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The Impact of School Buildings on Student Health and Performance: A Call for Research

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Executive Summary

The importance of school buildings has been recognized as a fundamental element of society since the beginnings of America and beyond. Today, roughly a quarter of our nation's population, including our youngest citizens, spends the majority of their days in school buildings. As a result, schools have become a contentious and heavily scrutinized part of civil society.

And yet, many of our nation's schools are in disrepair, with systems in need of repair or replacement. But with state and local budgets growing increasingly limited, funding allocation for school construction and renovation needs to be carefully weighed. It is important to ensure that investments are going toward efforts that can best foster healthier buildings and environments.

As this research field moves forward, the need for collaboration will only grow, especially as we learn to make our research more broadly applicable and actionable. This exciting and necessary task promises to strengthen our understanding of the relationship between school buildings and student health and learning, which, to date, is more viscerally understood than logically proven. Our challenge, laid out in this document, is in filling gaps and clearly building links on a chain, investigating the essential phenomena at play when children are impacted by their school buildings.

What do we know today?

In some areas, we have strong evidence to support the notion that school buildings impact student health and their ability to learn, and we know exactly how to ensure that the impacts are positive. For example, we know how to build classrooms that minimize background noise and allow voices to be heard clearly, which will allow students to hear their teachers and protect their aural health. We have clear evidence that certain aspects of school buildings have an impact on student health and learning, such as:

- When deprived of natural light, studies have shown that children's melatonin cycles are disrupted, thus likely having an impact on their alertness during school (Figueiro & Rea, 2010).
- Teachers report higher levels of comfort in their classrooms when they have access to thermal controls like thermostats or operable windows (Heschong, 2003, and Lackney, 2001).
- According to researchers at Lawrence Berkeley National Laboratories, when ventilation rates are at or below minimum standards (roughly 15 cfm per student), an associated decrease of 5%–10% occurs in certain aspects of student performance tests (LBNL IAQ Resource Bank).
- In recent studies, when ventilation rates were lowered from 17 cfm/person to 10 cfm/person, researchers saw a 15% increase in symptom prevalence for Sick Building Syndrome (ibid).

What do we need to find out?

While there have been studies on the impact of environments on children—and the benefits of green buildings more broadly—more research is needed. Some of the larger research questions are:

- When prioritization is necessary, which building projects can be expected to have larger impacts on facility quality and student health?
- What are the impacts of high-performance school buildings, above and beyond an adequate (and potentially new) school building?
- How do high-performance design features interact with each other? Relationships such as those between daylighting and acoustical design are understood less in terms of how they interact than in isolation.

How can stakeholders help drive needed research?

This brief not only discusses the influence a school facility can have on student occupants, but also closes with the important role stakeholders need to take to advance, identify and require research into the connection between school buildings and student health and learning. From translating research into actionable advice to engaging students in research projects, we can mobilize advocates to speed up the research process and the dissemination of research findings. We can get feedback to practitioners and school leaders who need it and increase funding for the improvement of school buildings.

At the end of the document is a set of resources to help readers learn more and increase involvement with the work outlined in this brief. These resources provide more in-depth information about ongoing research efforts and identify some organizations to work with when conducting research or discussing work in this area.

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Introduction

Why do green schools matter?

As a society, we care deeply about the state of our schools, perhaps because, as one turn-of-the-century scholar stated, "[i]t is a case in which the lives and health of your children, and your neighbor's children, are at stake, and it is your duty to know" (Mills, 1915). Thus, schools have become a highly contentious and heavily scrutinized part of civil society. And yet, despite the attention they receive, most are far from the best examples of American building. Indeed, in a recent report, the American Society of Civil Engineers gave public school buildings a D grade on their overall condition (American Society of Civil Engineers, 2009). As school buildings have deteriorated, it is only responsible to step back and ask whether these failing buildings may have an impact on the vital work of teaching and learning that takes place inside.

What investments are being made in school facilities today—and what still need to be made?

The past decade has seen an unprecedented investment in school facilities, with over $20 billion being spent annually on average in school construction. Although investment has fallen off in recent years (as all construction has), K–12 school districts in 2010 still spent $25.2 billion on new construction and major renovations (McGraw-Hill Construction, 2011).

However, this investment has only made a small dent in the needs of school districts, and most recent estimates place the value of deferred maintenance and capital investment needs in U.S. public schools at roughly $322 billion (M. W. Filardo et al., 2006). This disparity has led many advocates to lobby for school bond levies, federal appropriations, grant programs and other funding measures, and it has increased the demand for research that strengthens the connection between school facilities and academic outcomes.

Thankfully, there is growing attention to the need to improve school buildings through healthy, green design and operations, and this trend is growing. According to McGraw-Hill Construction's *Green Outlook Report* (2010), green schools accounted for over a third of new education construction in 2010. As citizens and education policy-makers, we need to be specific in recommending where to allocate funds. Advocates for adequate school buildings look for clear connections to reassure the community that their money will have an impact where it matters most—on young people's health and well-being.

What influence can schools have on students and teachers?

In recent years, school administrators and designers have become increasingly convinced that the quality of school buildings can have an impact on student health and learning. It makes sense to them that, when classrooms are clean, healthy and daylit, students will be more comfortable, less prone to illness and more focused on their studies. Facilities managers and designers share many anecdotes about school renovations and new technologies, relating their personal experiences and producing numerical results of improved attendance, fewer complaint calls or even reduced reports of asthma incidents.

In addition, our knowledge grows every day about the potential hazards of unknown chemicals, poorly understood technologies and prolonged exposures to conditions such as loud noise or low-spectrum fluorescent lighting.

It is in this context that researchers and others are reexamining the potential role that school environments may have on the health of the people who spend their days learning in them.

