Green Schools as High Performance Learning Facilities

National Clearinghouse for Educational Facilities

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September 2010

The United States will see nearly $90 billion in K-12 school construction between 2010 and 2012, according to estimates by McGraw-Hill Construction, a leading national construction forecaster. (McGraw-Hill Construction, 2010)

This tremendous capital expenditure going to new construction and renovation of schools, coupled with global concern for the environment, means many school decision makers in jurisdictions across the country will be considering the cost and value of green schools.

With those factors at the forefront, the question that comes to mind is:

What Is a Green School?

In practice, a green school is the physical result of a consensus process of planning, design, and construction that takes into account a building’s performance over its entire 50- to 60-year life cycle. The main focus of the process is to reinforce optimal learning, a goal very much in keeping with the parallel goals of resource efficiency and minimal pollution.

Such buildings provide clean fresh air, a comfortable temperature range, abundant light, and low distraction from unwanted noise while also maximizing resource efficiency, minimizing pollution, and teaching students the importance of innovation in the built environment.

The U.S. Green Building Council (USGBC), on its Greenschoolbuildings.org Web site, defines a green school as:

–A school building or facility that creates a healthy environment that is conducive to learning while saving energy, resources, and money.”

There are two levels of focus for green architecture. The first, thinking globally, contributes to a stewardship of resources and looks to the needs of future generations. The second yet equally important level, thinking locally, considers the health, safety, and welfare of people within the community, including students, faculty, administrators, support staff, and visitors. Both levels are important to address, since about a fifth of the U.S. population spends time in a school each day, according to estimates from the National Academy of Sciences. (NRC, 2006)

What Are the Benefits of a Green School?

Learning Benefit: An investment in healthy environments pays real dividends

In the case of optimizing health for students, teachers, and operations staff, it is hard to differentiate objectives between a –green” and a –conventional” school because the aim is the same: keeping everyone present, alert, healthy, and learning.

However, in terms of providing enhanced learning opportunities, the data about better-built schools point to better learning. U.S. Environmental Protection Agency (EPA, 2010) research reports find that students who attend schools in poor condition score 11 percent lower on standardized tests than students who attend schools in good condition. (EPA, 2010)

Budget Benefit: Operational savings far outweigh potential increases in construction costs

When considering green schools, keep in mind that they may cost more at the outset to cover better materials, more efficient systems, and higher-quality construction. However, over time, these systems will more than pay for themselves in healthier indoor environments and savings in energy and water. A 2006 study of 30 green schools nationwide showed that a 2 percent increase in first cost—about $3 per square foot—paid back $10 per square foot in energy and water savings alone over the course of the buildings’ service lives. (Kats, 2006)

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Prepared under a grant from the U.S. Department of Education, Office of Safe and Drug-Free Schools

According to another source, green schools save $100,000 per year on average, with 30 to 45 percent reduction in water use and a 30 to 50 percent reduction in energy use and utility bills, compared to a typical school. The result is a payback of the 2 percent first-cost premium within a few years. (USGBC, 2010)

In a Massachusetts study generally critical of "green" versus "standard" schools, researchers still found that green schools use approximately 19 percent less fuel than the median of standard schools, notably from more efficient boiler control systems. According to the study, all schools can find additional savings available through better control of lighting, heating systems, and plug loads, and through increased use of energy modeling analysis. (Cadmus Group, 2010)

Taking that a step further, when all opportunities for savings are examined, green schools use an average of 33 percent less energy than conventionally designed schools. (Kats, 2006) Moreover, energy considerations account for only a fifth of the operational benefits of creating a green school. (NRC, 2006) Therefore, the potential payback to the nation's power grid is enormous for investing in upgrading the performance level of new and existing schools.

School systems can achieve savings by focusing not only on how they design schools but also on how they operate them, and designers can play a part by ensuring that their designs are both implementable and operable in the long run.

Health Benefit: The productivity payback

A healthier school environment is another benefit of green schools, beyond lower operating costs. Healthier school environments have been shown to improve student focus, retention, and test scores; enhance teacher performance; and lower absenteeism among both students and teachers.

By also tallying savings from reduced emissions, higher productivity, teacher retention, and employment impacts, and lower rates of asthma and other illnesses, we see an additional payback of $64 per square foot. This is a total payback 20 times the initial investment for a green school. (Kats, 2006)

The vital nature of making this investment becomes even clearer when one looks at the enormous scale of public and private enrollment in elementary and secondary schools—a total of 54 million students in the United States during the 2007-08 school year. The 133,000 public and private elementary and secondary schools and local education agencies employed a total of 6.2 million full-time staff in the 2007-08 school year, of which 51 percent were teachers. (U.S. Dept. of Ed., 2008, 2009a, and 2009b)

Operational Benefit: Every little bit counts

Saving money in operations is beneficial to school performance because it frees up those operational funds for more teachers, equipment, and activities. Such expenditures are fundamental to the learning experience, yet they are facing increased scrutiny as school jurisdictions face perpetually tight budgets.

A school is a system of systems, and too many schools are currently operating below standards. (NEA, 2000) The solution to optimizing school systems and addressing the monumental array of environmental challenges, such as greenhouse gas emissions, will not come from one silver bullet, or even several. Instead of one huge, centralized technological solution, change will come mostly through incremental improvements, many of which will seem simple and have minimal cost implications, but, because school buildings are everywhere, the cumulative effect will be very large. (Kats, et al, 2010)

Pedagogical Benefit: Schools as teaching tools

Of course, with schools, an overriding measurement of their success is their effectiveness as teaching tools. In recent decades, there has been considerable research tying environmental quality to student achievement. For example:

- Fresh air lessens the likelihood of ailments; most notably, asthma, the leading cause of school absenteeism.
- Though conventional school designs readily achieve proper light levels for rooms, work surfaces, and hallways, research into circadian rhythms of children suggests that daylight (or prolonged exposure to bright, full-spectrum light during the day) is important for maintaining healthy sleep cycles.
- Studies have repeatedly shown acoustic distraction from air, road, and train traffic lowers student achievement. What is less generally understood, though, is that children under the age of 15 are still developing the skill of hearing speech over background noise (such as air vents), so noise is much more distracting for them than for older children and adults.

- Thermal comfort can be challenging because designs need to balance clean air with energy efficiency and low background noise. This balance reintroduces concepts such as operable windows and radiant heating.
- There are even innovative approaches to security design that view student motivation as positive rather than suspect and use ―pride of place" to keep students focused on learning, without having to turn to metal detectors and on-campus police.
- A school that teaches the importance of sustainable practices through example can be a powerful part of the school curriculum.

