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Green Classroom Retrofit Toolbox (GCRT):

Evidence-Based Design Guidelines to Adapt K-12 School Facilities for Climate Change

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Abstract

Existing classrooms and educational spaces are problematic. They consume 30% of the nation's electricity, generate 35% of our waste, use 8% of water resources and are responsible for 20% of green house gas (GHC) and carbon dioxide emissions. While, the new construction sector of the building industry has benefited from products and green building strategies to produce high performance sustainable schools, existing classrooms, however, have been largely ignored. This problem is magnified due to the large amount of occupied classroom space in the US, which exceeds 20 billion square foot (this figure also includes labs, lecture halls, and meeting spaces). These existing educational spaces, generally a product of the past 30-50 years, are energy and environmentally unconscious. Since many of the new building products and sustainable technologies are not applicable to existing classrooms retrofits, this research project intends to target this problem through the development and implementation of the Green Classroom Toolbox (GCRT) comprehensive project.

This paper provides a synopsis of the methods and scope of the findings from the Green Classroom Toolbox (GCRT) project and provides a roadmap for its future application and replication. The goals and objectives of this project are to develop green design guidelines for retrofitting existing educational spaces that are based on carbon neutrality metrics and student achievements outcomes. The basis of these guidelines is the analysis of data from a multi-disciplinary pilot research project that we have recently completed in addition to an extensive meta-analysis of prior studies and energy modeling simulations. One of the significant targets of this project is to link green retrofit best practices with their energy and carbon emission reductions as well as their impact on human health and student achievements.

The guidelines developed were centered on extensive evaluation of best practices that:

- Increase the productivity, comfort, and health of students in retrofitted classrooms;
- Facilitate integrated design and cooperation between designers;
- Reduce environmental impacts and move us towards carbon neutrality environments in schools, and
- Have a potential to be a model for future replication and dissemination.

1. An Overview of Existing Classroom Environments

Every day, 55 million students attend schools and classrooms. The American Society of Civil Engineers reported that our aging educational buildings are in worse condition than any other infrastructure, including prisons. EPA estimates that 40 percent of our nation's 115,000 schools and universities suffer from poor environmental conditions that may compromise health, safety, and learning of more than 14 million students (USGBC, 2008). These conditions—which include asbestos, lead, radon, pesticides, cleaning agents, building materials, molds, leaking roofs, underground fuel tanks, poor heating and ventilation systems, inadequate lighting, and failing plumbing—contribute to a host of health concerns for both students and personnel. Problems are compounded by density. In addition, educational facilities have four times the number of occupants per square foot than most offices.

A recent and rapidly growing trend is to design green schools with the specific intent of providing healthy, comfortable and productive learning environments (Figure 1). While, the new schools construction of the building industry has benefited from products and green building strategies to produce high performance sustainable schools, existing classrooms, however, have been largely ignored. This problem is magnified due to the large amount of occupied classroom space in the US, which exceeds 20 billion square foot (this figure also includes labs, lecture halls, and meeting spaces). These existing educational spaces, generally a product of the past 30-50 years, are energy and environmentally unconscious. Since many of the new building products and sustainable technologies are not applicable to existing classrooms retrofits, this research project intends to target this problem through the development and implementation of the Green Classroom Retrofit Toolbox (GCRT) comprehensive project. The significance of this study lies in its attempts to quantify the impact of green school retrofits on the triple bottom line of people, planet, and profit. This will provide huge benefits to school districts and an excellent financial return to tax payers due to the fact that more than 46% of all future schools' construction is either planned additions (27%) or retrofits (19%) (Figure 2).

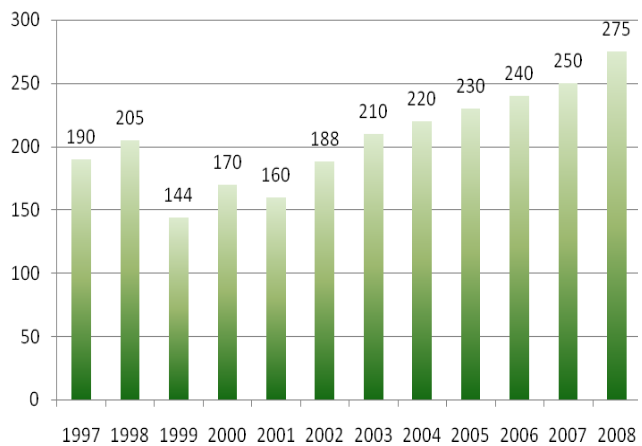


Figure 1: Education construction (million SF)
(source: McGraw-Hill Construction & Analytics 2006)

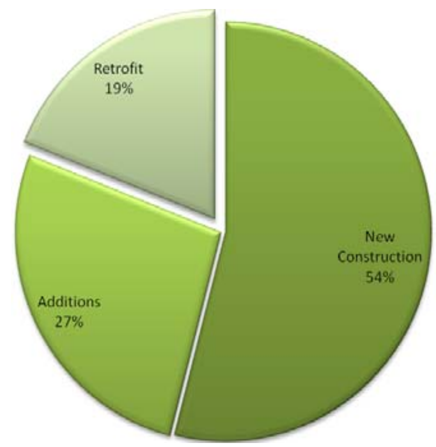


Figure 2: Schools project types by value
(source: McGraw-Hill Construction, 2006)

Currently, there is a great opportunity to impact the construction boom in schools and educational buildings. Building high performance schools is reported to be the fastest growing sector of the building industry (McGraw-Hill, 2007). It is projected that this sector of the building industry will grow in construction by 65% in the coming five years (Figure 3) and is expected to capture 27.4% of the construction value (Figure 4) toping the construction market by both value and number of projects. Although green schools provide a range of benefits as stated above, there is a current gap in information regarding their energy and CO_2 performance as well as their impact on sick days, reduced operations and maintenance, life cost, reduced insured and uninsured risks, improved power quality and reliability, increased state competitiveness, reduced social inequity, and educational enrichment (National Research Council, 2007). The lack of quantifiable information and evidence-base design guideline for this building sector could lead to a devastating missed opportunity in directing that building momentum the right way.

With this momentum in building green schools there is a parallel effort to retrofit ailing conventional ones and greening their facilities (McGraw-Hill, 2007). Conventional schools are typically designed to comply with building and energy codes only. To meet minimum code performance, these schools delivers classroom environments that are not designed specifically to provide comfortable, productive, and healthy work places for students and faculty. Based on a national review of 30 green schools a study by Capital E (Kats, 2006) reported green schools cost less than 2% more than conventional schools - or about \$3 per square foot (\$3/ft2) - but provide financial benefits that are 20 times as large. He also pointed out to a lack of documented studies that evaluate relative and comparative scenarios for green retrofitting existing schools in a cost-effective way to enhance student learning, reduce health and operational costs and, ultimately, increase school quality and competitiveness. This research problem and gap in the existing literature acted as the main driver for the Green Classroom Retrofit Toolbox (GCRT) research project. For this project we have focused our research on classrooms green retrofit scenarios and their impact on the triple bottom line of planet, people, and profit (3P).