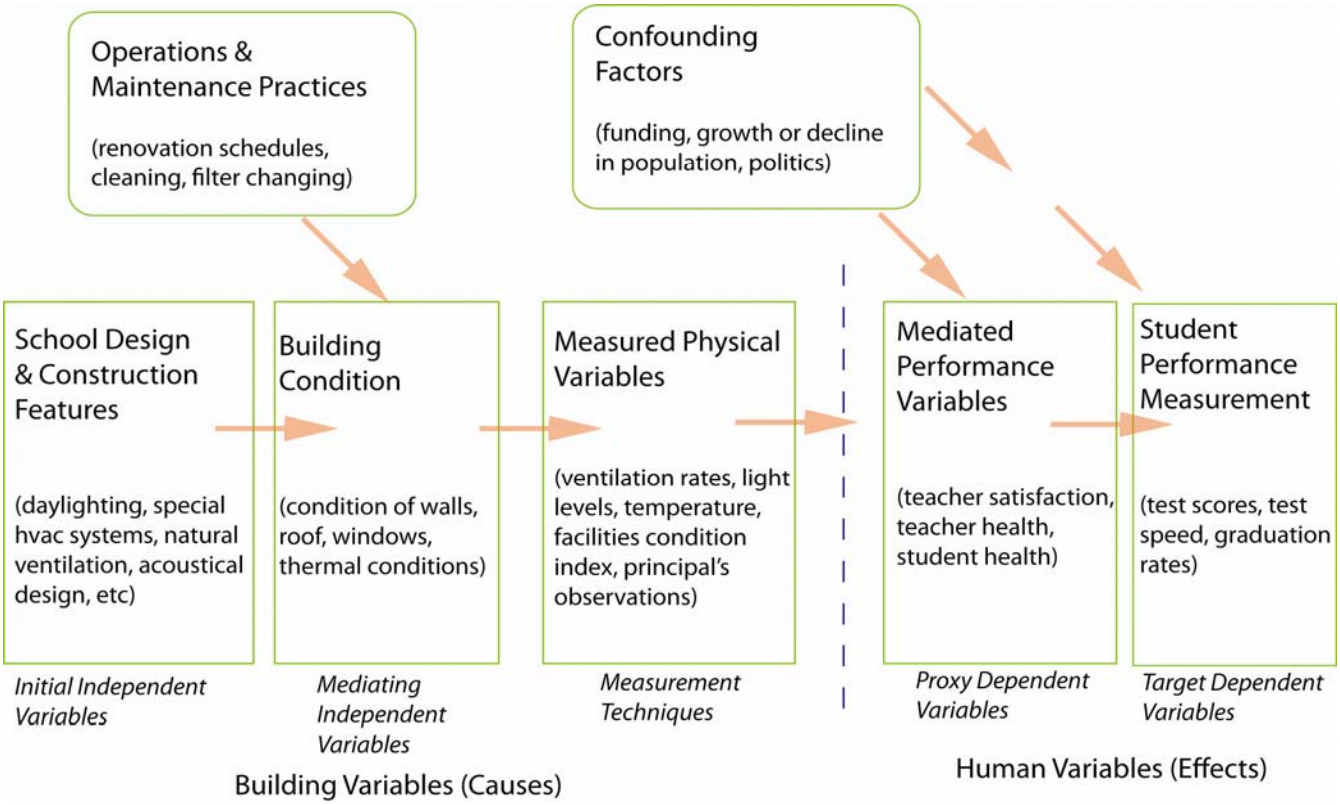
Generally, we have a good sense of how to build and maintain healthy school buildings. We have less understanding, however, of exactly how much they can impact children's health. Much of our knowledge is based on anecdote, other building types and common practice and trends. Demand is high in the schools sector for more solid evidence to support these notions, in order to increase investment in school facilities and help practitioners more precisely understand which building systems and conditions have the biggest potential to have a positive (or negative) impact on students.

In scientific terms, it is more difficult than we might think to prove in a clearly quantifiable way that an action taken to improve a school facility has a direct result on student health or learning. Any experienced teacher or parent can tell you that there are a host of influences on a young person's health and learning. And as public health researchers have long known, separating out the many aspects of a child's environment to find the cause of a health problem is a complex and difficult task.

Many researchers from the education, public health and building science fields have engaged in these questions, but the research is not consistently strong. In their comprehensive review of the connection between "green" school facilities and student health and well-being, a specially appointed committee of the National Research Council (NRC) clearly expressed the difficulty in conducting research on this connection: "Given the complexity of interactions between people and their environments, establishing cause-and-effect relationships between an attribute of a green school or other building and its effect on people is very difficult. The effects of the built environment may appear to be small given the large number of variables and confounding factors involved (National Research Council, 2007, p. 4)."

This cause and effect issue is one of the largest challenges we face when attempting to provide clear information about the impacts of building design decisions on children's health. It has led many different groups to develop their own "causal chains," describing how we imagine that school buildings impact health and learning (see Mendell and Heath 2005, the NRC report and Woolner et al for examples). These diagrams help dissect the larger problem into a set of smaller, more manageable questions to test. Figure 1 is a causal chain that describes the scope of questions considered in this research field.

Figure 1:



This diagram can be useful when describing what we know and what we need to find out about a particular phenomenon in schools. For example, we know that mold in a room can contribute to asthma rates, but we may not have proven that a certain type of maintenance practice alleviates mold growth. So, rather than needing to prove that the maintenance practice leads to fewer asthma attacks, we can simply test to see if the practice prohibits mold growth. This method can be especially useful when it is hard to get access to children's health and learning data; we may find that we do not need it if that link in the causal chain is already proven elsewhere.

Another important dynamic in this field is the desire to understand not only the difference between inadequate school facilities and adequate ones, but also between adequate (functional, "normal," well-maintained) facilities and high-performance ones. Using a car metaphor as an illustration, Stricherz notes in an essay from 2000 that there was no research to date that showed that student performance improves "when facilities go from the equivalent of a Ford to a Ferrari—from decent buildings to those equipped with fancy classrooms, swimming pools, television-production studios and the like" (Stricherz, 2000). This notion is widely agreed upon, but happily there is growing research in the "Ford to Ferrari" realm that has emerged in the past 12 years since Stricherz wrote his essay (G. I. Earthman, 2004; Schneider, 2002; Woolner, et al., 2007).

The difference between facilities of varying quality is not only important in determining how to help students excel, but it is also important in matters of equity. In comparing schools, and especially considering high-performance

facilities in comparison to standard ones, researchers must be aware of issues of equity and perceived equity in the communities in which they are working. A study from the 21st Century Schools Fund found that, although unprecedented investments were going towards school facilities, “these billions of dollars spent on facilities have not been equally available to affluent and low-income communities and for minority and white students” (M. W. Filardo, et al., 2006). Allocation of funds for school facilities is often spread unequally across states, within states and within districts because of politics and the ability of various groups to apply for available funds. Filardo reports that 31 states have seen legal action against the adequacy or equity of public education systems, including school facilities. In four states, the facilities specifically were the focus of the lawsuits.

In September 2011, the Center for Green Schools at the U.S. Green Building Council (USGBC) convened a meeting of school facilities researchers and stakeholders in Boston to discuss the progress made in connecting childhood health and school building conditions and to address research priorities. The participants of the meeting are listed in Appendix C and consisted of researchers in a variety of fields, including public health, architecture, education, planning, policy and a small group of advocates and practitioners. The primary focus of discussion was to examine the past ten years of research in the field, to identify what needs to be done in the development of new research and to work toward better translation of research into practice and policy. This document has been greatly informed by that meeting and endeavors to take the steps suggested by the participants, translating research and facilitating clear lines of communication about the research field and its needs.

What outcomes do we anticipate?

This brief is intended for designers, school staff, school officials and researchers to explore questions that are central to the task of making these connections between school facilities and student health. It considers three central questions:

1. *What do we need to know so far* about this connection?
2. *What we are trying to find out* about this connection?
3. *How can we investigate* this connection?

Significant efforts have been made already in answering some of these questions, particularly in a 2006 National Research Council report entitled *Green Schools: Attributes for Health and Learning*. This document summarizes the information contained in the NRC report and others, making it easier for readers to see how they can contribute to advancing research in this arena.

How students…HEAR

Acoustics are fundamental to learning

Ample evidence exists that classrooms can have a negative impact on students' ability to hear, thus clearly making it difficult for them to absorb and retain information. Two major aspects of acoustics can have an impact. First, **background noise** can make it more difficult for students to hear teachers, and for teachers to speak without raising their voices and suffering fatigue as a result. It is widely understood that most people cannot comprehend a noise if it is not 15 decibels louder than the background noise level. Second, rooms that create more echoes due to hard materials can impair what acousticians call **speech intelligibility**. Acousticians have determined that speech is difficult to understand if a room is full of echoes, and they have developed a measurement for this called **reverberation time** (RT). A sound with a reverberation time of longer than 0.6 seconds is considered difficult to understand, and acousticians can predict and calculate these conditions based on the interior surface qualities of a room.