As mentioned earlier, the health benefits of green buildings (which are detailed on pages 8-12 of this report) have wide-ranging repercussions. In fall 2005, Turner Construction, one of the largest construction management companies in the United States, surveyed building-sector executives and found that more than 70 percent of those who have worked in developing green schools believe that these facilities reduce student absenteeism and improve student performance. Other school studies in Illinois; Washington, D.C.; Washington state; Oregon; Pennsylvania; and North Carolina found that:

- Student attendance rose by 5 percent after cost-effective indoor air quality improvements,
- Better school facilities can add 3 to 4 percentage points to a school's standardized test scores, even after controlling for demographics,
- Green schools effected a 15 percent reduction in absenteeism and 5 percent increase in student test scores,
- Students moving into a new green school experienced a 15 percent reduction in absenteeism from their previous school,
- Students moving from a conventional school to a new LEED™ Gold building experienced substantial improvements in health and a 19 percent increase in average student oral reading fluency scores, and
- Student test scores before and after students moved into the country's first LEED Gold K-12 school provided compelling evidence that learning and test scores improve in greener, healthier buildings. (Kats, 2006)

Taking heed of these remarkable results, state programs for green schools have already made great strides in California (CHPS, 2005), Washington (WGS, 2009), and Massachusetts, all now merged with Collaborative for High Performance Schools. (See the Related Resources section below for a link to more information.)

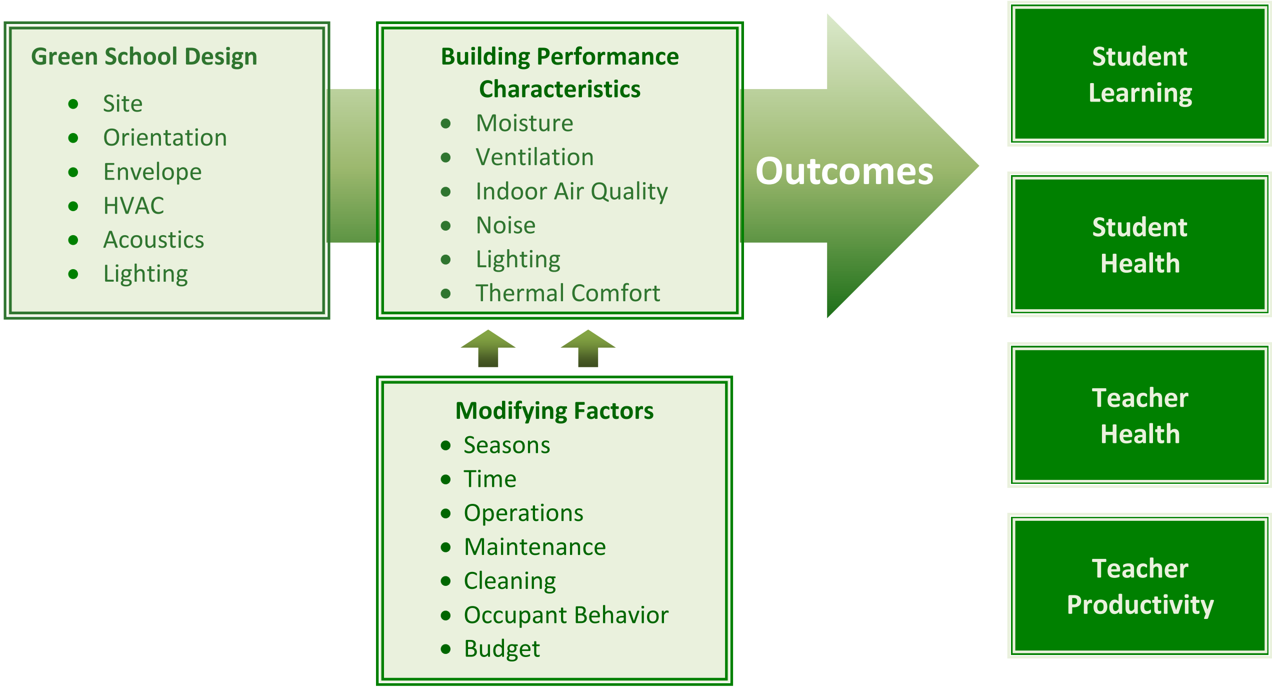


Chart evaluating links between green school design and outcomes for learning, health, and productivity, *adapted from Green Schools: Attributes for Health and Learning. (p.3)*

Commissioning, because one size does not fit all

Appropriate design is one of the key contributing factors to green, healthy schools, along with high-quality construction and a well-planned operations and maintenance schedule. Commissioning is a developing discipline that addresses these concerns, including planning and design, and leads to practical and financially feasible construction and operations. Commissioning brings together a team of people knowledgeable in all phases of a project's planning, design, construction, and operations. The team sits down with school administrators, faculty, students, parents, and community leaders at the very beginning of a project to discuss goals—including green goals of maximum resource efficiency and minimum pollution—so that the very difficult trade-offs of cost and effectiveness can be addressed. As with any extremely complex series of decisions, achieving balances and trade-offs is a critical part of the equation for creating green schools. (ASHRAE, 2005)

The complicating factor here is that there is no jurisdiction-specific definition of what a green school should be, because every school will have its own set of priorities, challenges, opportunities, and constraints. Plus, no one person can possibly comprehend the multiple layers of complexities of cause and effect among combinations of factors, such as: teacher satisfaction and performance, student comfort and learning (or test proficiency), lighting and alertness, fresh air and thermal control, systems maintenance and illnesses, or noise and attention span.

To grapple with these decision-making complexities, the team of stakeholders involved in considering a new or existing green school needs to include administrators, school board members and other community leaders, maintenance staff, planners, and designers, as well as students and faculty. And they will all have their own insights into maximum return on investment in school facilities. With green schools especially, there is always the factor of projected performance of building systems versus actual performance, which should be monitored and refined over time. (AIA, 2010)

Another very important variable is occupant behavior. Teachers need to know not to stack materials on top of ventilators. Students need to be mindful of washing or sanitizing their hands on a regular basis and not leaving food accessible to vermin. Maintenance personnel will have to adopt a set schedule of filter changing and building-system inspections in addition to their daily maintenance routines. Such behavior modification is well within the realm of possibility, as witnessed by the behavioral changes most people have made in their recycling habits over the years—at school, at home, and in the workplace. (Matsch, 2000) Turning off lights, closing and opening windows and doors when appropriate, and reporting water leaks, broken windows, and other flags as soon as they become apparent are all occupant behaviors that help keep buildings resource-efficient and healthy.