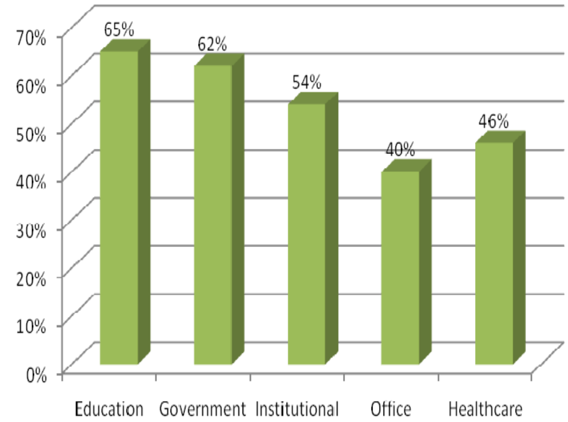


Figure 3: Top five sectors expected to have growth in green construction (source: Green Buildings Smart Market Report, Mc-Graw-Hill Construction, 2005)

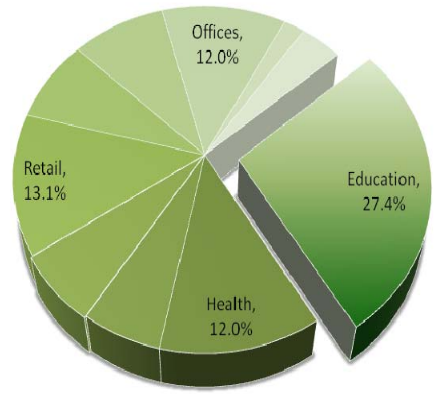


Figure 4: Commercial construction activity by value (source: McGraw-Hill Construction & Analytics, 2006)

2. An Action Research Approach to Green Classroom Retrofits

There is a current application gap in incorporating research findings of green buildings performance and their impact on occupants in the early design stages of projects in general and green schools retrofits, in particular (Elzeyadi, 2008). This problem is magnified in school environments as most previous research has resulted in inconclusive evidence leading to speculative relationships between sustainable strategies and students' behavior (National Research Council, 2007). This knowledge gap is due to three main reasons: First, previous studies that focused on green buildings tended to favor a case study approach that lacked external validity beyond the case in question or the context of the findings. Second, studies that focused on broader strategies studying larger populations--such as relationships between daylighting availability and student test scores in schools--used a survey epidemiological approach with week internal validity and did not investigate certain design strategy such as a specific toplighting system design. These studies could not confirm a relationship between specific design elements and targeted outcomes of neither the school building nor students' performance. Third and perhaps the most important gap in knowledge is the failure of both approaches to provide actionable items and evidence-based green performance strategies that designers could directly incorporate in future buildings design and retrofit scenarios.

To overcome the limitations cited in previous work, this interdisciplinary research project targeted this problem through the development of actionable green classroom retrofit tools. As reported by Ahrentzen (2006) the design and buildings professions have not established an agenda for organizing, disseminating, and advancing the state of knowledge of how good design is best employed to create long-term economic and social value. Typically, examples of "best practices" provide little evidence of what makes them "best" or even establish the criteria for why they are being judged as "best." For this reason, we developed our tools and tested them based on a deductive approach. First, a check list of identified best practices of classroom and schools retrofits collected from focus groups of designers, facility managers, and school principles was established. Second, the list of best practices was systematically evaluated using a triple bottom line scenario. The practices were tested for their energy and carbon effects as well as their impact on occupants' health and well-being.

2.1 Conceptualizing the Green Classroom Toolbox (GCRT)

This project conceptualized the school environment from a place-based experience perspective. This conceptualization (Figure 5) relies on the general assumption that any environment is composed of "people" and "buildings" on the macro-scale as well as "buildings" and the overall "environment" on the mega-scale (Elzeyadi, 2003). It is important to acknowledge that "people" in a school setting is composed of students, faculty, and staff. However, we are mainly focusing our investigation on the student portion of schools' population in the study's conceptual framework (Figure 5). This framework grows out of a perspective that treats students and their school environments as interdependent elements of a system. This systems epistemology rests on the idea that the environment is an organic structure; it has parts that are connected to each other by complex interactions in a way that smaller parts of the system can be identified; the components can be dissected into sub-systems of independent variables (sub-systems), mediational variables (mechanisms), and outcomes (products).

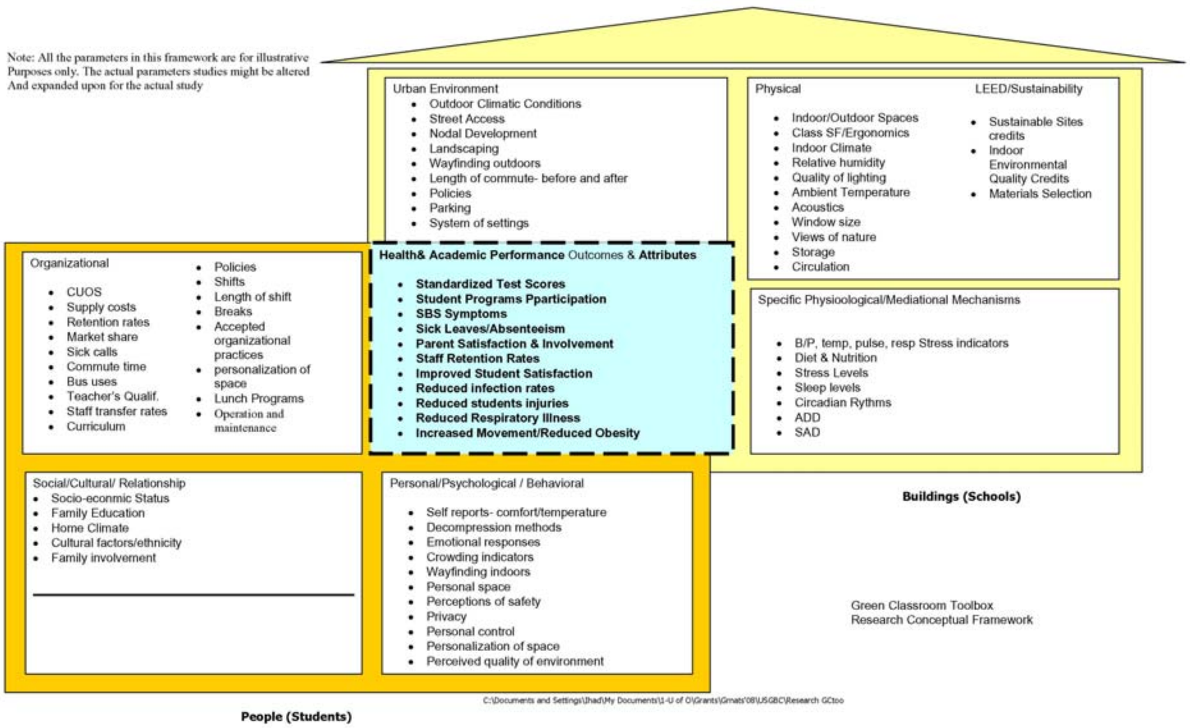


Figure 5: GCRT Conceptual framework
(based on an unpublished literature review see Elzeyadi, 2008)

2.2 GCRT Objectives and the Triple Bottom Line

The following goals and objectives guided the tasks of the GCRT project:

- The tools developed should analyze the impact of separate green retrofit strategies while acknowledging a greater interrelationship between these strategies on the building and its occupants' performance.
- Identify not only design retrofit strategies and best practices but also operations and maintenance ones that have been typically neglected in previous design guidelines (National Research Council, 2007).
- Provide evidence-based tools that have clearly specified attributes and practices.
- Classify the researched best practices and strategies based on categories that are relevant to building professionals. These are: (1) Energy & Atmosphere (Envelope, Lighting, HVAC, and Ventilation), (2) Materials & Resources (Site construction, Structural, non-structural), (3) Environmental Quality (IAQ, Comfort, and Acoustics), (4) Sustainable Sites (Density, Light Pollution, and Transportation), and (5) Water & Waste (Building fixtures, Landscaping, Recycling).

3. GCRT Process and Phases

To generate a comprehensive evidence based design guidelines for green classrooms retrofits, we have conducted the following tasks:

1. Survey and classification of existing classrooms types and typologies,
2. Focus groups with school buildings designers, operators, principles, and contractors to generate a check list of best practices of green retrofit scenarios and products for classrooms.

3. An energy and carbon performance simulation analysis of the best practices identified previously for a prototypical K-12 school. This analysis simulated energy and carbon performance of each suggested best practice of green retrofit as compared to a base case of a proto-typical school building in the pacific northwest region of the US.
4. Meta-analysis of previous studies linking the identified green design strategies to students' health and performance outcomes.

3.1 Methods and Approach

This project was planned in three phases. The first phase researched and identified classroom retrofits Best Practices (BP) based on a survey of opinions from schools' principles, building designers, and facility managers. The second phase used an experimental design approach to test the energy and carbon emissions performance of each retrofit BP strategy identified in the first phase using computer simulation and energy modeling software. The third phase analyzed BP based on their impact on occupants' performance relying on meta analysis of previous studies and literature reviews.

3.2 Project Phases and Tools

The following sub-sections explain the research procedure for each phase of the project.