Indoor ambient noise is not the only issue in classrooms, however. One important study in this area considered students at a school in the regular flight path of an airport, noting that, while controlling for confounding factors like socioeconomic status, students in that school performed as much as 20% lower on a reading test than children in another nearby school (G. W. Evans & Maxwell, 1997).

What do we know today?

Research in classroom acoustics is a robust field in which a clear connection has been made between proper acoustic design in schools and acoustic performance. This performance in turn has a direct effect on speech intelligibility and therefore on student learning outcomes (Acoustical Society of America (ASA), 2009). One of the easiest ways to understand this connection is to imagine, as some researchers have simulated, what happens when students are unable to hear even 10% of a teacher's spoken words because of interferences in the acoustical environment. Many well-controlled studies corroborate the importance of low background noise level and speech intelligibility in maintaining appropriate acoustic conditions for student learning (Berg et al., 1996; Crandell & Smaldino, 1995; Knecht et al., 2002). Studies have also measured how unexpectedly poor many existing classrooms perform acoustically, demonstrating the extent of the problem (Feth & Whitelaw, 1999, Sato & Bradley, 2008).

One recent study looked at classroom reverberation and children's performance and well-being in a set of classrooms in Denmark (Klatte et al, 2011). In classrooms with different reverberation times (RT), they compared the children's short-term memory, speech perception abilities and attitudes about their classrooms and teachers. They compared classrooms with RTs from 0.49 to 1.1 seconds (the ANSI standard calls for a maximum of 0.6 seconds in regular sized classrooms) and found a significant negative impact on short-term memory and speech perception as reverberation time increased.

What research on the acoustical environment is still needed?

We need to understand much more about how classrooms impact students' hearing and how best to design schools in order to enhance the acoustical environment in the classroom.

- The education community needs more information on the state of existing classrooms today in order to understand how much improvement is needed. What percentage of American classrooms need acoustic improvements?
- Which is a more prevalent problem in classrooms: background noise issues or speech intelligibility?
- In newer high-performance buildings, according to one study, acoustics are the most frequently cited area of dissatisfaction among occupants and are worse than non-'green' buildings (Baker, 2010). What is the issue in high-performance buildings, and how can they be designed better?
- How can we better understand children with hearing impairments, and how do we best provide for their needs in classroom environments?

A reliable standard helps the industry

The school building industry has a tool for designing excellent classrooms in regards to acoustics—a standard released by the Acoustical Society of America, called *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools* (also known as ANSI-ASA 12.60). This document lays out a set of performance standards for classrooms and also has a great deal of information about the connection between acoustic design and student learning.

How students…BREATHE

Clean indoor air—a valued but elusive resource

One measureable impact that school buildings can have on teachers and students is in the area of air quality and ventilation. Building systems and materials can either have a positive impact on overall air quality in a building (when heating, ventilation and air conditioning (HVAC) systems filter out pollutants in ambient air), or they can contribute to a deterioration of air quality, through increased particulate matter, volatile organic compounds (VOCs) and other toxic materials, moisture intrusion that leads to mold problems and other toxins and irritants. Many building professionals are becoming aware of how many materials in our indoor environments are unhealthy for us, especially building materials.

One group of well-known toxins in the building industry is VOCs, carbon-based chemicals that easily evaporate at room temperature. VOCs can have a variety of health impacts including respiratory issues, visual disorders, memory impairment and more. Mold also receives much attention, primarily for contributing to respiratory illness and asthma.

But there are several other toxins whose prevalence and impacts have just begun to be understood more fully. These are toxins such as formaldehyde (present in many building products, such as furniture and casework) as well as Phthalates and Bisphenol A (BPA), both of which are present in many plastics used in construction. These chemicals are not only problematic in terms of breathing and respiration, but also more generally can have health impacts simply due to proximity or skin exposure. More details about specific air quality issues in schools are publically provided by the U.S. EPA.

What do we know today?

This area of research has developed significantly as HVAC system technology has evolved and as knowledge of Sick Building Syndrome (SBS) has spread more widely. This field of research is highly technical and largely consists of medical research. A research summary written by Mendell and Heath in 2005 provides a list of known studies that investigate the effects of various air pollutants on children's health in schools. This study makes clear, however, that there is not yet enough evidence to indisputably link air pollutants to a direct impact on learning. These same researchers and others at Lawrence Berkeley National Laboratories (LBNL) have also recently developed an online library called the Indoor Air Quality Scientific Findings Resource Bank, which gives thorough information on the many aspects of this field.

One area where research is clearly required is the lack of adequate ventilation in classrooms, despite long-standing codes and practices of the HVAC industry (Godwin & Batterman, 2007). Many classrooms do not have active ventilation but depend exclusively on windows and doors. In one field study on real measured ventilation rates in schools, some classrooms were reported to have mechanical ventilation rates as low as 3.4 cubic feet per minute (Turk et al., 1989). That is less than a third of the required rate (15 cfm) provided by ASHRAE in Standard 62 for classrooms. According to the LBNL Resource Bank, "Three studies of ventilation and respiratory illness (one performed in military barracks, one in a nursing home and one in a jail) found an increase in respiratory illness with very low ventilation rates compared to substantially higher ventilation rates (2.5 versus 20 cfm per person, 8 versus 26 cfm per person, 4 versus 8 cfm per person). In these studies, the

percentage increase in respiratory illness in buildings or spaces with the lower, compared to higher, ventilation rates ranged from approximately 50% to 370%. Similar results might be expected in other high density buildings such as school classrooms, though no data are available." The Resource Bank also reports similar details about the impact that ventilation rates can have on SBS. In fact, one major synthesis of existing research declared that sufficient evidence existed to say that ventilation rates ***below 50 cfm*** per person can negatively impact the health and productivity of occupants, which is an astonishingly high number to achieve in practice.

Recent years have seen significant strides in research regarding ventilation rates, CO_2 levels and student achievement in schools. In one notable study, researchers found that task speed increased significantly in students (10–12 years old) when outdoor air supply rates were increased from 6.4 to 18 cfm/person, which produced a CO_2 level change from 1300 to 900 ppm (Wyon & Wargocki, 2007). CO_2 levels and ventilation have also been shown to have a connection to average daily attendance (ADA). In a 2004 study, Shendell et al studied 409 typical classrooms and 25 portable classrooms in Washington and Idaho, comparing indoor CO_2 levels to student attendance records. In classrooms where CO_2 was measured to be regularly surpassing 1000 ppm, they saw a 0.5%–0.9% average decrease in ADA. Incidentally, in portable classrooms, annual ADA was 2% lower than in traditional classrooms.

Research has also been conducted on the presence and condition of the ventilation systems themselves and their connections to student health and learning. One study showed a decrease in respiratory illness (asthma in particular) in schools in Sweden that had new ventilation systems installed (compared to schools with older ventilation systems or none) (Smedje & Norbäck, 2000). However, the results have been mixed. Rosen & Richardson found a drop in absenteeism in another study where electrostatic air cleaning technology was installed, but only for 1 out of 3 years of their study, making the results somewhat inconclusive (Rosen & Richardson, 1999). Wyon and Wargocki also reported testing airborne particles, electrostatic air cleaners and test performance in their 2007 studies but found no notable relationships. So, while these phenomena are clearly being investigated, there are few conclusive findings so far.