Planning, Design, and Operations Considerations for Green Schools

In the past decade alone, government and non-government organizations have significantly advanced the concept of making buildings sustainable. For example, the U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA) have a joint program, ENERGY STAR, which works to protect the environment through energy efficient products and practices. In addition, the DOE National Renewable Energy Laboratory gathers and disseminates a large body of information on building performance. DOE also holds a biennial student competition for designing and building small homes—the Solar Decathlon—a two-week exhibition on the National Mall in Washington, D.C., that draws hundreds of thousands of people.

At the state and local levels, the U.S. Conference of Mayors in 2007 and the National Association of Governors in 2009 voted to support the achievement of carbon-neutral buildings (those that do not contribute greenhouse gases to the atmosphere) by 2030. In June 2010, 25 mayors representing a population of 13 million Americans and Canadians from the Great Lakes and St. Lawrence River region of North America formed the Cities Transforming Towards Sustainability program to protect water resources, promote low-carbon energy, adopt green planning and design, and encourage green development. (S. V. Davis 2010)

In addition, a number of national organizations have developed well-received rating systems for measuring sustainability. The U.S. Green Building Council established Leadership in Energy and Environmental Design (LEED™). The Green Building Initiative developed Green Globes®. The Living Building Institute created the Living Building Challenge. (This particular rating system calls for buildings to have the environmental impact of a tree, enhancing the purity and availability of earth, air, and water). All of these systems are intended as voluntary, market-driven rating systems rather than regulatory requirements. However, some jurisdictions in the United States are beginning to require that buildings achieve some level of recognition by such rating systems. At the same time, the International Code Council, which develops the International Building Code, the model code most jurisdictions around the country use as the basis of their building requirements, is working to keep current with regulatory trends by developing the International Green Construction Code. (AIA, 2010)

To get an idea of the kinds of issues and decisions school officials, designers, and constructors face in planning and designing green school facilities, it may be helpful to understand what some of these rating systems address.

Leadership in Energy and Environmental Design (LEED™)

The U.S. Green Building Council initially developed the LEED rating system to address all buildings. Recognizing the unique nature of schools, USGBC developed LEED 2009 for Schools New Construction and Major Renovations Rating System. (USGBC, 2009) The project checklist for LEED for schools has seven categories, five of which have requisite goals and all of which have additional goals that award a school project various points. (Basic LEED certification moves on to three higher levels—Silver, Gold, and Platinum.) The seven categories are: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design, and Regional Priority.

Sustainable sites
Selection and preparation of a site for a school can be a particular challenge because of space and budget constraints. If the land is donated, it may be a parcel away from public transportation access. If it is an urban infill, on the other hand, it may have limited access to open space. Both these scenarios would cost points. However, the opportunities to gain points still abound to develop community connectivity, redevelop sites hampered with accumulated waste (brownfields), provide adequate bicycle facilities, plan for fuel-efficient vehicles, control parking accommodation, protect and restore habitats, control storm water, minimize heat islands on roof and open-ground areas, control light pollution, and plan for multiple facility uses. This LEED category has two requirements for points. The first is controlling erosion and dust from construction activity. The second is conducting an environmental site assessment and implementing any required pollution remediation that is identified.

Water efficiency
This category requires the reduction of water use through installation of low-flow fixtures. Other ways to earn credits include elimination of potable water use in landscaping, innovative treatment and use of wastewater, and reduction of use of municipal water supplies and wastewater systems.

Incidentally, green roofs are recognized as effective in managing storm water runoff from the building and mediating solar heat gain. Roofs as a landscaping element do add a level of maintenance complexity, however, since the soil, drainage, and filter levels can hinder roof inspection for leaks, and roof gardens will require design detailing for rooftop foot traffic. (Gelfand et al, 2010)

Energy and atmosphere
The first requisite for this category is commissioning of building energy systems, which is a process of verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, and operated to meet the owner's project requirements (ASHRAE, 2005). Two other requisites are to establish a baseline of performance for managing both energy and refrigerants. Additional LEED points are awarded for enhanced performance related to these three requisites as well as for on-site renewable energy (e.g., geothermal heat pumps, cogeneration of combined heat and power, or solar panels for hot water or electricity), measurement and verification of building performance over time, and use of Green-e Energy program-certified grid power.

Materials and resources
Recycling is required under this category. Reusing an existing building's structural and nonstructural systems during a major renovation gains points, as does managing construction waste; reusing materials; and using materials that are recycled-content, regionally obtained, rapidly renewable, and/or made of wood certified by the Forest Stewardship Council.

Indoor environmental quality
LEED for schools requires meeting minimum performance levels for indoor air quality (based on ASHRAE Standard 62.1-2007) and acoustic performance, as well as controls on environmental

tobacco smoke around the school. Credit points include a system for monitoring CO_2 levels to make sure enough fresh air is coming into the building and that there is increased ventilation above the ASHRAE 62.1-2007 standard. Credit points are awarded for establishing a construction indoor-air-quality management plan to cover the construction period and before occupancy. To control the source of indoor-air contaminants, points are awarded for using materials that emit low or no levels of volatile organic compounds (VOCs) or other indoor chemical and pollutant sources, and materials that prevent the growth of mold. This category also addresses lighting and thermal control systems, the introduction of daylight and views into school spaces, and enhanced acoustic control.

Innovation in design
This category allows the school building team to earn additional credits for innovations not mentioned in LEED 2009 for Schools New Construction and Major Renovations. Credit is also given for having at least one team member who is a LEED-accredited professional, and for designing and operating the school as a teaching tool to foster an appreciation and understanding of sustainable design among people who occupy and visit the school.

Regional priority
The intent for this category is to "provide an incentive for the achievement of credits that address geographically specific environmental priorities."

Collaborative for High Performance Schools (CHPS®)

The Criteria for High Performance Schools is similar to USGBC LEED, but was developed specifically for schools by the Collaborative for High Performance Schools (CHPS®). CHPS began in California in 1999. Its rating system has since been adopted by other states, including Colorado, Connecticut, Maine, Massachusetts, New York, New Hampshire, Rhode Island, Texas, Vermont, and Washington.

A quick side note before getting into the rating system. CHPS also developed a six-volume *Best Practice Manual,* which is a valuable resource in itself. The six volumes encompass planning, design, rating-system criteria for new buildings and renovations, modernizations,maintenance and operations guidelines, commissioning, and relocatable classrooms. CHPS also provides support through its website, www.chps.net, which features research papers, supporting documents, and databases on green-school design, construction, and operations.

