SCHOOLS FOR HEALTH

FOUNDATIONS FOR STUDENT SUCCESS

HOW SCHOOL BUILDINGS INFLUENCE
STUDENT HEALTH, THINKING AND PERFORMANCE

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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.

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.

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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).

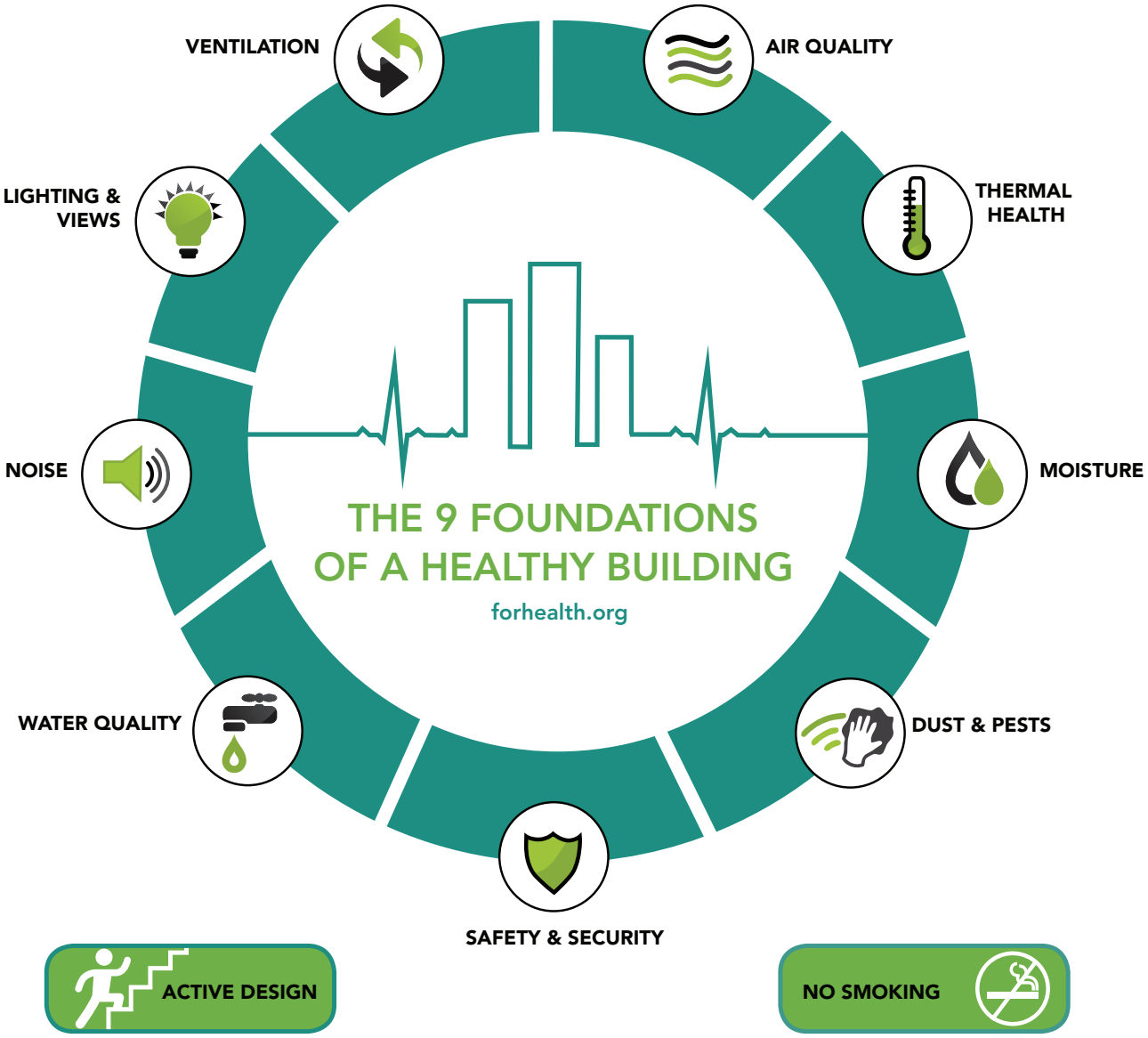
- In June 2016, the cafeteria and main office of a K–8 school and high school in Portland, Oregon, were closed after dangerously high levels of radon gas were detected. Several classrooms also showed radon test levels above the federal action limit. Radon is a naturally occurring radioactive gas that 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 (CO_2) 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 CO_2, continuously exhaled by building occupants. High CO_2 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 CO_2 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 CO_2 concentrations exceeded 1000 ppm in 66% of classrooms and that peak CO_2 concentrations surpassed 3000 ppm in 21% of classrooms surveyed. Shendell and colleague (2004) measured CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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).