3.2.1 Phase 1: Survey of Best Practices

A cross-sectional survey was designed to elicit responses from K-12 schools' owners and principles (O&P), architects and engineers (A/E), as well as facility managers (FM) on their views of best practices of classrooms green retrofit strategies. The survey participants were chosen to represent a sample of each of the groups involved in decisions regarding schools and classroom energy and environmental upgrades. Data was collected using focus groups and interviews across building professions and different geographical locations. This enhanced our analysis of the various opinions by subgroups and helped in achieving stronger research triangulation. A total of 24 professionals participated in focus groups as well as phone and personal interviews. Each interview lasted approximately 20 minutes and included both open-ended and structured questions. Focus groups were 60 minutes in average. The stratified sample of respondents was theoretically weighted to include larger numbers of building designers since they represent the most diverse group. They included architects, energy/mechanical engineers, and lighting designers. Thus more emphasis was placed on the sample design to include a higher representation from this specific group. Building owners/principles was the second important category and it included equal number of respondents from those two groups (Table 1). Results from this phase of the research generated a check list of best practices for classroom retrofits and green remodel strategies identified in section (4) of this paper.

Location	A/E Designer	F. Man.	O & P	Total
Portland, OR	3	2	3	8
Salem, OR	2	1	2	5
Eugene, OR	6	2	3	11
Total	11	5	8	24

Table 1: Respondents & locations of focus groups survey participants

3.2.2 Phase 2: Experimental Simulation of Best Practices

Energy analysis computer simulation experiments were conducted for each best practice strategy identified in phase-1 of this project. These simulations were run using Integrated Environmental Solutions Virtual Environments™ (IESVE, see www.iesve.com) ApacheSim module. ApacheSim is a rigorous building thermal simulation approach that conforms to ANSI/ASHRAE Standard 140. The simulations were conducted on a two-storey prototypical elementary school building in Eugene, OR. The building is a U-shaped double corridor classroom facility with a gross area of 54,802.11 sq. ft. and a 25% glazing to outside wall ratio (Figure 6). For experimental purposes, all best practices were compared to a base case model using one geographic climate location of Eugene, OR with 44.12° North Latitude, 123.22° West Longitude and elevation of 357 ft. Each design retrofit strategy related to the building envelope or building performance that could be modeled using our analysis software was conducted. The energy simulations were based on a Sketch-up™ building model and were run via the "IESVE sustainability tool kit" plug-in modules (Figure 7). Each one of the identified best practices was run separately to compare its impact on the building energy use and carbon generation (CO_2) levels as proposed in the Architecture 2030 challenge (Mazria, 2006). In addition, a combined and optimized best practices model with most strategies combined was also modeled to provide an indicator of the mega impacts of the identified best practices on the total energy and CO_2 emissions performance of the building. The detailed energy and emissions analysis included: Energy consumption (MMBtu), Carbon emissions (lbCO2), 2030 Challenge Targets (kBTU/ ft^2), Thermal Comfort (%PPD limits), Peak HVAC loads (btu/h.ft^2), Ventilation rates (cfm), and daylighting analysis (avg. fc/h operation).

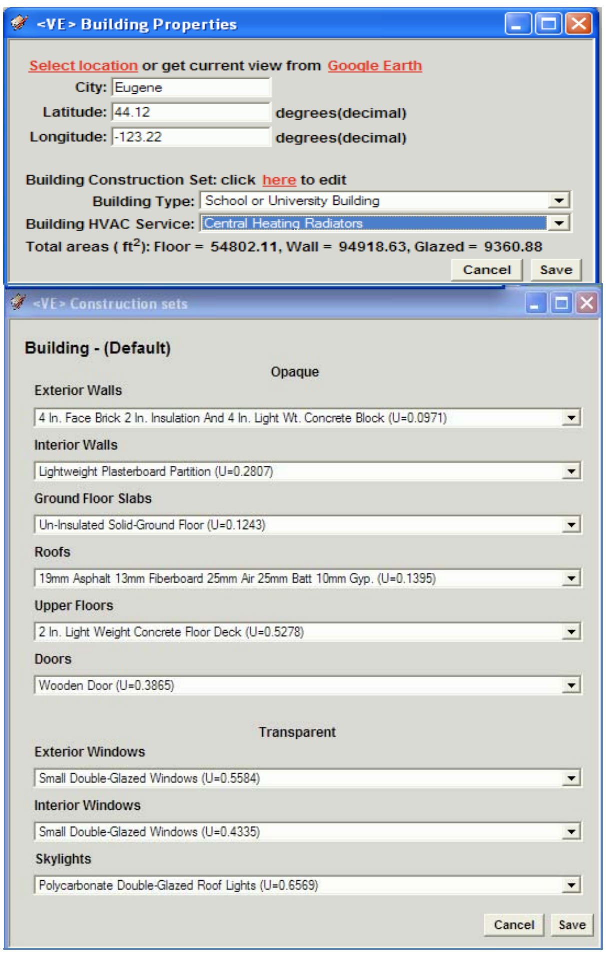


Figure 6: Building parameters and specifications for Energy & CO2 simulations using IESVE™ software

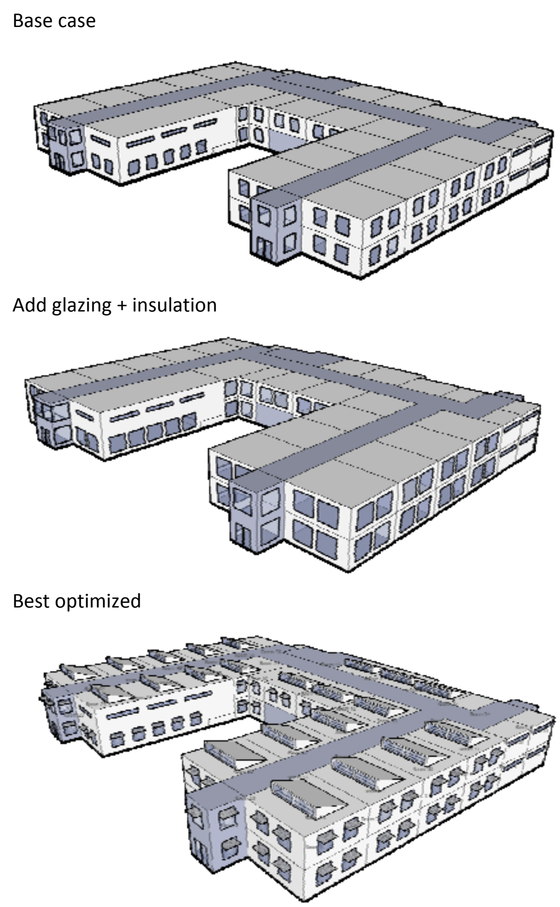


Figure 7: School building Sketch-up™ models prepared for IESVE™ simulations

3.2.3 Phase 3: Meta-Analysis of Health and Performance Impacts

According to the US General Accounting Office, almost two-thirds of schools in the US have building systems that are in need of extensive repair or replacement (Kats, 2006). Similarly, a published document by the American Federation of Teachers notes low IAQ levels below codes in nearly 15 thousand schools (Schneider, 2002). Despite the large body of research linking health and productivity issues with specific building design attributes, empirical studies looking at these issues in schools have been limited and failed to acknowledge linkages between specific design strategies and occupants outcomes . This limits the relevant data available to understand and quantify benefits of high performance, healthy design in schools in general and retrofits in particular. To overcome this limitation, we conducted a general meta-analysis of research studies linking green design strategies to tasks done by "employees" in offices and other work environments. These workers are generally involved in tasks such as reading comprehension, synthesis of information, writing, calculations, and communications, which are very similar to the work students do. We have reviewed 150 empirical studies that assessed indoor comfort and performance in office environments. This summary was combined with previous reviews done by Capital E (Kats, 2006) and Fisk (2000) to outline the potential impacts of green schools on occupants' health and productivity related to improvements in indoor air quality, temperature control, and lighting quality.

4. Anatomy of an Evidence-Based Green Classroom Retrofit Toolbox

The project goal was to develop a set of tools and evidence-based guidelines to help architects and schools designers as well as schools' principles make informed decisions for implementing green retrofit to their classrooms. To that end, we have developed three main decision support tools. The first is a check list of best practices compiled from focus groups and interviews of 24 school buildings designers, facility managers, as well as principles. The second tool was a prioritization guide that provides some comparative analysis and rankings to the best practices list based on their impact on building energy consumption and carbon emissions. The third tool is a meta-analysis guide that links these best practices to their impact on people health and performance in schools. These tools are intended to provide supporting documentation for the triple bottom line impacts of the green retrofits best practices on the planet (emissions), people (health and performance), and profit (energy savings). It is to be noted that the tools were analyzed and developed based on opinions, contexts, and climates of the Pacific Northwest and a specific middle school typology. We hope to replicate this study-- in the future--to other context and climates of the US as well as to develop a series of case studies of school retrofits that demonstrate the application of these guidelines.