Now, to the rating system. The Volume III Criteria for High Performance Schools, first released in 2001 and updated every three years, specifically facilitates the design of learning environments that are healthy, comfortable, resource efficient, safe, secure, adaptable, and easy to operate and maintain. In short, CHPS notes, these learning environments embody the next generation of schools. The criteria are also useful for setting and communicating goals clearly to project managers, funding providers, designers, the construction team, and utilities companies, all within the regional, district, and site-specific prescriptions for school design. (CHPS, 2010)

The criteria for achieving green schools address seven main categories: Leadership, Education, and Innovation; Sustainable Sites; Water; Energy; Climate; Materials and Waste Management; and Indoor Environmental Quality.

Each category is subdivided into classes. These include prerequisites for CHPS recognition as well as optional credit points for higher levels of recognition. As of the second quarter of 2010, CHPS had developed five project types: new school construction, major modernizations, new buildings on an existing campus (classroom or non-classroom), minor modernizations, and additions (classroom or non-classroom).

Self-certification to third-party review
CHPS began as a self-certifying building rating program (CHPS Designed). With the introduction of CHPS Verified™, project managers were given the option of a more objective, third-party review—an approach that recognizes the multiple challenges school officials face with student population growth, demand for improved student performance, and social and financial constraints. The next step is CHPS Verified Leader. Plus there is an Operations Report Card.

CHPS Designed is a self certification recognition system. It is ideal either for a school district's first attempt at using the CHPS criteria, implementing the criteria late in a project, or school districts with limited need for an independent project review. The program relies on a project scorecard that helps design teams manage the points they are claiming. It can be used to designate responsible team members and track compliance with credits. Participation in CHPS Designed is free, and the primary accountability rests on the school district and design team.

CHPS Verified™ combines project management, the CHPS criteria, and a third-party assessment to ensure that the school project is designed and built to the highest performance standards. The Verification Program User Guide, available online, outlines design and construction review requirements and what each registered project will receive. Participation gives design teams access to project management tools and identifies incentive funding. Accountability rests on the school district, design team, CHPS, and an assigned independent reviewer.

CHPS Verified Leader™ is a higher level of recognition for school projects that perform well beyond minimum eligibility requirements. CHPS Verified Leaders™ are CHPS Verified™ and have inspirational designs that architecturally express their high performance features. To be eligible for recognition as a CHPS Verified Leader™, new school projects must earn a balance of high scores across the designated performance priorities.

The Operations Report Card (ORC) is a new CHPS program that benchmarks the current performance of existing schools, provides a report card of results, and makes suggestions for improvement in five categories. These categories include: energy efficiency, thermal comfort, visual comfort, indoor air quality, and acoustics.

While designed for district-wide deployment over multiple school sites, this interactive online tool is also useful to single public schools, charter schools, and private schools. After entering all of the requested information, CHPS will provide an ORC summary numeric score of current performance, explanations in each category, and a customized list of suggested improvements. The modest cost to the school system is based on a sliding scale for the number of schools a jurisdiction registers. All of the measurements needed to complete the ORC can be taken by existing school or district staff. More information about the report card program can be found online at www.chps.net/orc

Green Globes™

At present, Green Globes™, developed by the Green Buildings Institute (GBI), is the only green building rating system that recognizes and rewards the use of life cycle analysis (LCA) LCA in building design.

Although score-card rating systems, such as LEED and CHPS, are comprehensive and clear, they are also fairly prescriptive—they present checklists of factors to be met, more than goals to be met. The LCA approach of Green Globes is to start with performance goals and then work to meet those goals by establishing design solutions. Green Globes is a consensus-based green building rating system formally approved in March 2010 by the American National Standards Institute and GBI.

Life Cycle Analysis

Life cycle analysis for buildings addresses the performance-based input and both the harmful and beneficial output of a building. It takes into account the harvesting of raw materials, production and shipping of finished systems; includes construction and operations over the building's life; and ends with demolition, including recycling and disposal (AIA.) The purpose behind LCA is to consider environmental performance as objectively as possible, especially in minimizing both the use of nonrenewable resources and the output of pollutants. (Skopek, 2005)

LCA can get pretty technical. In analyzing global environmental impact through LCA, building engineers and architects talk about things such as input/output analyses, cradle to grave, and embodied energy to compare one building system to another; and the calculations can quickly become daunting. Scientists and software programmers are addressing this complexity by developing systems-performance databases and computer-aided calculations and the architectural, engineering, and construction professions are adopting building information modeling (BIM). These approaches, which test how a building will perform over time, are based on computer-simulated projections of how materials and systems will hold up and interact with one another over a 50- or 60-year life cycle, and take into account scheduled maintenance and replacement. (AIA, 2010)

Computer simulation allows a wide variety of factors to be considered in how resource-efficient and environmentally sustainable a building is likely to be—from producing and transporting materials and systems to the construction site, to how long they last in use and how re-useable each element will be when it has reached the end of its life cycle. The resulting calculations show the total impact of that material or system, which can then be compared with other systems. For instance, the building design team can evaluate whether to select a steel or concrete structural framing system, a brick-and-block structure, or some other structural system based on local availability, building size, site characteristics, availability of skilled labor, and other factors germane to the school district and user-defined goals.

If this cradle-to-grave building model identifies an area in which a significant amount of non-renewable resources are consumed or pollution is created, the design and operations teams will very quickly see possible opportunities to take another approach or use alternative systems. The earlier these decisions are made, the more cost-effective they will be.

With these kinds of performance projections in hand, decision makers can determine site orientation and design of a building, specification of materials and systems, construction means and methods, commissioning, and operations and maintenance, all based on what best fits their initial green school criteria. In some cases, the analysis includes a weighting system that provides a numerical score that non-tech-savvy decision makers can easily comprehend and use to make educated selections.