It should also be noted that, in addition to indoor air quality, student health can be adversely affected by poor outdoor air quality in and around school buildings (Frumkin et al, 2007). A great number of sources of outdoor air pollution can affect children and adults alike, and the U.S. EPA has recently published a comprehensive guideline on school siting that addresses many of these issues (see Resources section).

What research on air and pollutants is still needed?

Since public health research has already shown a strong connection between air pollutants and respiratory health, the focus of recent research has tended to be more in understanding the impacts of design decisions and building materials. The most informative research in air quality considers HVAC design and materials specifications as the independent variables and examines the effects that these decisions have on (a) direct air pollutant measurements, (b) health impacts or (c) productivity impacts. Specifically, the following issues need further consideration:

- How do various HVAC system designs and maintenance procedures impact air quality?
- How does materials selection, such as those that include VOCs, affect student health and learning?

How students…SEE

Classroom lighting and visual experience

Research on lighting and classrooms has been conducted for over a century, but attention in recent years has focused on the importance of natural light, after a departure from natural lighting for two decades in the 1970s and 1980s. Part of the issue has been understanding more precisely why natural light seems to have good results in schools. Intuitively, it makes sense that daylight would enhance the learning environment, but, because school districts are asked to justify facilities decisions using quantifiable means, researchers have attempted to show more conclusively that daylight is objectively positive for schools. This research includes seeking objective information about specific daylight design strategies (like skylights, clerestories, frosted glass, etc.) to ascertain whether certain strategies are more beneficial than others in terms of student health and learning.

The visual qualities of a learning environment are some of the most crucial building aspects to design properly since children depend heavily on sight in the learning process. In the early days of lighting research in schools, the focus was purely on quantity—in how much light to provide for given tasks. Quantity of light is largely agreed upon today. Less understood are issues of how light quality impacts student health. The question that follows, then, is how to ensure that we achieve a truly high-performing visual environment through design.

What do we know today?

The impact of daylight on student health and learning has been thoroughly studied. Up until the 1970s, it was widely appreciated that natural daylight was necessary for healthy learning environments. But when the energy crisis hit in the early 1970s, designers began building schools with no windows to save energy. They conducted research at this time to test how the change impacted students and found no discernable impact on test scores. However, researchers did find that teachers and students were very dissatisfied, but they did not believe that these attitudes could impact student performance and, thus, did not deem the dissatisfaction critical (Baker, 2011).

School building professionals have learned from experience, and we have begun to understand the biology of this phenomenon. For example, one study found that students without access to natural light showed a delay in seasonal cortisol production, a hormone that is positively associated with concentration abilities (Kuller & Lindsten, 1992). More recently, Figueiro and Rea showed that dim light melatonin onset (DLMO) is delayed significantly (by 30 minutes) after a five-day intervention in which a group of 8th graders wore glasses that kept out all short-wave (solar) light exposure while they were at school. DLMO helps entrain the circadian system, and thus, this study showed that an absence of short-wave light (daylight) can contribute to sleep problems in adolescents.

Regarding academic impacts, one well-known study showed that students in daylit classrooms had greater improvement over the course of one school year in math and reading standardized tests than students in windowless classrooms (Heschong Mahone Group, 1999). The numbers from this report are often oversimplified to state that daylighting improves test scores by vast margins. However, the authors of the study were quite clear on this point, noting, “We have merely shown an association between the presence of daylight and higher student performance, not shown that daylighting causes students to learn more.” A paper by Boyce et al

notes that when other factors are accounted for, the percentage increase in student performance that can be attributed directly to daylighting is 0.3%, a considerably smaller number than the 20% or 26% often cited from the Heschong Mahone study (Boyce, et al., 2003). It is still a positive impact but must be seen as part of a system of factors that contribute to student performance.

Other aspects of the classroom environment can be informed by what we know about how children see. For example, it is well known by doctors that eyestrain and visual acuity problems can develop if students have only short distance views available to them. In order to keep eyes healthy, long distance views are needed, indicating that views to the outdoors should be present and unobstructed where possible. In another study by the Heschong Mahone Group, *Windows and Classrooms*, researchers found an association between academic achievement and classroom views to the outdoors (Heschong, 2003).

What research on classroom lighting and views is still needed?

Our understanding of quality lighting environments is always growing, and there are many opportunities for further studies in this area.

- Significant demand exists for more feedback comparing visual comfort of different natural and artificial lighting configurations.
- Also needed are more documentable and performance-based design guidelines that can reliably produce excellent visual environments (in classrooms and otherwise). Therefore, a research opportunity is available to test the effectiveness of potential metrics.
- In the field of artificial lighting, the emergence of Light Emitting Diode (LED) lighting may warrant more intensive research as this new technology slowly makes its way into school buildings. LEDs have the potential for flicker, and a recent working group of the Institute of Electrical and Electronics Engineers (IEEE) released a report on the matter. The report stated the need for field research to investigate the flicker more fully. Automatic shading devices and other window technologies, such as electrochromic glass, may also warrant field research, none of which is necessarily unique to children and schools but should be considered in a school context.
- In one guide for the construction of school buildings from over a century ago, the author noted that window sills should “not be higher than 3½ feet from the floor, since it is desirable that the pupils should be able to rest their eyes at times by looking out at more or less distant objects” (Briggs, 1899, p. 8). While this subject has been often theorized, few existing studies have looked at the question of views from classrooms specifically. Also of interest would be research that looks specifically at students with learning disabilities or higher levels of distractibility, in order to better understand how views may affect different types of learners.

How students…FEEL

Thermal comfort in the classroom

Studies since the 1930s have supported the notion that classroom interiors needed to be kept within a small band of temperatures to be comfortable. This knowledge has been reflected in U.S. and international building codes (Brager & de Dear, 1998; Fanger, 1970). Indeed, our understanding of rough temperature comfort ranges remains clear, but, as has been the case with many aspects of the indoor environment, we have learned in recent years that basic quantification of thermal comfort is not the whole story. Thermal comfort is not just about providing ample amounts of adequately heated or cooled air but is also related to user control, air velocity, radiant surfaces, clothing and activity level. As these issues have been considered more thoroughly, a more complex research field has emerged.

What do we know today?

The idea that a constant neutral thermal environment is needed in school environments is still popular, as shown in a well-regarded literature review by Schneider in 2002, which reports that "students will perform mental tasks best in rooms kept at moderate humidity levels (forty to seventy percent) and moderate temperatures in the range of sixty-eight to seventy-four degrees Fahrenheit." The trend to focus exclusively on controlled temperature and humidity grew to its most extreme in the 1970s in school buildings, as designers eliminated windows altogether in an attempt to keep temperatures constant while reducing energy use. However, recent research questions the logic that 'neutrality' is always comfortable and points out the types of discomfort that many occupants of contemporary buildings report. Occupants especially complain of being too hot in the winter indoors and too cold in the summer as typical indoor conditioning is insensitive to outdoor conditions (Brager & de Dear, 1998). These 'neutral' air-conditioned spaces may also not always be best for student health. In a recent study in a hot and humid climate, researchers found that students attending naturally-ventilated child care centers had lower levels of asthma symptoms and allergies than those in air-conditioned child care centers (Zuraimi et al., 2007).