4.1 Best Practices Survey

Responses regarding best green retrofit practices from a survey of different professionals were grouped into categories for analysis and compiled into a comprehensive check list (Figure 10). This list of best practices was generated from focus groups and interviews of 24 school building architects and engineers (A&E), facility managers (FM) , as well as school owners and principles (O&P) in the three largest cities in the state of Oregon, US. In addition to generating a comprehensive check list of experts' best practices, the survey intended to uncover the reasons and limitations of professionals to adopt such practices as well as to organize them in categories that are meaningful to designers and practical for future adoption. In average, 75 percent of the surveyed group identified "energy conservation" as the primary reason to adopt best practices with FM citing it as the most important reason (94%) followed by A&E (74%) and O&P (60%). Secondary reasons for implementing these practices were to provide "indoor environmental quality – IEQ" (68%) as well as to provide "connections to nature - Biophilia" (63%). The other three reasons reported in order were "Global warming – Environment" (45%), "Right thing to do" (28%), and "Recycling" (7%) respectively. A breakdown of the reasons by each group is displayed in Figure 8.

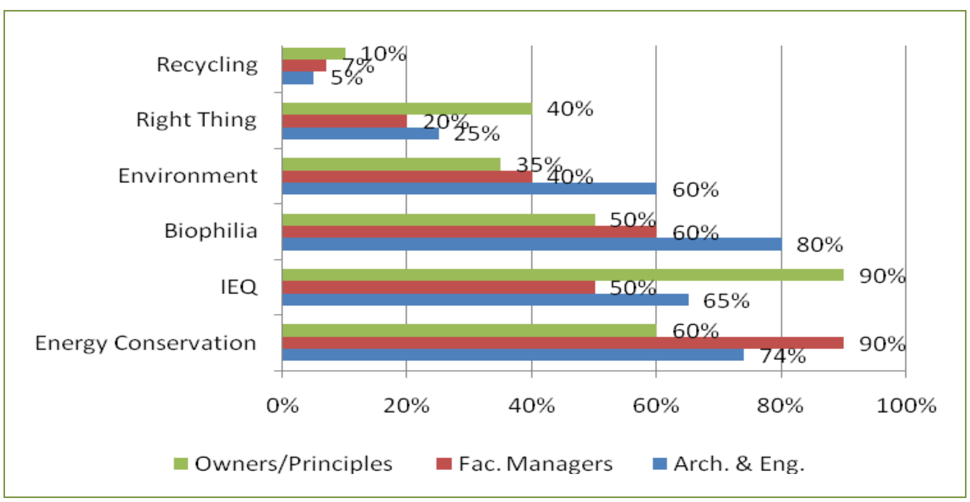


Figure 8: Reasons to adopt green classroom retrofits identified by different focus groups

Professionals form the users groups identified a total of 27 best practices related to “Energy and Atmosphere (EA).” The second largest identified best practices are grouped under the “Indoor Environmental Quality (IEQ)” category with a total of 12. The rest of the identified best practices consisted of seven practices under “Materials & Resources (MR),” three practices in “Outdoor Environmental Quality (OEQ),” two others in “Water & Waste (WW),” and two in the “Sustainable Sites (SS)” category. Given that these best practices were chosen due to their applicability for retrofits projects, it is not surprising to see fewer items in categories that pertain to site choices, orientation, outdoor conditions, and building form. This might be the reason that strategies in these categories were less identified by practitioners involved in the study (Figure 9). Figure 10 provides two sample pages from the compiled best practices reference check list.

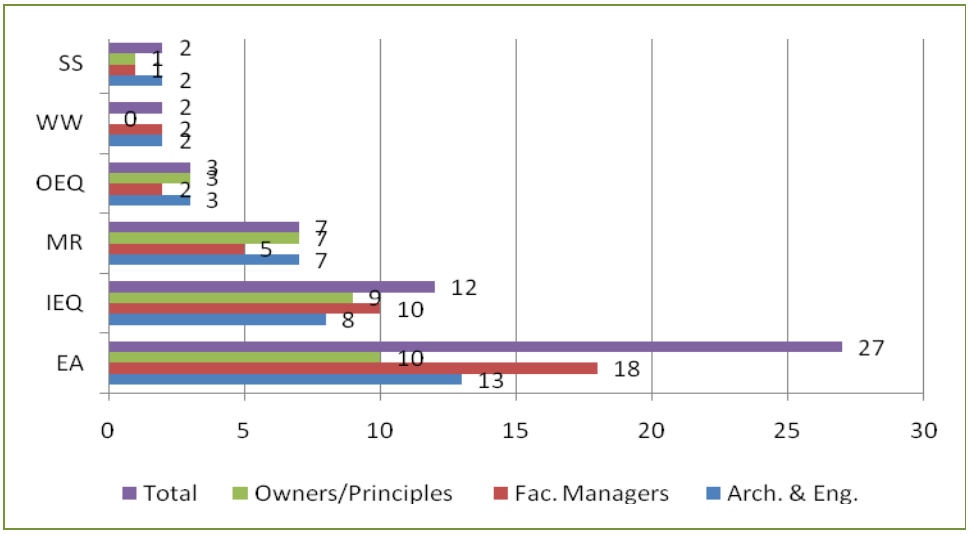


Figure 9: Number of best practices identified by different focus groups sorted by categories

BEST PRACTICES LIST

Energy & Atmosphere
Add DDC controls at existing utility service point for steam and chilled water.
√ new √ renovation _ remodel √ operations
Zone space uses to group functions with similar scheduling needs and to maximize advantages of orientation and daylighting.
√ new √ renovation √ remodel _ operations
Solar or on-demand hot water
In buildings with low hot water demand, install a solar water system or on-demand hot water devices, allowing building steam to be shut off entirely in warm weather.
√ new √ renovation _ remodel _ operations
Building envelope -
Orient new buildings north-south or other form that maximizes daylight potential.
√ new _ renovation _ remodel _ operations
Wall insulation
new √ renovation √ remodel _ operations
Improve ceiling/roof insulation in remodels of top floors, target R-40 assembly
new √ renovation √ remodel _ operations
Improve floor insulation, target R-20 assembly
new √ renovation √ remodel _ operations
Improve slab edge insulation, target R-7 x 24" continuous perimeter
new √ renovation √ remodel _ operations
Decrease infiltration and heat loss through windows: either replace or weather-strip sash
new √ renovation _ remodel _ operations
Reroofing projects: increase roof insulation to R30 or as much as possible. Use cool roof technology.
new √ renovation √ remodel _ operations
Reroofing projects: consider photovoltaic roofs where appropriate.
new √ renovation _ remodel _ operations
Add unheated vestibules at entrances.
√ new √ renovation _ remodel _ operations
Install propped door alarms if security systems are installed at entrances.
√ new √ renovation _ remodel _ operations
Ensure that all exterior glass has a purpose: light or view, and doesn't exceed 30% of wall area.
√ new √ renovation _ remodel _ operations
Prevent solar contact on south and west glass in cooling season.
√ new √ renovation _ remodel _ operations

Daylighting and windows - provide daylight to at least 75% of interior space and harvest it effectively.
√ new √ renovation _ remodel _ operations
Configure ceilings to maximize daylight penetration from windows into work space: preserve light penetration from highest part of windows. Target daylight factors for classrooms and offices = 2% to 5%.
√ new √ renovation √ remodel _ operations
Install interior windows where daylight can be brought through one room to the next.
√ new √ renovation √ remodel _ operations
Provide exterior shading of south and west glass, possibly east
√ new √ renovation _ remodel _ operations
Develop plan for effective harvesting of daylight through daylight controls of electric lighting.
√ new √ renovation √ remodel _ operations
Install light shelves where appropriate.
√ new √ renovation √ remodel _ operations
If awnings are to be replaced, consider photovoltaic panels for south facade awnings..
√ new √ renovation _ remodel _ operations
Consider top-lighting (4% to 6% of roof)
√ new √ renovation _ remodel _ operations