Calculating pollutants

Environmental impacts from the manufacture and transportation of materials, construction, operations and maintenance, and demolition are going to differ from situation to situation. Green life-cycle analysts try to simplify the process as much as possible to make comparisons easier. One typical pollution impact category, for instance, is global warming potential, which is measured in tons of CO_2 equivalents. What that means is that scientists have given a global warming potential value to carbon dioxide that is the standard for measuring other global-warming gases. Methane, for example, is considered to be 23 times more potent a greenhouse gas than CO_2. Therefore, one unit of methane is valuated as 23 CO_2 equivalent units. (Units of mass or volume vary from country to country—even from project to project—which complicates comparisons even further, making automation all the more valuable.) (AIA, 2010)

Other commonly calculated pollution impacts on air, water, and soil that green life-cycle analysts consider include: ozone depletion, acidification (acid rain), photochemical pollutants (smog), toxicity, and eutrophication (fish-kill potential). There are many more possible impact categories. The ones mentioned here are the most commonly recognized by federal entities such as the U.S. Environmental Protection Agency, Occupational Safety and Health Administration, National Institutes of Health, and National Institute of Standards and Technology. (Lippiatt, 2007)

Acidification potential: Acidifying compounds emitted in a gaseous state either dissolve in atmospheric water or are fixed on solid particles. They reach ecosystems through rain or snow. The two compounds principally involved in acidification are sulfur and nitrogen compounds.

Ecological toxicity: The ecological toxicity impact measures the potential of a chemical released into the environment to harm terrestrial and aquatic ecosystems.

Eutrophication potential: Eutrophication is the addition of large quantities of mineral nutrients, such as nitrogen and phosphorous, to water and the surrounding soil. These nutrients can cause rapid plant growth in water, such as algae blooms, which makes oxygen levels in the water plummet, and in turn, suffocates fish and other aquatic species. Eutrophication can significantly reduce bio-diversity in a body of water.

Fossil fuel depletion: This impact addresses only the resource depletion from extraction. It does not measure the potentially enormous impacts of the extraction, such as oil spills. This category helps demonstrate positive environmental goals, such as reducing the energy needed to produce a product or producing a product with renewable, non-fossil-based energy.

Global warming potential: This characterizes the change in the greenhouse effect due to emissions and absorptions attributable to humans.

Ozone depletion potential: Emissions from some processes may result in the thinning of the ozone layer, which protects the Earth from certain parts of the solar radiation spectrum.

Smog formation potential: Under certain climatic conditions, air emissions from industry and fossil-fueled transportation can be trapped at ground level, where they react with sunlight to produce photochemical smog. Certain regions of the world are climatically more susceptible to smog.

Water use: Water resource depletion has not been routinely assessed in LCAs to date, but researchers are beginning to address this issue to account for areas where water is scarce, such as the western United States.

Green Schools, Health, and Productivity

Factoring in all the issues to develop a green school is demanding. As a team, the planners, architects, engineers, constructors, and commissioning and life-cycle assessment professionals have their hands full weighing all of the site, design, specification, construction, and operations options that will deliver a green building. Much of their decision making, though, is based on what the elected and appointed officials, school administrators, teachers, students, parents, and involved community members want in their school facility. As outlined earlier in the report, it can be described in a fairly straightforward programmatic direction: the school should support education by providing healthy and productive learning environments while making the most of limited resources. As the body of research shows, those strides forward are facilitated by introducing good indoor-air quality, pest control, lighting, acoustics, thermal comfort, and personal security into our school systems.

Indoor-Air Quality. A particularly important part of creating good indoor environmental quality is having good indoor air quality. (Dougan and Damiano, 2003) This means acceptable levels of airborne contaminants, such as volatile organic compounds (VOCs), carbon dioxide (CO_2), and other pollutants, notably pathogens and allergens, including viruses, microbes, mold, and dander. The first line of defense against pollutants is to eliminate or contain their sources inside the school building: such as wet areas, VOC-emitting building materials, and some cleansing agents. Even occupants' presence in the school will build up CO_2, moisture, dirt, lint, and dander if areas are not ventilated and properly maintained.

Water infiltration—via leaks, condensation, vapor infiltration, and sometimes the poor construction practice of not keeping building materials dry—is a major source of occupant discomfort. Although preventable through proper siting, design detailing, care during construction, and diligent maintenance, water is always trying to find a way inside buildings and, if it does, it invariably leads to damage. Not only does water degrade building elements, it provides a growth medium for mold and other micro-organisms—typically hidden behind walls, under finishes, and in air ducts and other mechanical equipment. Moisture is especially problematic in air-handling drain pans, conduits, and vents, which harbor micro-organism growth and distribute the resulting allergens and pathogens throughout the building.

The resultant danger for occupants is generally known as sick building syndrome. It manifests itself as a number of ailments; chief among them, asthma. More than 10 percent of children in the U.S. suffer from some level of asthma, the leading cause of student absenteeism. Research found an average of 3.4 days of asthma-related absence per person in 1994-1996. (Cox-Ganser, et al., 2005) If translated to the 2007-2008 U.S. student population, that would equate to 183.6 million days of absence total. That does not take into consideration that persons with asthma or other sensitivities who are in school may experience reduced performance in their presence of environmental factors that trigger their asthma. (Dougan and Damiano, 2003)

A Carnegie Mellon building performance program identified 17 substantial studies that document the relationship between improved air quality and health. The health impacts include asthma, flu, sick building syndrome, respiratory problems, and headaches. These 17 separate studies all found positive health impacts (i.e. reduction in reported prevalence of symptoms) ranging from 13.5 percent up to 87 percent improvement, with an average improvement of 41 percent. (Kats, 2006)

Lawrence Berkeley National Laboratory conducted a meta-analysis that suggests that building dampness and mold are associated with increases of 30 to 50 percent in respiratory and asthma related health outcomes. (Fisk et al., 2007) In an average-sized new school of 900 students, even 20 fewer children a year with asthma would result in an associated annual cost savings of $33,000. (Kats, 2006)

Mold-related irritants in a Finnish school caused respiratory-related absenteeism nearly twice as high as a standard Finnish school. The respiratory infections stopped once the mold source was removed. (Koskinen et al., 1995)

Low-emitting materials. In addition to airborne pathogens, symptoms such as respiratory irritation, drowsiness, and nausea can result from volatile organic compounds (VOCs) in building finishes, other indoor-air pollutants, and irritant particles in the air, including some so small they stay airborne for days. The most effective means of maintaining clean air is to remove or contain the polluting sources and specify materials that emit low or no levels of VOCs. Of particular concern in this regard are: adhesives and sealants, paints and coatings, carpet systems, composite wood, and agrifiber products. Low or no-VOC options for the first three are widely available, fairly easy to obtain, and have only minimal additional cost if any. Low-emitting composite wood and agrifiber products, though, can be harder to obtain, as suitable products are less readily available. Prices for composite wood materials with no added urea-formaldehyde can vary widely, depending on the product selected and market conditions. Some states are considering banning building materials with added urea-formaldehyde, which should have a positive impact on costs. (Langdon, 2007) Formaldehyde measurements are already generally low in schools, below 0.05 ppm. Nonetheless, research suggests that even low levels may lead to an increased risk of sensitization to allergens. Furthermore, the U.S. Environmental Protection Agency has classified formaldehyde as a probable human carcinogen. Therefore, formaldehyde levels in schools should be kept very low. (Daisey et al., 2003)