However, the knowledge that a reasonable and constant temperature can positively impact student health and learning is still relatively firm. Current research continues to produce findings that indicate that even small temperature changes can have an impact on student performance. Wyon and Wargocki, in their recent studies published in 2007, showed a significant effect on student speed on the same tests when temperatures were lowered from 77° to 68° F. The result was reported to be a linear relationship, where reducing air temp "by 1.8° F improved performance in terms of speed by from 2%–4%" in all tasks.

One particularly crucial area of recent research looks into the effect that perceived or actual personal control over temperature can have on overall comfort and health. First, studies in the 1990s showed that teachers have a strong preference for thermal controls of some kind and see it as an influence on student achievement and their own performance (Heschong, 2003; Lackney, 2001). Questions remain, of course, regarding how to provide individual thermal control while keeping energy use in check. In a more general sense, thermal comfort research in schools continues to be more focused on testing energy savings potential. Most current effort focuses on achieving acceptable thermal conditions and ventilation rates with lower energy consumption.

What research on thermal environment is needed?

Our challenges lie less in understanding how to create a static thermal environment than in learning how best to add to our growing toolkit of thermal comfort strategies in ways that enhance student health best. A few of our primary challenges in this area are as follows:

- As newer, low-energy heating and cooling methods become more popular in high-performance buildings, there is a greater need to understand the potential impacts these systems (e.g., underfloor air distribution, radiant heating and cooling, natural ventilation) can have on student health and well-being.
- Additionally, the demand is constant for more information on what the ideal level of control over temperature and ventilation should be in a classroom, to optimize both comfort and energy performance.
- Finally, thermal comfort can be an important aspect of research into air quality, since the two are inextricably connected in many regards. Thus, research in both fields should consider the potential related impacts of how air is delivered to classrooms and the quality of that air.

How students…THINK AND LEARN

Cognitive functioning and the environment

Any teacher will tell you that many factors impact how a student learns. Interest is growing in studying how cognition is affected by environmental factors, and yet our understanding of the biology of learning and thinking is still in its infancy. What we understand thus far is largely in relation to hormones, such as those discussed in the "How Students See" section (see page 13). More frequently, connections between the school environment and learning have been made not with a *direct causal* linkage but rather from observational studies that note where student performance differences have been found that could be attributed to environmental factors. These studies are very promising, but they do not necessarily guarantee that practitioners will see the same effects in their schools.

What do we know today?

Much of our knowledge about the connection between good school facilities and student learning comes from observational studies. For example, a recent study looked at one school district in Connecticut and found that when school construction projects were undertaken by the district, test scores across all schools went up noticeably afterward (Neilson and Zimmerman, 2011). This finding is promising since researchers accounted for differences in socioeconomic levels and other confounding factors. Still, more controlled studies are needed—even a national study that looks at similar phenomena—so that other potential causes can be ruled out.

Another group of observational studies looks more at connecting environmental factors to students' abilities to be fully alert or even attend class, the reduction of which would have an obvious impact on learning. For example, studies mentioned in the "How Students Hear" section (see page 9) showed that a large percentage of teachers' words were missed in adverse acoustic environments. We can therefore infer an impact on learning without needing to use test scores or other more complex, problematic metrics. Alternatively, researchers engage education specialists to help them derive appropriate tests to evaluate student learning for their research. Wargocki and Wyon (2007), for example, worked with experts in educational metrics to establish appropriate measures of subjects' performance in their recent research on ventilation rates in classrooms. The more fresh air provided, the better students performed on these specific tests.

A few organizations, such as the Academy of Neuroscience for Architecture, are working to develop a more scientific basis for how school environments impact student cognition. This research often looks more generally at how environmental factors affect our brains and thus is relevant but not specific to school environments.

What research on learning and cognition is needed?

Although some have a natural tendency to believe that the connection between better school buildings and student learning is clear, proving this in a scientific experiment is difficult. There are many dynamics at play, requiring researchers from very different fields to work together. This diversity of perspectives has led to a "paucity of clear, replicable empirical studies, particularly research which addresses specific elements of the environment" (Woolner et al., 2007, p. 48).

Educational researchers and educators are the first and most vocal skeptics of overstated claims about academic outcomes since they know how many elements can influence student learning and standardized test scores in particular, including the importance of quality teaching and parental support (Boyce et al., 2003). On the other hand, building researchers are disappointed to see oversimplification of building systems and how they are evaluated when reading studies from the education or economics fields. Interdisciplinary research is necessary to address these issues. Specific research studies needed in this area are as follows:

- Studies that look at average daily attendance (ADA) as a proxy for student learning to study the effects of building systems like lighting, heating system type and air filtration techniques. ADA impacts may be seen over the course of a year and may relate to or indicate various health issues.
- Comparisons of nearly identical school buildings (such as prototype designs) that have one different building component (a different daylighting approach or lighting controls, for instance), looking for effects by using a proxy for student learning like specially-designed tests or satisfaction surveys.
- National studies that look at college admissions rates and other metrics of student achievement and compare these factors to school building details, such as HVAC system type, floor coverings, daylighting strategies or similar specific, actionable factors.

What do standardized tests measure?

The use of standardized test scores in evaluating school buildings is a growing controversy in the field. As Schneider notes in his seminal literature review on the topic of school facilities and academic achievement, "standardized test scores have been a principal measure of learning outcomes. And in much of this work discussed [in the review], higher test scores have become the holy grail of facilities reform" (Schneider, 2002, p. 8).

However, the validity and usefulness of standardized testing in America is highly contentious, especially since the passage of the No Child Left Behind Act in 2001. As one prominent educational scholar notes, "[i]n contrast to testing in most other countries, testing in the U.S. is primarily controlled by commercial publishers and non-school agencies that produce norm referenced, multiple-choice instruments designed to rank students cheaply and efficiently. These instruments were initially created to make tracking and sorting of students more efficient; they were not intended to support or enhance instruction" (Darling-Hammond, 1991).

The trend towards using standardized test scores is understandable, given that they are currently tied to funding for schools and school districts, and the data are relatively accessible to researchers. However, when we design studies to look at the impact of daylighting, CO_2 levels, acoustics and other environmental factors, the important question is which specific cognitive skills we are hoping to optimize.

How students…MOVE

Physical activity

One of the most pressing concerns today regarding the health of children is the ever-increasing rates of obesity, which many tie to the decrease in children's physical activity in recent decades (Frumkin et al, 2007). In 1969, roughly 50% of America's school students walked to school; today, as few as 5% of students walk (ibid). Some scholars have speculated that school location directly affects commute patterns and community cohesion, which can have an impact on well-being, health, safety and security.

School planners and designers are beginning to address this concern in guidelines and regulations in order to create school sites that are more accessible to pedestrians and bicycles. Many other factors are at play, including highly publicized issues regarding school cafeterias, recess time and physical education. As Frumkin notes, "school is an opportunity to promote health," and thus, can be seen not only in light of minimizing risk but also of generating positive experiences for young people. One key focus in recent years has been on Active Design principles, which look at designing spaces and communities to promote physical activity. Schools can use these principles in design and operations to encourage more active play and travel habits.

What do we know today?