Efficient electric lighting - provide the right amount of light at the right place
Replace electric lighting if watt density exceeds 1.5 w/sf. Consider using a light source that lights ceiling and walls to create a psychologically brighter environment.
√ new √ renovation √ remodel _ operations
Design, locate, and control lighting to harvest daylight efficiently.
√ new √ renovation √ remodel _ operations
Install electric lighting controls
Occupancy sensor: use multiple contact sensors, vacancy-type.
Daylight sensor: If windows are present, install solar sensing switching in areas within 15 feet of exterior windows.
√ new √ renovation √ remodel _ operations
Consider a lighting strategy with low levels of ambient lighting plus task lights.
√ new √ renovation √ remodel _ operations

Use interior finish reflectances of 90% ceiling, 70% walls, 20% floors.
√ new √ renovation √ remodel _ operations
If light fixtures are not replaced, upgrade them to current UO standards for lamps (T-8) and ballasts (high efficiency electronic ballast)
√ new √ renovation √ remodel _ operations

Thermal Comfort & Ventilation -
Use demand control (CO2 sensors) for outside air in large spaces.
√ new √ renovation √ remodel _ operations
Oversize ducts to reduce static pressure, using less power and increasing equipment life.
√ new √ renovation √ remodel _ operations
Use premium-efficiency motors and direct drive fans for maximum electric efficiency.
√ new √ renovation √ remodel _ operations

Heat source - maximize energy efficiency
Implement heating systems that eliminate simultaneous heating and cooling of air before it is delivered.
√ new √ renovation _ remodel _ operations
Reuse waste heat from sources like server rooms.
√ new √ renovation _ remodel _ operations
Use heat exchangers on exhaust air to temper incoming air.
√ new √ renovation _ remodel _ operations

Appropriate cooling - consider cooling measures in this order, appropriate to the space use, in deciding whether mechanical cooling is needed:
1. Thermal envelope upgrades
2. Reduce interior loads (efficient devices, occupancy sensors)
3. *Shade exterior of windows with plants or shading devices
4. Maximize cooling with outside air (economizer) and night flush cooling
5. Provide air movement through paddle fans under local control
6. Provide mechanical cooling through chilled water radiant panels or through mini-split systems.
7. Install mechanical air conditioning: appropriate in areas with significant heat loads from equipment, laboratories, open office areas, ________. Try to avoid mechanical cooling in individual offices and in classrooms.

√ new √ renovation √ remodel _ operations

HVAC control
Zone exterior rooms separately from interior rooms.
√ new √ renovation √ remodel _ operations
Ensure that building services are under DDC control at the building entrance (steam, chilled water).
√ new √ renovation _ remodel √ operations
Provide public "Dashboard" showing performance.
√ new √ renovation _ remodel _ operations

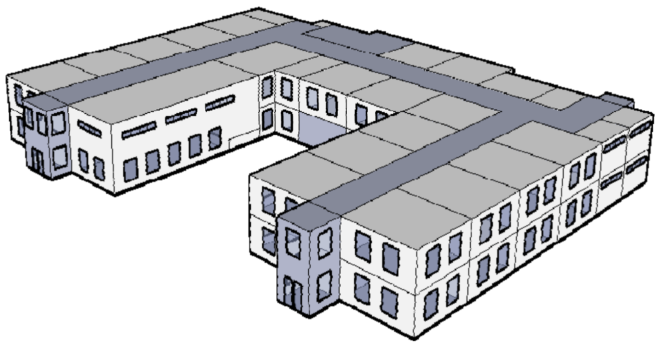
Materials & Resources
Construction waste
Recycle construction waste to achieve recycling rates of 75% to 95%.
√ new √ renovation √ remodel _ operations
Materials
- Less is more: preserve and reuse building fabric
  Using less material is more sustainable than adding layers of finish or replacing materials that are in excellent condition.
  √ new √ renovation √ remodel _ operations
- Maintenance matters:
  The environmental effects of maintenance needs to be considered along with initial environmental cost. Example: floor finishes that must be waxed annually will generate air pollution throughout their service life.
  √ new √ renovation √ remodel _ operations
- Durability matters:
  Materials that are very green but not durable are not sustainable. Conversely, investment in very durable materials can amortize an environmental (and financial) cost over many decades, increasing relative environmental performance to a high level.
  √ new √ renovation √ remodel _ operations
- Recycle content:
  Choose materials that have a high percentage content of recycled materials
  √ new √ renovation √ remodel _ operations
- Locally harvested or manufactured materials:
  Choose materials that are harvested/extracted or manufactured within 500 miles of Eugene whenever possible.
  √ new √ renovation √ remodel _ operations
- Avoid vinyls
  PVC and other vinyls cause environmental harm during the manufacturing process and should be avoided.:
  √ new √ renovation √ remodel √ operations

Floors
Floors receive a high percentage of maintenance effort, are replaced more frequently than other materials, and have a greater effect on indoor air quality. The following floor materials are acceptable, and a summary of their environmental attributes is listed:
Recommended:
Diamond-polished concrete - no added material; no waxing needed, long life?
Ceramic tile - very long life; no waxing needed
Carpet tile - spot-replacement possible, no VOCs during routine maintenance
Rubber (virgin, non-wax) - long life, no waxing needed

Figure 10: Sample check list of best practices identified from focus groups

4.2 Energy and CO2 Analysis of Best Practices

One of this project's objectives is to evalaute and analyze the best practices identified earlier for their impact on school buildings and classrooms energy conservation as well as carbon (CO_2) emissions as one of the main causes for climate change. For this task we conducted energy simulation analysis for each best practice strategy identified earlier. These simulations were conducted using IESVE™ ApacheSim module (www.iesve.com). The simulations were conducted on a prototypical two-storey elementary school building base case. The base case building is a U-shaped double corridor classroom facility with a gross area of 54,802.11 sq. ft. and a 25% glazing to outside wall ratio (Figure 11a). Similar to national trends of school buildings energy use (see McGraw-Hill, 2007), the current simulation model predicted the existing school base case would consume 46% of its total energy for space heating, 20% for water heating, 19% for Lighting, and 15% for cooling, and other equipment (Figure 11b).



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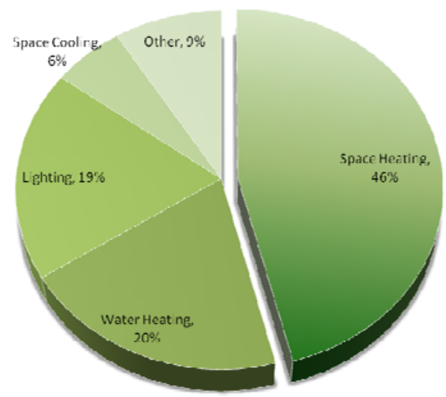

b

Figure 11: Breakdown of Energy use by building system category (based on base case school building simulations)

The total yearly energy consumbtion calculated for the simulations were converted to kwh/ft^2/year from kbtu/ft^2 /year to nomralize for the different sources of power supplied to the building. Figure 12 to Figure 14 compare the impact of different envelope best practices on the yearly total building energy consumbtion (kwh/ft^2), heating energy (kwh/ft^2), CO_2 emissions (lb/ft^2), and average daylight levels in foot candles (fc) for the classrooms schedule. Figure 12 shows ceiling insulation (R40) as well as cool roofs with radiant bariers to be one of the most effective strategies for reducing energy loads and carbon emissions with respect to the envelope insulation categories of the best practices check list. Figure 13 shows the strong impact of top lighting strategies such as roof montiors and modular skylights on energy and emissions reductions. The same figure also provide input that effective sidelighting lies in the range between 35%-45% wall to glazing ratio for this climate and specific building typology. Figure 14 provides analysis on thirteen of the enevelope and daylighting best practices upgrades compared to the base case school as well as an optimized best practices model with most green upgrades. The optimized best practices model is shown to redcuce energy consumption for the school by an average of 50% in lighting and heating energy and an associated 59% in carbon emissions reduction. This demonstrates that Architecture 2030 challenge to reduce our carbon emissions by 50% by the year 2030 (Mazria, 2006) is achievable with today's building technology and products.