Controlling the pollution potential of indoor chemicals is usually fairly easy to achieve with little added cost. In most cases, requirements for chemical mixing areas and other spaces where potential pollutants are routinely handled are already in the design. (Langdon, 2007)

Maintenance cleaning, however, is building-wide. The selection of maintenance products is very important, and considerations should include potential long-term effects for maintenance staff as well as other building occupants who spend a good portion of their day in classroom areas. Some findings about these products may be surprising. In California alone, cleaning supplies release 32 tons of contaminants into the air each day (Nazaroff, 2004). The Environmental Working Group tested 21 cleaning products and found they released 457 distinct air contaminants. One common disinfectant powder alone emitted 146 contaminants, the most of any products tested. On the other end of the spectrum, one certified green janitorial glass and general purpose cleaner emitted just one air contaminant. (EWG, 2009) Germicidal cleaners have gained in popularity, although for general cleaning, water and disinfectants appear to be as effective as germicidal treatments. In the higher-tech range, where there are no air-pollutant emissions, ultraviolet germicidal radiation may be effective in keeping air ducts and other hard-to-access areas free of pathogens, although the possible detrimental effects of ultraviolet light radiation have not been thoroughly determined. No-touch doors, faucets, and toilets offer further no-emission options to supplement surface cleaning. (NRC, 2006)

Carbon Dioxide (CO_2) levels. There is a correlation among high CO_2 concentrations and unpleasant odors and symptoms such as headaches, dizziness, feeling heavy headed and tired, and having difficulty concentrating. Those health symptoms occupants characterized as "irritations of the upper airways" were also higher at higher CO_2 concentrations. (Daisey et al., 2003)

The concentrations of CO_2 found in most schools and offices are usually well below the 5,000 ppm occupational safety standard for a 40-hour industrial workweek. However, because ASHRAE ascertained that children experience unpleasant symptoms at these levels, it has recommended indoor CO_2 concentrations be maintained at or below 1,000 ppm in schools. (WSU)

Carbon dioxide levels tend to elevate during building habitation, which can be harmful to building occupants. Because the occupants of a building are a major source for CO_2, it is impractical to remove the source as a remediation method. Ventilation is the effective alternative. Studies have shown, though, that classroom ventilation rates are often below the minimum rates specified in codes, which result in elevated CO_2 levels. Moreover, a 1,000 ppm increase in the difference between indoor and outdoor CO_2 concentrations has been associated with 10 to 20 percent relative increases in student absenteeism. (Shendell, et al., 2004) CO_2 monitors that activate ventilation systems automatically determine that ventilation is required, which menas that the ventilators will not run unnecessarily when the building is not occupied. When the facility is not occupied, such as during the summer, monitor-activated systems turn down ventilation rates and control excessive heating/cooling loads. (NRC, 2006)

Ventilation. Ideally, classrooms should be provided with a minimum of 13-15 cubic feet per minute (cfm) of outside air per person. (ASHRAE 62.1-2004) Ventilation rates at schools do not consistently meet this standard, however. (NRC, 2006) A study of 10-year-old children in which the average air temperatures were reduced from 23.6^{o}C (74.5^{o}F) to 20^{o}C (68^{o}F) and outdoor air supply rates were increased from 11 to 20.4 cfm per person for a week, found that school tasks, from reading to mathematics, improved measurably, indicating that increasing fresh air and decreasing temperatures slightly can substantially improve children's of schoolwork. (Wargocki et al., 2005)

Other key factors beyond ventilation rates include mechanical ventilation effectiveness (e.g., air flowing from top to bottom, which keeps the ventilating air cleaner than from baseboard up), filter efficiency, humidity, and maintenance (the last two being most important for controlling mold and other asthma-exacerbating conditions). (NRC, 2006)

Ventilation is also more effective if the diluting air supply is itself clean, which it isn't always. For example, ventilation ducts near loading docks or bus idling areas will bring combustion gases into the building. (USGBC, 2005) Moreover, in the United States, at least 20,000 schools are within a half-mile of a major industrial plant that emits potentially dangerous chemicals. (USA Today, 2010)

To keep water, dirt, and pollutants outside from being brought inside, source control is the most effective means. Drain grates at doorways will help keep mud, snow, and rainwater from getting tracked into a building. Entry grates carry minimal costs, unless the building has multiple entries. (Langdon, 2007)

Construction dust is also a concern during school renovations and before occupation of new schools. Control measures are best considered when negotiating services with the contractor. (U.S. EPA, 2010)

Humidity is also a factor. Mite and mite allergen levels fell 98 percent and 78 percent respectively when dehumidifiers together with air conditioning maintained relative humidity below an average of 46 percent. Effectiveness was negated when relative humidity was above 51 percent. (Arlian et al., 2001)

