school, their brain has grown 90% of its full adult capacity (Stiles & Jernigan, 2010). This suggests that the first 2,000 days of life play a critical role in the future success and emotional function of a child. Adult disparities may be linked to childhood adversity. For example, individuals who were exposed to adverse conditions as a child and experienced childhood emotional problems (e.g., inappropriate self regulation) had significant increases in the highest levels of adult inflammation (Appleton et al., 2012). Broadly, prolonged exposure to significant adversity in childhood (e.g., neglect, abuse, injury, caregiver illness) can result in toxic stress that alters the development of the body's stress response, immune, cardiovascular, neurological, and metabolic system (Center on the Developing Child, 2017).



V. 21ST CENTURY SCHOOLS

The average school building in the United States has a lifespan of about 50 years. This means that a new school built today may continue to serve as a central place for the learning and development of children well past the middle of the century. Between now and then, it is difficult to anticipate how K–12 education will change, but we do know this: by the time today’s kindergarteners see their own children graduate from high school, the world will be very different from today.

The Urbanization Mega-Trend

In 2050, the global population is projected to increase from 7.2 to 9.6 billion people (United Nations, 2013), two-thirds of whom are likely to live in cities (United Nations, 2014). As the world becomes increasingly urban and globalized, more schools may be located in proximity to busy airports and roadways that generate traffic and noise pollution. It is imperative that these considerations are taken into account when siting schools and making design choices that will affect generations of students to come.

A Changing Climate

Climate scientists estimate that by midcentury average global temperatures may be several degrees warmer, sea levels several inches higher, and intense precipitation events more frequent than we experience today (Intergovernmental Panel on Climate Change, 2014; U.S. EPA, 2016d). These changes will have profound consequences for the health and well-being of our nation’s current and future K–12 students.

Higher temperatures not only increase levels of ozone and other air pollutants that exacerbate cardiovascular and respiratory illness, but they can also increase levels of pollen and airborne allergens that aggravate asthmatic symptoms (World Health Organization, 2015) and, as a result, directly affect student performance (Park, 2016). Hotter temperatures will continue to place greater demands on heating and cooling systems, and greater care will need to be taken to ensure that indoor environments remain comfortable for school building occupants. It is predicted that extreme heat will lead to increased number of droughts and wildfires, resulting in increased fine particulate matter intrusion in schools (Nazaroff, 2013). Children’s physical and visual health may also be at risk as hotter outdoor temperatures limit opportunities for outdoor play.

With climate change extending the season and geographic range of insect- and rodent-transmitted illnesses (World Health Organization, 2015), concerns about how to manage pests and infectious outbreaks effectively are also likely to become increasingly important. Flooding from heavy precipitation and sea-level rise increase the risk of incurring moisture damage and mold growth indoors, making occupants potentially more vulnerable to exposures that can adversely affect their respiratory health.



A Call for Standardized Health Performance Indicators

To date, there has been promising progress in research addressing how various building parameters interact and influence the well-being of school occupants, but much more remains to be done to ensure that school administrators are fully empowered to make tailored, cost-effective decisions for each school. Collecting diverse, yet consistent, Health Performance Indicators (Allen et al., 2015) allows schools to capture metrics that help them better understand what may cause poor academic performance before it happens. The establishment of common metrics to be gathered at the level of the student, school, classroom and building would benefit researchers, students, teachers, parents, architects and administrators.

The traditional definition of student achievement emphasizes quantifying performance with standardized test scores or grade point average. Because these metrics are common and readily accessible, research studies rely almost exclusively on using them to infer effects of the learning environment on schoolchildren. Yet many researchers know that test scores and grades can also be influenced by a number of other contextual factors and acknowledge that reliance on these metrics cannot provide a full picture of how well students are doing in school. The passage of the Every Student Succeeds Act — a national education law that requires K–12 schools to track a nonacademic indicator of student success — is shifting the national conversation about how student achievement is defined (Every Student Succeeds Act, 2015). The existing body of research on the impacts of school buildings demonstrates the need for incorporating more diverse indicators of success that capture health and well-being in schools, such as increased class participation, reductions in student obesity and diabetes, and reductions in teacher absenteeism. We propose creating a national SMART platform, modeled after the MA-SMART program.



A Call for a National School Infrastructure Assessment

School facilities represent the second largest sector of U.S. public infrastructure spending after highways, and yet no comprehensive national data source exists on K–12 public school infrastructure. Even at the state level, school facilities information is often scant. The dearth of official data and standards for our nation’s public school infrastructure has left communities and states working largely on their own to plan for and provide high-quality facilities. According to the Healthy Schools Network (2015), the U.S. Department of Education has never had any in-house staff with expertise in school-facility management or child environmental health. Moreover, there is no federal regulatory agency with the authority to intervene in schools to address known environmental health hazards; Occupational Safety and Health Administration regulations and Centers for Disease Control and Prevention health hazard evaluations and guidance are designed to protect the health of adult employees, such as school teachers and staff, but no agency has the overarching responsibility to ensure that children’s health is safeguarded at school. This must change. A National School Infrastructure Assessment, and National Director of School Infrastructure, are needed.



VI. SCHOOLS FOR HEALTH

Evidence for Action

The scientific evidence we have presented in this report represents only a fraction of the available research supporting the need for action. There is overwhelming evidence for researchers, legislators, designers, parents, teachers, school districts, and community members to make compelling, fact-based arguments for elevating the role of the school building in the national conversation on education.

When We Act It Makes a Difference

If we act, there is reason to be optimistic. School districts that have improved school infrastructure have seen dramatic benefits, as the research cited in this review has indicated and the following examples illustrate. A study of 33 school districts in Florida found that students' mean passing percentages improved on state mathematics and reading tests after transitioning from old to new, code-compliant school buildings (Lumpkin, 2014). When Ohio schools invested \$10 billion from a statewide capital subsidy for facility improvements, the percentage of students achieving test score proficiency increased 8–9% in the two years after construction and occupancy of the new and renovated buildings (Conlin and Thompson, 2015). In New Haven, Connecticut, a \$1.4 billion investment in a poor urban school district transformed its 50-year-old buildings through targeted improvements to HVAC systems and the inclusion of natural lighting. Subsequently, improvements observed in students' reading scores were comparable to the benefits gained from attending a high-performance charter school (Neilson & Zimmerman, 2014). These examples show the benefits of long-term thinking and of strengthening the quality of school facilities through increased funding and investment.

The Evidence is Unambiguous

The school building influences students' health and academic performance. Investing in school buildings is an investment in our collective future. It is time for action. It is time for Schools for Health.





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