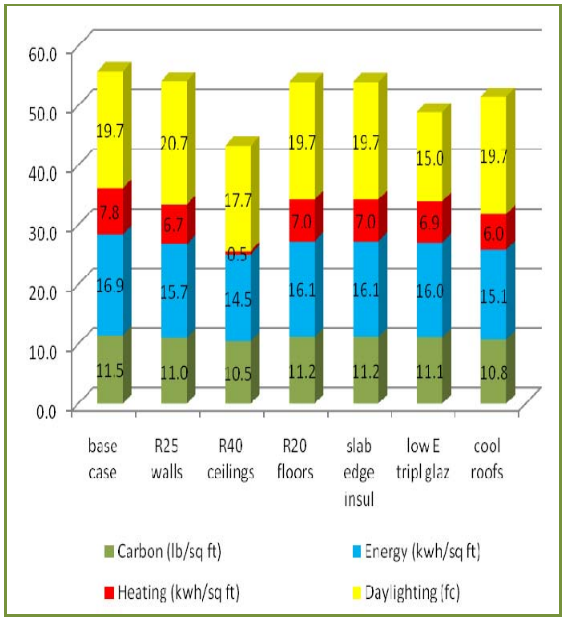

Figure 12: Energy and CO2 yearly emissions simulated by applying envelope insulation retrofits to base case school

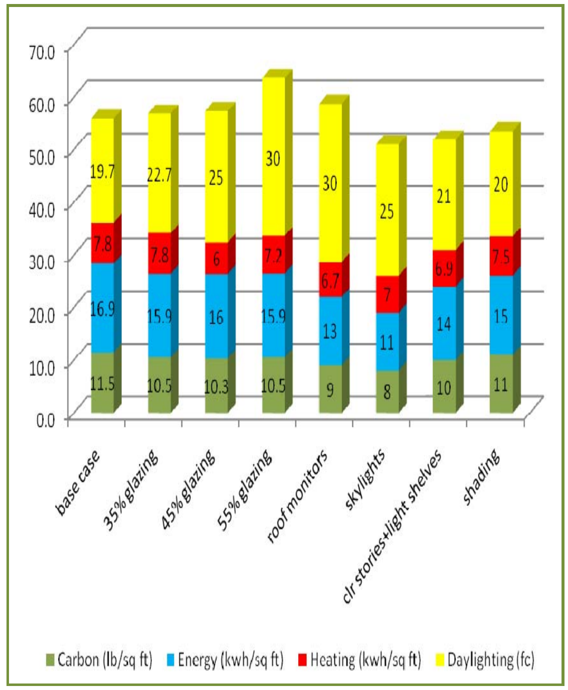

Figure 13: Energy and CO_2 yearly emissions simulated by applying daylighting retrofits to base case school

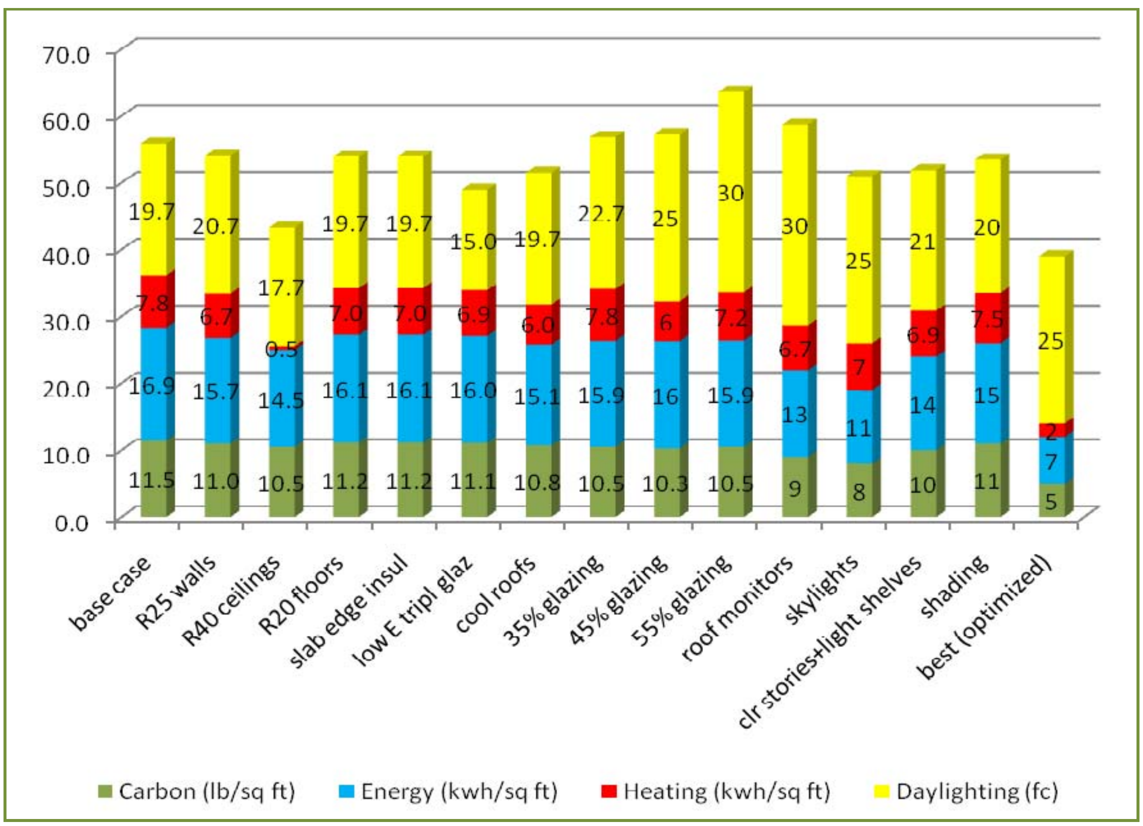

Figure 14: Energy and CO_2 yearly emissions simulated based on applying a sample of best practices to base case school

4.3 Occupants' Performance Related to Best Practices

Data used in the following analysis is partially based on a literature reviews published by Capital E (Kats, 2003 & 2006). The review is supported by research conducted at the Center for Building Performance at Carnegie Mellon University, Building Investment Decision Support (BIDS) program. The BIDS program reviewed over 1,500 studies that investigated the relationship between building systems, such as lighting, ventilation, and thermal control, on occupants' outcomes, such as productivity or health (Loftness et al., 2002). In addition, our analysis included data from a study conducted by William Fisk (2000) linking health and productivity gains of buildings to better indoor environments and energy efficiency (Figure 15). We have also conducted a separate meta-analysis of more than 150 specific studies linking indoor environmental quality and comfort issues to occupants' performance in green buildings (see Elzeyadi, 2002). For simplicity and generality, we grouped impacts related of health, productivity, task performance, and test scores under the general heading of "human performance." Summary from these reviews is classified below under Green Retrofits Related to: Indoor Air Quality, Temperature Control, and Day/Lighting Quality.

Source of Productivity Gain	Potential Annual Health Benefits	Potential U.S. Annual Savings or Productivity Gain (2002 dollars)
1) Reduced respiratory illness	16 to 37 million avoided cases of common cold or influenza	$7 - $16 billion
2) Reduced allergies and asthma	8% to 25% decrease in symptoms within 53 million allergy sufferers and 16 million asthmatics	$1 - $5 billion
3) Reduced sick building syndrome symptoms	20% to 50% reduction in SBS health symptoms experienced frequently at work by ~15 million workers	$10 - $35 billion
4) Sub-total		*$18 - $56 billion*
5) Improved worker performance from changes in thermal environment and lighting	Not applicable	$25 - $180 billion
6) Total		*$43 - $235 billion*

Figure 15: Potential health and productivity gains associated with green buildings (based on Fisk, 2000)
Citation: Kats, 2003 used with Greg Kats permission, December 2008

Green Retrofits Related To Indoor Air Quality Positively Impacts Occupants Performance by 5-20%
The BIDS program identified 17 substantial studies that documented the relationship between improved air quality and health. The health impacts include asthma, flu, sick leaves, sick building syndrome, respiratory problems, and building related illnesses. These 17 separate studies all found positive health impacts corelated with improved indoor air quality ranging from 13.5% up to 87% improvement, with average improvement of 41% (Figure 16). Two studies of over 11,000 workers in 107 European buildings analyzed the health effect of worker-controlled temperature and ventilation. These studies found reduced illness symptoms, reduced absenteeism in comparison to occupants whose work settings lacked these features (Heerwagen, 2002). A large number of school specific studies indicate a significant positive impact as well. A review of two studies evaluating the impact of improved indoor air quality on colds and flu in schools found an average reduction of 51% in those with improved air quality (Loftness, Hartkopf & Gurtekin, 2005). Another analysis of two school districts in Illinois found that student attendance rose by 5% after incorporating cost-effective indoor air quality improvements (Illinois Healthy Schools, 2003). In a similar study of Chicago and Washington, DC schools, better school facilities were correlated to four percentage points increase in students' standardized test scores (Schneider, 2002b). Although many of these studies did not isolate the specific impacts of practices--from the Best Practice check list we developed--on performance, the impact of the attributes studied is related to many of these practices, such as increased ventilation rates, natural ventilation, increased insulation, and HVAC pollutants control (Figure 16). Based on the above we can very conservatively associate better indoor quality of different best practices to a 5-20% improvement in occupants' performance.