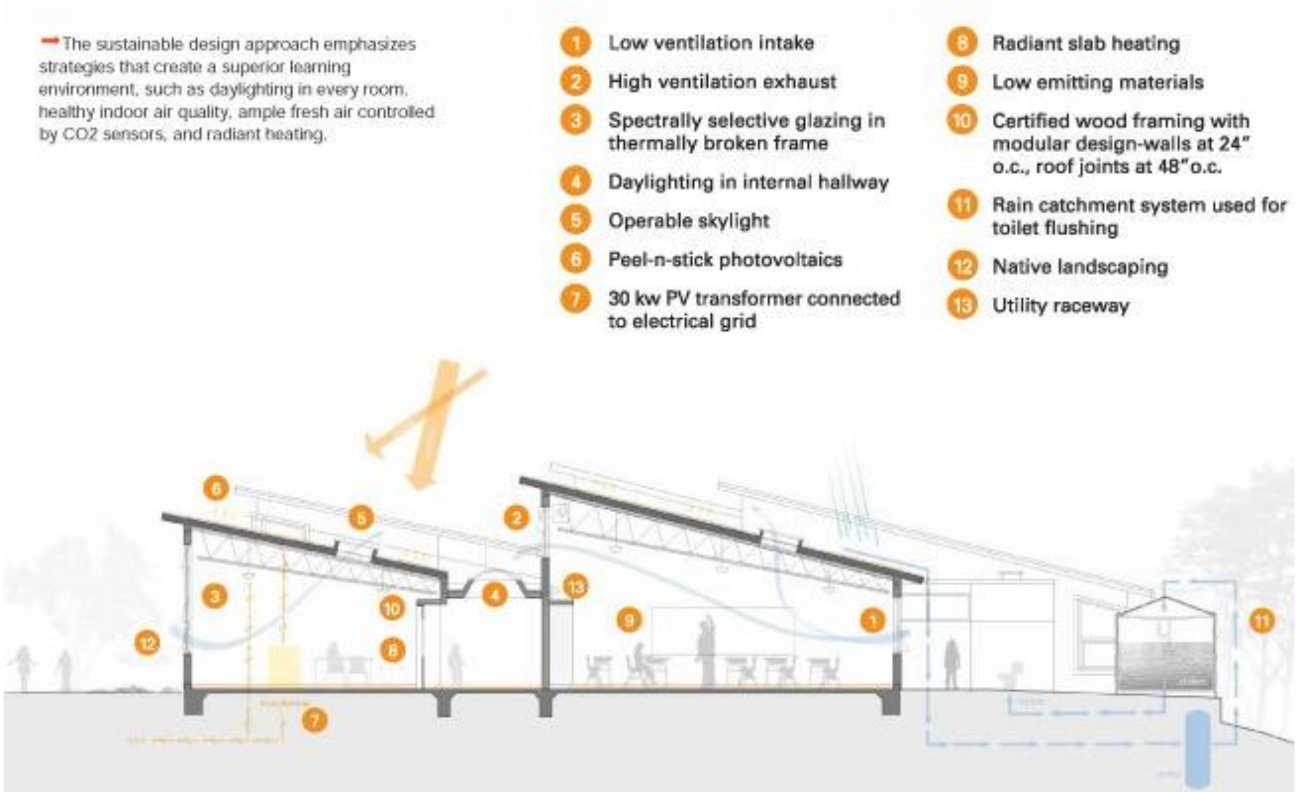
Although the least effective of air-cleaning tactics is filtration (behind source removal and ventilation), it is useful for clearing the air of dust and dander particles if filters fit snugly and are changed regularly. The use of MERV-13 filters, as called for in the LEED for schools Indoor Chemical and Pollutant Source Control credit, usually represents a minimal added cost, if any, since many projects already require this as good practice. In smaller projects with small or package systems, it may not be possible to add the filters. (Langdon, 2007)

Integrated Pest Management. Unfortunately, the school district and general use policies and specifications for sanitation and maintenance typically fall far short of even basic integrated pest management (IPM) measures. Simple adjustments, such as installing door sweeps at the base of exterior doors to prevent pest entry, can reduce pest complaints by up to 65 percent. Changes in the behavior of building maintenance staff and occupants, such as targeting eradication areas rather than generalized use of pest eradicators and strict control of food sources, are also important. Schools and other public buildings have been able to reduce pest complaints and pesticide use by 71 to 93 percent through IPM, with no long-term increase in costs. (Greene and Gouge, 2009)

Daylight and Access to Views. One study showed a direct statistical correlation between the amount of daylight in elementary school classrooms and the performance of students on standardized math and reading tests. Overall, elementary school students in classrooms with the most daylight showed a 21 percent improvement in learning rates compared to students in classrooms with the least daylight. These results, which have important implications for school design, affirm that daylight has a positive and highly significant association with improved student performance. (Heschong–Mahone Group, 2002)

To maximize daylighting without increasing glare or heat gain, design elements such as light shelves for daylight distribution and proper sizing and placement of windows will be necessary to allow for their orientation to the sun. Other considerations for windows are whether they allow in excess outside noise and whether they are operable or will have shades (both of which will require human or automated controls to accommodate outdoor conditions, such as rain, wind, and sun). Additionally, specifying efficient lighting fixtures to supplement available daylight will ensure maximum energy conservation. (NRC, 2006) Good views to the outside are also positive and highly significant to student performance. (Heschong–Mahone Group, 2003)

Another aspect to daylight is its effect on Circadian rhythm, which in turn affects sleep cycles, among other things. Studies have shown that people experience positive effects from strong, extended durations of short wavelength light in the blue range. (Brainard, G.C., et al., 2008) It appears that students need to see the sky in the morning; a recent study has shown that deprivation of that blue light will delay the sleep cycle at night, a condition termed teenage night-owl syndrome. (Figueiro and Rea, 2010) Thus, exposure to full-spectrum light appears to be very important to classroom wakefulness and sufficient nighttime sleep for students.



The Chartwell School in Seaside, CA, accommodates children in grades 1-8 who have learning challenges, such as dyslexia. The school, designed by EHDD Architecture, earned LEED new construction Platinum certification and received a 2010 AIA Committee on the Environment Top 10 award. Green features include extensive daylighting and photovoltaic panels, which make the building a net-zero energy consumer. CO_2 sensors, a passive ventilation design, and low-emitting interior materials provide ample fresh air. And a rain-collecting cistern provides water for irrigation and flushing, easing the load on the municipal potable water supply. Rendering by EHDD Architecture.

Acoustics. Acoustic problems affect children's academic performance for two reasons: noise is a distraction and it makes the children unable to understand the teacher because of inappropriate levels of signal-to-noise ratio, articulation loss of consonants, noise criteria rating, and reverberation. (Singer,M.J., 2003) This is particularly true for children already challenged by disabilities (U.S. Access Board, 2009) or who use English as their second language. (Nab˘elek and Donahue, 1984)

It has long been established that children chronically exposed to noise distractions, such as outside traffic, have lower reading scores than those who attend school and live in places with quieter surroundings. (Bronzaft, 2007) As mentioned earlier, background noise is particularly distracting for children under the ages of 13 to 15 because younger children have not yet developed their listening skills to be able to differentiate the spoken word from the background sound. (NRC, 2006)

The standard for acoustical performance in schools is ANSI/ASA S12.60. It lists three background noise sources: building systems, exterior sound transmission, and sound transmission from adjacent spaces (which includes noise from HVAC and plumbing systems and electrical and light fixtures). (ANSI, 2002)

Increased noise levels also affect teachers who must speak more loudly to be heard and understood above the background noise sources. A fifth of teachers report having missed work because of voice strain. (Smith, et al., 1998)

Thermal Comfort. When performing school work in a temperature range from 62^o to 92^o F, students demonstrated that school environments can be too cold or too hot for optimal performance with regard to error rates and speed of work. The error rate was highest at 62°F and lowest, by about 20 percent, at 80°F. Students worked most slowly at 80°F, however, and fastest, by about 10 percent, at 68 °F. The children's reading speed, reading comprehension, and multiplication performance was poorer when temperatures ranged from 81 to 86°F than at 68°F. In one study, the decrease in reading speed and comprehension at 81°F, compared to 68°F, was as much as 30 percent. (Lawrence Berkeley Labs, 2009)