In connecting physical activity and children's health, today we know more about the size and characteristics of the problem. For example, we know that today, more than 15% of school-age children are overweight and that this number shows a three-fold increase since the late 1970s (Ogden et al, 2002). We know how few students walk or bike to school, and we know how often they play video games and for how long. We also know why students do not tend to walk to school; in a recent study, 55% of parents reported that distance was a major reason why their children did not walk to school, and 40% reported the reason to be traffic danger (Dellinger and Staunton, 2002). We know that children are more likely to walk or bike to school when schools are not only close to students' homes but also when the route to school is safe and traffic is lighter (ibid). One report on a pilot 'Safe Routes to School' program in California reported increases in walking by 64%, in biking by 114%, in carpooling by 91% and an overall decrease of single occupancy vehicle trips by a whopping 39% (Staunton et al, 2003). These programs are growing in popularity and clearly have a potential to make a profound impact.

Fewer data exist to document the success of any particular solution that relates to school buildings, but researchers and policy-makers have begun looking at the importance of school siting and its effects on communities, especially as it pertains to suburban sprawl and car travel. Schools have long been criticized for contributing to sprawl through their siting—an issue that has received a substantial amount of scholarship, but which is outside the scope of this review.

What research on physical activity is needed?

While a lot is known about how important physical activity is for children's health, less is known about how to ensure high levels of physical activity through the design of schools. Research is still needed to test theories about how these designs should be executed and how to improve them. Two major opportunities:

- Design features such as central, appealing staircases could encourage students to take stairs in multi-storied school buildings, thus increasing their physical movement and, ultimately, improving health. However, there is as yet no evidence recorded to support this notion. If data were available, it may help move school design in this direction.
- There is a growing understanding of how school siting impacts student transportation, but more data are needed to support this connection and help direct communities toward smarter siting decisions.

How Stakeholders Advance Research:
SCHOOL STAFF AND LEADERSHIP

Why help from school staff and leadership is important

As stewards and managers of school buildings and operations, school staff and leadership can play a central role in collecting useful information about what is working in schools and then making it available to school districts across the country. They are primary decision-makers about what types of research projects can occur in schools and a major influence on local and state school-related policy.

Communicating needs

What decisions do school staff and leadership need help making about how to build and operate schools? Researchers want to partner with school staff and leadership to help them make more informed decisions, but they need guidance from school boards and facilities staff about what research would be useful and feasible. If you have a need for information or more research into a persistent question for your schools, please contact the Center for Green Schools at schools@usgbc.org.

Getting districts/school involved

Without realizing it, school staff and leadership may already be conducting research on schools. For example, they may retrofit a building and then study its impact on health, learning, energy consumption, etc. Why not take these projects to the next level?

- Participate in **national efforts** like EnergyStar, EPA Tools for Schools and other programs that help build national databases about school buildings.
- **Compare** schools to each other. Do you have prototype school designs? A comparison can reveal how two identical buildings perform with different people in them or how slight changes to a prototype can yield different outcomes.
- Carefully **document** operations at your schools so that you can recognize trends related to asthma rates and absenteeism before and after renovations.
- Work with teachers, students and community members to **build awareness** about how their actions at school can affect health, and look to them for help in investigating your schools.

Sample study for a school district facilities office

Since school district staff personnel usually have ample access to information about school buildings, one simple action to take is to compare buildings or classrooms with each other, looking at an issue like electric light usage, CO_2 concentrations or transportation choices of students and teachers. These building and usage characteristics can then be compared to available data that may be related, such as average daily attendance, asthma rates or other health metrics—such as headache complaints. These types of studies can help provide valuable information to the industry and are difficult for those outside of school administration to manage.

Sharing experiences

Many districts are making similar decisions regarding their school facilities. By writing in trade magazines, attending conferences and otherwise sharing lessons learned through successful and less successful programs and projects in their district, school staff can both inform research and help others make better decisions in the future. Some forums to consider (see links below under Resources):

- School Planning & Management Magazine
- CEFPI publications and conferences
- American School and University Magazine
- Center for Green Schools School Sustainability Leaders network
- DesignShare

How Stakeholders Advance Research: TEACHERS AND STUDENTS

Why help from teachers and students is important

The health and well-being of students and teachers is the primary reason school staff, consultants and researchers engage in work to create high performance school buildings. Therefore, they have a unique opportunity to get involved, give feedback about experiences and be active participants in helping build and maintain better schools.

Getting involved in national efforts

Teachers and students have many ways to participate in making school facilities healthy and supportive environments, and this involvement can help connect them to local and national organizations or universities that may be interested in working with schools or classrooms to strengthen their research. Resources are also available to help teachers and students conduct their own research, either in class or as an extracurricular project(s).

National efforts:

- Consider projects like the "Through Your Lens" Photo essay contest that asks students to take pictures of their schools and talk about their observations. This contest enables students to get involved in understanding their schools, while documenting the schools' condition and submitting it to a central national source.
- Ask school administrators for ways to get involved in projects like the U.S. EPA's Indoor Air Quality Tools for Schools, and look for opportunities to research conditions such as air quality, acoustics, asthma reporting or other measurable conditions.

Curricular research projects:

- The Green Classroom Professional Program educates teachers on how to collect basic information about their classrooms and school buildings, such as light levels and air quality indicators.
- Green Education Foundation's Sustainability Education Clearinghouse has a number of resources to help teachers plan lessons to investigate school building conditions with students.

Another simple way for teachers and school staff to help advance the body of research is to support good record-keeping at schools. As is the case in all of these efforts, coordinate with school facilities staff and administration to ensure that everyone is working together when collecting data. Facilities staff will want to know what kinds of measurements teachers and students are taking in the facilities they care for. They may already have programs and procedures in place, and classroom efforts will be best used if the information and data collected aligns with school-wide and district-wide efforts.

Sample study for a middle school classroom project

Teachers and students have access to information about buildings that is very hard for others to find because they are, in many ways, the real eyes and ears of the school. These observations can be turned into both educational opportunities for young people and useful reports on building conditions for district leadership and other groups. A variety of projects are available as sample curricula on websites like the Green Education Foundation's Sustainability Education Clearinghouse (see resources section). One example is the Heating and Cooling Audit, a walk-through audit that helps students learn about issues like drafts through windows, solar heat gain and basic ventilation principles.

How Stakeholders Advance Research: DESIGN AND CONSTRUCTION PROFESSIONALS

Why help from design and construction professionals is important

Architects, engineers, building product manufacturers and others in the building industry have a central role to play in providing the knowledge, services and products needed to build and maintain high performance learning environments. As a result, building professionals can encourage research by clearly communicating questions to the research community and rigorously applying Post Occupancy Evaluation (POE) techniques to investigate the effects of design, construction and operational choices in school buildings.

Developing robust feedback loops

The architecture and engineering industries have more opportunities today to institutionalize feedback loops into standard practice. Simple POE studies with occupants and building systems are becoming popular, as practitioners find many benefits for their own practice that come from these follow-through techniques. To support research into children's health, consider employing programs like the ASHRAE Performance Measurement Protocols for indoor air quality, acoustics and thermal comfort to ensure that design intentions were met for various indoor environmental quality factors.

Getting a school portfolio involved

Firms that specialize in school facilities may already have data and critical access to school facilities that may be an opportunity for research studies. In LEED certified school buildings, these opportunities may be even richer since the additional documentation could be useful in comparison research.

- Encourage schools to participate in **national efforts,** such as EnergyStar, EPA Tools for Schools and other programs, that help to create national databases about school buildings.
- **Compare** completed school building projects to each other. Did certain technologies work better in certain environments or school types than others? Did specific design strategies encourage desired behaviors within the schools?
- Carefully **document** lessons learned from design and construction processes, and, where possible, honestly report these lessons, especially in the event of unforeseen consequences.
- Work with teachers, students and community members to **build awareness** about how schools can affect health, and help them investigate their schools.