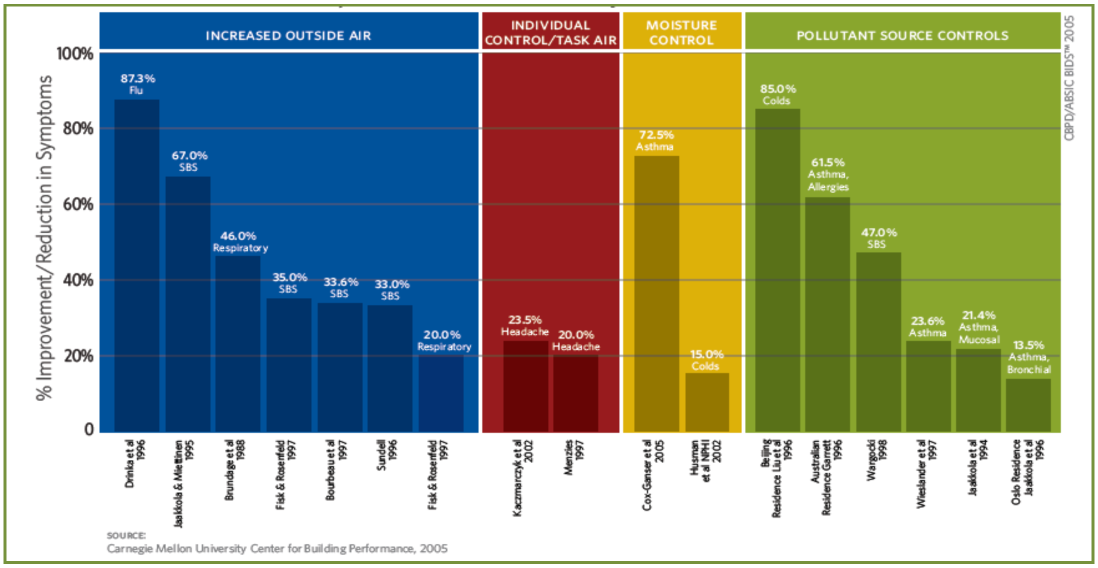

Figure 16: Health and productivity gains from better indoor air quality associated with green buildings

Citation: Kats, 2006 used with Greg Kats permission, December 2008

Green Retrofits Related To Temperature Control Positively Impacts Occupants Performance by 3-10%

The effects of indoor temperature control and thermal comfort on teachers and students satisfaction in classrooms are clear. In a large office phone survey conducted with key personnel from a range of best practices companies and schools in the USA, Ducker Worldwide (Ducker. 1999) found a high correlation between the indoor air temperature and occupant satisfaction. Teachers percieve a high correlation between thermal comfort and student comprehension of lessons (Elzeyadi, 2008). Research indicates that the best teachers emphasized that their ability to control temperature in classrooms is very important to student performance (Heschong, Elzeyadi & Knecht, 2001). Despite the domination of the typical American Society of Heating Refrigeration and Air conditioning Engineers (ASHRAE) variables--clothing levels, metabolism, air temperature, mean radiant temperature, relative humidity and air velocity-- in the design of the thermal environments in schools, other psychological factors associated with green classrooms have been shown to increase people's satisfaction with their thermal environment and produced sensational shifts in their thermal perception and productivity levels as well (Elzeyadi, 2002). These variables include personal control, purported temperature shifts, perceived room décor, window availability, pride and status. A review of 14 studies by Carnegie Mellon on the impact of improved temperature control on productivity (Figure 17) found a positive correlation between percieved and experienced control and productivity improvements up to 15%, and with an average (mean) of 3.6% (Loftness et al., 2005).

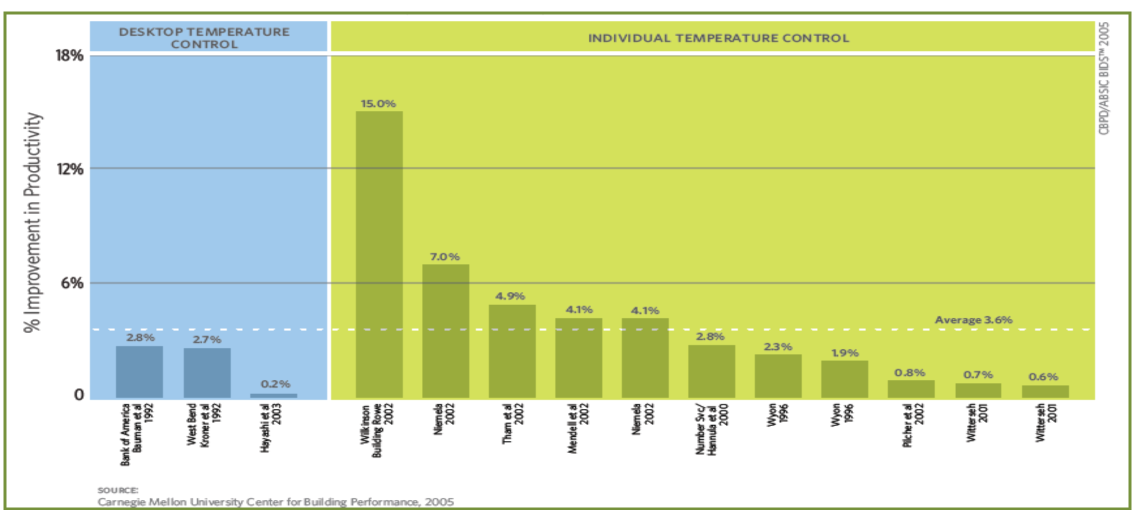

Figure 17: Health and productivity gains from better temperature control

Citation: Kats, 2006 used with Greg Kats permission, December 2008

Green Retrofits Related To Day/Lighting Quality Positively Impacts Occupants Performance by 5-20%
Green school design typically emphasizes providing views and ambient daylight for classrooms and educational facilties. These strategies have been associated with improvements in performance on standarized students tasks scores with an average of 10-20% (Heschong Mahone Group, 2000; Heschong, Elzeyadi & Knecht, 2001). In a study of 200 utility workers, those with the best views performed 10% -25% better on tests (Loftness, 2002). The consensus findings in a review of 17 studies from the mid 1930s to 1997 found that good lighting "improves test scores, reduces off-task behavior, and plays a significant role in the achievement of students." (Loftness et.al., 2005). Another synthesis of 53 generally more recent studies also found that better daylighting quality fosters higher student achievement (Elzeyadi, 2002).