Certain temperatures (not varying due to convection more than 3°F from the floor to five feet high) were better for different grades. Kindergarten and primary-grade students were most healthful and comfortable when the air temperature was 65° to 68°F, and older students were better at 68°F. The relative humidity in a space for learning also strongly influences student comfort. Students reported finding 72°F and 60 percent relative humidity quite acceptable. As air temperatures rises, however, the relative humidity should decrease to maintain comfort. (Castaldi, 2004)

Security. A planning and design concern from the outset, building security is an often overlooked health and productivity element of green school design. An authoritarian presence is often the opposite of an effective security strategy. Security shoe-horned into place as a last-minute program requirement is typically expensive and obtrusive. (O'Neill, et al., 2009) In terms of green design, a security strategy needs to extend beyond metal detectors and police on school campuses. In fact, students will recognize that green design is a show of respect for their best interests and dignity. (Ofer, et al., 2009)

A green design that considers security up front begins with a threat-based risk assessment. It balances security and sustainability by considering new technologies and systems. The goal is to integrate these systems through all building elements, such as outdoor and indoor lighting; heating, ventilation, and air conditioning systems; the exterior envelope; monitoring systems; and landscaping. Further, for large projects, it may be possible when ordering security systems to request pre-fabrication of security components to reduce packing materials, which, in turn may earn LEED Materials and Resources credits and reduce on-site installation costs. (O'Neill, et al., 2009)

Joint Community Use of Schools

Joint-use schools create partnerships with a wide variety of community activities. Examples include non-school-hour use of libraries, assembly spaces, and grounds for adult education, park space, health clinics, youth programs, and farmers' markets. Getting these initiatives from concept to reality requires close cross-community involvement and buy-in during the planning process, possibly including acceptance of creative financing approaches involving institutional partners. The environmentally beneficial potential is itself wide-ranging, from maximizing the use of school sites and their educational and recreational infrastructure to reducing urban sprawl by attracting more people to live and raise families closer to the core of a city or town. Reducing sprawl reduces the environmental impacts of traffic through transit-oriented, pedestrian-friendly development. Community-centered schools allow people to engage in their community as a community. (NSBN, 2006)

Green School as Teaching Tools

Using the green school itself as a teaching tool allows students to see up close, and in real life, how sustainable planning, design, and construction work together.

In LEED for schools (USGBC, 2009), a school can earn credit toward certification in the Innovation in Design category by integrating the sustainable features of a school facility with the school's educational mission. The LEED category requires the school to design a curriculum based on the high-performance features of the building and commit to implementing the curriculum within 10 months of LEED certification. Beyond simply describing the sustainable features of the school, the curriculum must explore the relationship among human ecology, natural ecology, and the building; meet local or state curriculum standards; be approved by school administrators; and provide 10 or more hours of classroom instruction per year, per full-time student.

The USGBC also recommends that project teams coordinate closely with school administration and faculty, where possible, to encourage ongoing relationships between high-performance features of the school and the students. Such ongoing engagement between the school and sustainability professionals enhances the development of an educational program that integrates the school building with the ongoing curriculum in the school.

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Related Resources

Advanced Energy Design Guide for K-12 School Buildings. A free download for personal use of this report on achieving 30 percent energy savings using off-the-shelf technology is available from the American Society of Heating, Refrigerating, and Air Conditioning Engineers. http://www.ashrae.org/publications/page/1604

Collaborative for High Performance Schools. Best practices for achieving high-performance planning, design, construction, and operations of schools. http://www.chps.net/dev/Drupal/node

Energy Information Administration provides a collection of energy education resources. http://www.eia.doe.gov/kids/energy.cfm?page=kiddie_resources

EPA Life Cycle Assessment: Principles and Practice provides an introductory overview of Life Cycle Assessment (LCA) and describes the general uses and major components of LCA. http://www.epa.gov/nrmrl/lcaccess/lca101.html

Green Buildings Initiative. Information on the Green Globes rating system. http://www.thegbi.org

Green Existing Buildings Toolkit. http://www.usgbc.org/DisplayPage.aspx?CMSPageID=2114

The Third Teacher, building facilities as teaching sources. http://www.thethirdteacher.com

U.S. Green Building Council. Green School Buildings http://www.greenschoolbuildings.org

Whole Building Design Guide. Integrated planning, design, and construction through a holistic team approach is the focus of this high-performance building program. http://www.wbdg.org/index.php

Additional NCEF Resources

NCEF Green Schools webpage at NCEF website, http://www.ncef.org/green-schools

NCEF resource lists:

- *Case Studies—Green Schools and Universities* *http://www.ncef.org/rl/casestudies_HPS.cfm*
- *Daylighting School Facilities* *http://www.ncef.org/rl/daylighting.cfm*
- *Green Cleaning in Schools* *http://www.ncef.org/rl/green_cleaning.cfm*
- *Green Colleges and Universities* *http://www.ncef.org/rl/high_performanceHE.cfm*
- *Green Schools* *http://www.ncef.org/rl/high_performance.cfm*
- *Impact of Green Schools on Learning* *http://www.ncef.org/rl/green_schools_learning_impacts.cfm*
- *Indoor Air Quality in Schools* *http://www.ncef.org/rl/iaq.cfm*
- *LEED Certification for Schools* *http://www.ncef.org/rl/LEED.cfm*
- *Life Cycle Cost Estimating for School Facilities* *http://www.ncef.org/rl/lifecycle.cfm*
- *School Building Commissioning* *http://www.ncef.org/rl/commissioning.cfm*
- *School Energy Savings* *http://www.ncef.org/rl/energy.cfm*
- *Thermal Comfort in Schools* *http://www.ncef.org/rl/thermal_comfort.cfm*
- *Water Conservation in Schools* *http://www.ncef.org/rl/water.cfm*

The Mount Taber Middle School Rain Garden in Portland, OR, designed by Kevin Robert Perry, ASLA, has become a part of the environmental education curriculum for middle school and high school students in Portland. The project converted a portion of the existing school's parking lot into a cooling green zone adjacent to the school building. Rain water from the school's roof collects in the garden, turning the heat-sink hard-surface parking lot into catchment to control runoff and teach students the benefits of sustainable water management. The rain garden received a 2007 General Design Honor Award from the American Society of Landscape Architects. Photo by Kevin Robert Perry courtesy of the ASLA.