Being a resource for schools

Many architecture firms are developing robust tools to help school districts prioritize facility improvements, by developing educational resources for clients about the impacts of school facilities on learning. This document and its Resources section can help shape these conversations and can help professionals design and build facilities that will have the greatest possible positive impact on young people.

Equally important, during the hand-off of new or renovated facilities, ensure that building operators and occupants are aware of how to keep the building healthy and safe for students, teachers and staff. Discuss with occupants how to properly use thermostat controls, lighting controls and other building components to enable their classrooms to perform as healthy learning environments.

How Stakeholders Advance Research: RESEARCHERS

Why help from researchers is important

The field of school buildings research is small, passionate and diverse. It is also a complex field in the study of buildings and their operations and in investigations of children's health and learning. Both of these aspects of school buildings research have rich theoretical foundations, technical complexities and methodological frameworks. This section outlines some ways researchers can maximize their work to have the biggest impact on the ongoing conversation around children's health in school buildings. For further considerations regarding conducting research in school buildings, see page 29.

Gaps and opportunities

This brief, in its initial outline of the effects of school buildings on students, has laid out a number of gaps in knowledge that could be filled by researchers over the next few years. Key elements to remember when looking for opportunities to move the knowledge base forward include:

- Interdisciplinary teams. Since the field is diverse and complex, it may be helpful to engage someone from outside the discipline of the lead researchers. A buildings researcher will find a public health expert essential in designing the study's health metrics. An education researcher will benefit from the expertise of a buildings researcher in crafting building-related metrics.
- Consider the audience carefully. Is the team hoping to provide information that will lead to better investment into facilities or for a specific type of facility or building technology? While technical language that is specific to a certain discipline must be used for trade publications, journals and technical reports, consider translating research findings into a format that can be easily understood and practically applied in the field, whether in design, construction or school and district decision-making.
- Get advice. Check out literature reviews on the subject, especially the National Research Council report (see Resources section), which has useful detailed advice on study design in this field. Other reviews, such as Mendell and Heath's work (cited below), have gap analyses that may be helpful in defining research.

What to measure, and how to measure

In general, well-conducted studies in this field have a few characteristics in common. First, they measure specific student health and well-being outcomes that most closely and clearly fit the building trait in question (light relates to hormones, air quality relates to respiratory health, etc.). Second, they match the timescale and physical scale of measurement with the scale of the metric they are testing. For example, if one is testing impacts of poorly ventilated rooms on asthma incidence, it is most effective to collect data on a daily basis, since these data can fluctuate largely over small periods of time. Finally, well-conducted studies carefully use metrics of building condition, looking for objective and useful measures of building performance.

While subjective scores may be sufficient for the purposes of arguing for funding, these are less helpful to designers and facility managers looking for specific feedback on how to choose building improvements, select equipment and

maintain their buildings. The introduction of this document also contains other important considerations such as equity, teacher metrics and causal chains.

Sharing experiences

Many researchers use peer-reviewed journals as their primary means of communication to others, which is not always the most effective way to get the results out to practitioners. In addition, the field of school building research is very diverse in discipline, including researchers from public health, medicine, architecture, planning, education, economics, psychology and more. This diversity makes it difficult to use a single journal or forum.

Researchers in this field often use the National Clearinghouse for Educational Facilities as a forum, as well as the events and publications of the Council for Educational Facility Planners International. If you have research that would be beneficial in advancing healthy schools, reach out to these organizations, and to the Center for Green Schools at USGBC, for help in getting it into the right hands, in the format that will be best for your audience.

How Stakeholders Advance Research: GOVERNMENTAL AGENCIES

Why help from governmental agencies is important

Local, state and federal governmental agencies have been the source of some of the best information on the relationship between school facilities and childhood health. They often have the resources and drive to conduct research on schools in their jurisdictions, and they benefit from using these findings in policy-making and public education. Public health offices, EPA offices, national laboratories, energy-related agencies and others have the potential to be effective catalysts in this effort.

Examples of research from agencies

Research studies that have been brought together by governmental agencies, inside and outside the U.S., represent a wealth of information. One of the primary benefits of research from agencies is that it is typically published with rigorous standards of quality; however, as the results are not typically written for academic audiences, they are easier to understand and more action-oriented. Some exceptional recent examples are:

- Environmental Health Conditions in California's Portable Classrooms (State of California)
- School Facilities: Condition of America's Schools (U.S. GAO)
- Massachusetts Green Schools: Post Occupancy Study (Massachusetts School Building Authority)
- Lessons Learned from Case Studies of Six High-Performance Buildings (National Renewable Energy Laboratory)
- Tools for Schools Toolkit (U.S. EPA)
- School Siting Guidelines (U.S. EPA)

Convening, collecting and communicating

Governmental agencies can and do serve three primary roles in the field of school buildings research:

- As conveners, agencies have the opportunity to bring diverse experts together to discuss improving school facility conditions and to share knowledge about new research findings.
- As collectors of data, agencies often have access to large datasets that relate to public school buildings and have the ability to make this information available through their own research or by providing the data to researchers.
- As communicators, agencies have proven to be effective distillers and translators of information relating to healthy school buildings; through programs such as U.S. EPA's EnergySmart Schools and Tools for Schools Programs, agencies can help disseminate research findings to a larger audience.

How Stakeholders Advance Research: SUPPORTING ORGANIZATIONS AND INFORMATION NETWORKS

Why help from supporting organizations and networks is important

During the Boston Summit, participants agreed that one of the major needs in the field of school building research is better translation of research findings to the general public. Taxpayers, parents and teachers need accessible information about the importance of high performance school facilities and what makes them work. Media, including bloggers as well as more formal media outlets, and outreach organizations play a central role in building momentum in the green building movement and can play a variety of roles in the research arena.

Sending information where it is most needed

Most school building professionals are in need of better information about new technologies, design ideas and the measurable effect they can have on student health. Designers, builders and operators of school buildings typically go to a few sources to look for help:

- National Clearinghouse for Educational Facilities (NCEF)
- School Planning & Management
- American School & University
- Building industry trade publications
- DesignShare, Edutopia and others

Organizations like USGBC, CEFPI, the 21st Century School Fund and others can help find data and anecdotes to support the work of media and outreach organizations. Therefore, they should be considered a resource wherever appropriate.

Writing about research

Media of all types convey important research findings and stories to decision-makers and communities. They often have the capacity to re-package and translate complex and lengthy research into simple, straight-forward and actionable lessons for practitioners. With this ability also comes the responsibility to maintain the integrity and accuracy of research findings and to promote research that is sound.

One of the goals of this document is to define terms and concepts that should help stakeholders convey a clear and fair message about research findings. In particular, clear communication about causation is important. In other words, if a study found that a set of schools with better air quality also had lower frequencies of colds and flu, it does not necessarily mean that the researchers found that better air quality caused or “led to” the lower frequency. Instead, these two patterns were “related to” or “associated with” each other. While this distinction may seem trivial, ignoring it can contribute to readers believing that they can expect the same outcomes when they attempt the same actions in their schools, which may or may not be true, depending on several interacting factors. The lack of clarity can contribute to backlash when expectations are not met by a certain technology or design action and can ultimately hurt the effort to improve schools.

Media outlets can also help with anecdotal evidence. School boards and facility managers need stories about other schools that have tried new strategies and have learned lessons in the process, and they often turn to the popular press and trade journals for this information. Financial information is very useful in these stories since one of the most commonly asked questions tends to be, “Yes, but how much did it cost?” When possible to obtain, these details make decision-making easier.

Supporting research

Many outreach organizations and associated foundations look for ways to support research through sponsorship, publishing assistance or publicity. This document is written to provide guidance in this effort, supporting interdisciplinary research, clear causal linkages and well-bounded experiments. Foundations may also find the “top ten” list in the Resources section helpful to get a deeper exposure to some of the most pressing unanswered questions in the field.

Final Points to Consider When Researching School Buildings

Children and their environment

Children are more susceptible than adults to pollutants and other environmental contaminants in the environment for a variety of reasons. Most importantly, they take in roughly twice as much air by volume compared to their body mass as adults, meaning that they also take in twice the pollutants through respiration (Bearer, 1995). In addition, since they are closer to the ground, they can suffer from higher levels of exposure to toxins near the floor or ground environment. Finally, children have less ability to control their environmental exposures since they have less control in general over their situations and surroundings and have a less developed ability to communicate symptoms of illness or discomfort. These factors all contribute to the fundamental importance of conducting studies that focus on children.

Teachers and principals

Considerable research has been done into the impacts that various environmental quality factors have on teachers, much of it relying on well-established educational research to make the causal chain link to student achievement (Buckley et al., 2004). In a comprehensive report in 2006, Johnson showed that teacher quality and retention can be influenced by the teacher's environment, which in this case refers to multiple factors—indoor environmental quality, administrative support, supplies, etc.
In another study conducted by educational researchers, Buckley et al found that the quality of facilities had a "substantively important effect on teacher retention," even when statistically controlling for other potential factors like pay, parent and community involvement, age of the teacher, etc. (Buckley, et al., 2005). In fact, researchers found that facility quality showed a greater predictive ability on teacher retention than teacher pay for this group of study participants.

Decision-making and evaluation of school facilities

In constructing research studies, it is important to recognize the various decision-makers that one is attempting to influence and to appreciate the constraints and opportunities that they experience in their work. In the case of school facilities, a number of groups affect the way that schools are built and managed, and they will and should have an impact on how research is directed.

Also, school buildings constitute a substantial existing building stock that is continuously run and occupied, and these buildings are often in more need of help than new designs. The average school building today is over 40 years old, has experienced multiple small and large retrofits and can be expected to have different lighting systems, window types, air-conditioning systems and more (M. W. Filardo, et al., 2006). It is important to assume that a school building is neither a static nor uniform structure.

Often, researchers have been known to use a single number or label to characterize the many aspects of a whole building in an effort to simplify the measurement and compare school facilities to each other. For example, research has been done on the relationship between school construction spending and student achievement as well as on building age and student health and well-being. While valuable in the policy arena, most architects will say that this relationship varies wildly depending on what the funds are spent on. Newer buildings are not necessarily better than old ones (especially in schools, which tend to be periodically

renovated). Building age as a pure number has not proved to be a reliable indicator of building quality—for school buildings or elsewhere.

Another common metric for a building is a Facility Condition Index (FCI). Many schools and school districts keep some kind of FCI record, which covers major components and equipment, noting their age and state of disrepair. There is no single FCI format or approach across the country. It is a metric often favored by education researchers, who need a simple numerical measurement of the quality of an entire building. This approach can be problematic, however, in indicating how schools can be improved in a meaningful way. It can also be quite subjective in practice and therefore less reliable.

Researchers have also hoped to use LEED as a way to compare whole buildings to each other in these types of studies. However, these rating systems are performance-based, not prescriptive, and so do not all require the same building components or techniques. It is inaccurate to assume that they *all* have daylighting, low VOC materials or any other specific characteristic. This variety makes it difficult to use the certification to categorize a building unless we know which techniques the building used. To answer the question about 'green' schools conclusively, it may require assessing a very large set of schools (at the national scale, perhaps), with the hopes of factoring out the noise of individual building differences and regional disparities. Aside from this type of major study, researchers can focus instead on investigating individual building characteristics.

Appendices

Appendix A: The Center for Green Schools at the U.S. Green Building Council

The Center for Green Schools works directly with volunteers, school district staff, elected officials and partner organizations, as well as parents and students, to achieve its mission of bringing green schools to everyone within this generation. Each of these groups has a unique need to use the results of quality research to influence decision-making and reinforce the ability to back those decisions up with colleagues, other parents and students and other taxpayers. The Center is therefore supporting the research community by:

- providing forums for collaboration
- convening experts to discuss the direction of national research
- encouraging innovative and practical research pathways
- collecting and disseminating data from schools and government agencies

The U.S. Green Building Council, which houses the Center for Green Schools, has a history of encouraging innovative green building research to inform its LEED green building rating systems. USGBC attempts to close the loop of research, education and implementation in order to identify and recognize best practices in green building. Two current programs that help close this loop are the Green Schools Fellowship Program and the Research to Practice Program.

Green Schools Fellowship Program

The Center for Green Schools Fellowship Program provides school districts with a fully-funded, dedicated expert who collaborates with district leadership for three years to jumpstart sustainable and environmentally responsible practices into schools. The Fellows initiate or accelerate various initiatives, such as monitoring energy usage and decreasing consumption, disseminating environmental curriculum resources, establishing indoor air quality policies and practices, revising maintenance and transportation contracts and improving recycling, school garden and composting programs. The lessons learned in implementing these initiatives are shared directly with the Center for Green Schools to inform work with researchers, district leaders and school district sustainability leaders.

Research to Practice Program

The Research to Practice Program engages the higher education community through investigative green building research on their campuses and in their communities. Through Research to Practice, students, faculty and university staff aggregate in-depth analyses of untapped greening opportunities, ultimately advancing green building practice. Twelve higher education teams completed work under the Research to Practice Program during the first year. These teams researched a broad range of building issues, including performance, tenant satisfaction, financing, return on investment, LEED readiness, post-occupancy analysis, retrofitting, real estate development, integrative process, lifecycle impacts and more. By engaging students in green building research, the program connects them to professionals, engages them in critical thinking about green building and helps them gain valuable real world research experience.

Appendix B: References and Resources

Get Involved and Find Out More

- Center for Green Schools at the USGBC www.centerforgreenschools.org
- Council of Educational Facility Planners International, for conferences, journal and other resources www.cefpi.org
- DesignShare, for forums, articles, and competitions www.designshare.com
- EPA School Siting Guidelines http://www.epa.gov/schools/siting/
- EPA Tools for Schools Program (for Indoor Air Quality) http://epa.gov/iaq/schools/
- Green Education Foundation, for lesson plans and curricula for teachers http://www.greeneducationfoundation.org/
- Green Classroom Professional Certificate Program http://www.centerforgreenschools.org/main-nav/k-12/curriculum/Greenclassroom.aspx
- Lawrence Berkeley Labs Indoor Air Quality Resource Bank http://eetd.lbl.gov/ied/sfrb/
- National Clearinghouse for Educational Facilities, for a wealth of information on school buildings www.ncef.org

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Appendix C: List of Summit Participants

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