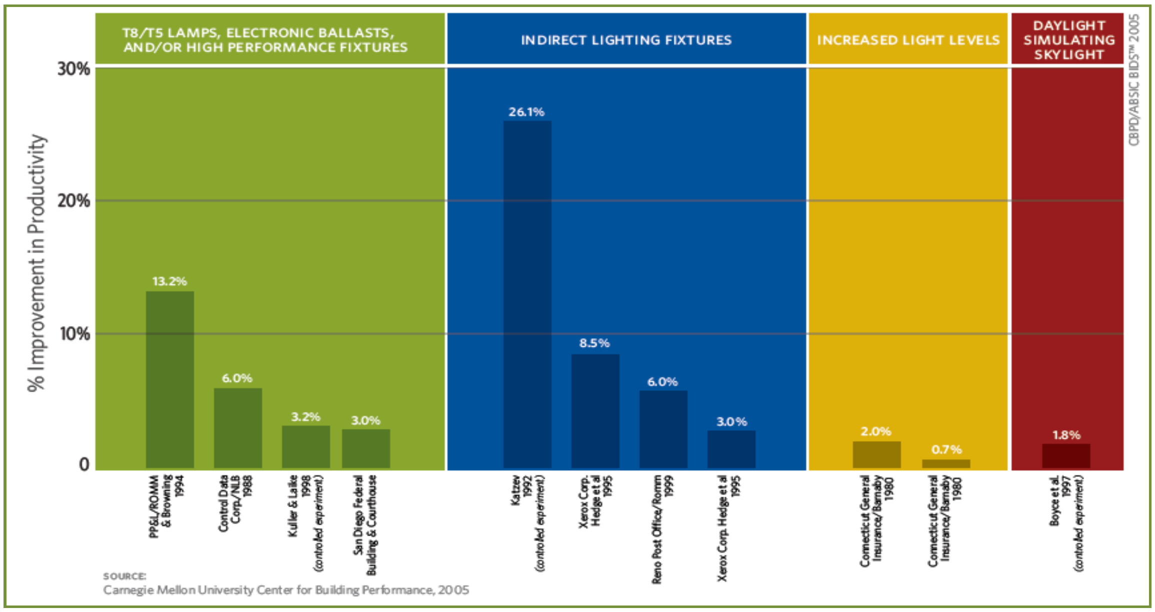

Figure 18: Health and productivity gains from lighting quality associated with green buildings
Citation: Kats, 2006 used with Greg Kats permission, December 2008

In a summary analysis performed by BIDS from 11 studies researching the relationship between high performance lighting fixtures and productivity found that productivity gains ranged between 0.7% and 26.1% with an average (median) of 3.2%. (Figure 18). Turner Construction (2005) surveyed 665 executives at organizations involved in the building sector. Of those involved with green schools, over 70% reported that daylighting in green schools reduced student absenteeism and improved student performance. In a different study Romm (1994) reported a 6% increase in postal workers performance and mood after a lighting retrofit that improved lighting quality, satisfaction, and energy efficiency. Boyce et al. (1994) have found that changes in the spectrum of light have influenced performance in visual tests with daylighting attributed to be the fullest in its color spectrum and thus could lead to the highest performance. In a laboratory experiment Katzev (1992) studied the mood and cognitive performance of four different types of lighting and found a correlation between lighting systems, mood, occupant comfort, and reading comprehension. In a similar experiment, Veitch et al. (1996b) found that luminaire type and control influenced lighting satisfaction and visual comfort. In the same experiment, energy conscious fluorescent lighting connected to electronic ballasts, which cause less flicker and humming noise than magnetic ballasts, were associated with improvements in verbal and intellectual task performance. Studies have also shown that facilities designed with high intensity light sources led to occupants' dissatisfaction due to high levels of eyestrain from excessive lighting. These studies appear to refute the long debated hypothesis that "more is better" in lighting. In fact, a lighting scheme with more layered approach to lighting levels and less waste in power intensity might be better perceived by the occupants (Elzeyadi, 2007a).

Similarly, lighting can affect interpersonal relationships between occupants. Lighting quality from relatively low versus relatively high lighting levels and "warm white" versus "cool white" lighting can affect mood and interpersonal relationships in a work environment (Leo et al., 1994). Different studies had shown that these qualities of lighting were also reported to (1) improve perception of stimuli, including positive evaluation of strangers' performance (*cf.* Isen, 1987, 80); (2) increase self-set goals and one's ability in performing various tasks (Locke & Latham, 1982); (3) enhance resolution of interpersonal conflict, collaboration, and cooperation; and (4) increase helping behavior towards others (Cunningham et al., 1970). To corroborate these findings Baron, Rea, and Daniels (1992) conducted one of the most comprehensive studies in a series of experiments using between-subject research design. Results were consistent with previous studies on the topic. The study corroborated previous findings regarding the positive effects of a warm-white fluorescent fixture with relatively low lighting level (150lux) on interpersonal relationships in offices.

Natural lighting and views associated with windows were also correlated to higher satisfaction and comfort of occupants. While windows satisfy the archetypal need to see the outdoor environment, they also provide a sense of orientation and relief from a claustrophobic sense of enclosure (Hopkinsons & Collins, 1970). Keighly (1973a; b) indicated that window size, proportion, and form have a great influence on the perception of overall satisfaction in the indoor space. His investigation showed that windows are essential to the indoor workspace as "visual rest centers;" they contribute to the overall visual comfort by relaxing the body muscles (Keighley, 1973a). Further studies showed that visual comfort related to window shape is a complex phenomenon as it depends on multiple related variables that are a form of aesthetic response to the indoor environment (Im, 1987). These variables are classified into four categories: physical, abstract, symbolic, and individual psychological variables (Im, 1984). In addition to these variables, researchers report that windows can create visual complexity in the indoor environment due to the change of scenes over time created by the effect of light and shadow on space (Collins, 1994).

Many of the previous research investigated visual satisfaction of windows in term of their shape and proportion of width to height for the optimum achievement of the outdoor view and sunlight penetration (Butler & Biner, 1989). Markus (1967) found that the occupant's distance from the window also affected view satisfaction. Previous office surveys concluded that window proximity affects occupant satisfaction for two reasons. First, the employee needs to approach the window for a change in sitting position. The second reason is related to better view perspective. Similarly, Stone and Irvine (1994) found that participants, with access to windows, in their experiment had more positive attitudes towards a creative task, while participants in windowless offices showed more positive response towards a procedural task. In both conditions boredom from the task was positively reduced when participants had access to a window.

In a survey of windowed and windowless offices, Heerwagen and Orians (1986) found that occupants in windowless offices use twice as much décor and pictures to personalize their office as compared to windowed offices. Most of these wall hangings in windowless offices contained surrogate views, especially of nature content. Similarly, Biner & Butler (1991) found that people in general compensated for the lack of windows in their environment and some of this compensation might be in the form of space personalization. Although this review of the literature stresses the importance of windows in work spaces and schools, precautions need to be acknowledged to avoid glare, visual distraction, and psychological phobias associated with windows in the direct line of sight of the occupant or reflecting on computer terminals. Based on the above substantial data set on productivity and test performance of healthier, more comfortable work and learning environments, a 3-5% improvement in learning ability and test scores in green schools appears reasonable and conservative. It makes sense that a school specifically designed to be healthy, and characterized by more daylighting, less toxic materials, improved ventilation and acoustics, better light quality and improved air quality would provide a better learning environment.

5 Challenges of an Evidence-Based Design Toolbox

The challenges of creating evidence based design guidelines and best practices are threefold. First, identifying best practices based on expert feedback can lead to mixed and contradictory lists. This is due to the fact that experts usually rely on their own anecdotal experience that lacks verification and external validity. Second, computer energy and carbon simulations possess limitations in modeling certain scenarios and practices, especially passive/energy conserving strategies. Third, given the complex relationship between people and buildings, it is hard to isolate the impact of specific design strategy on human performance in a cause-effect relationship. Other limitations of this study should be noted, specifically since the tools developed were based on opinions, contexts, and climates of the Pacific Northwest and namely Eugene, OR, as well as a specific K-12 school typology. We hope to replicate this study-- in the future--to other contexts, climates, and school typologies as well as to develop a series of case studies of school retrofits that demonstrate the application of these guidelines. It is the objective of this study to document the triple bottom line benefits for the planet (CO_2 reductions), profit (energy savings), and people (health and performance) of green classroom retrofits best practices. The data presented a clear and compelling case that retrofitting existing schools today is extremely cost-effective, and is the right thing to do for the future and learning of our children. It is the goal of this study to contribute to the gap in existing knowledge related to the availability of design analyses that target green schools retrofits. Most importantly is the development of check list evidence based tool readily available for architects, designer, and school principles. This paper provides a summary of the project to highlight the main results. The three tools identified earlier are available upon request. We hope these tools could aid school designers, facility managers, and principles in making informed decisions for retrofitting existing classrooms to meet the Architecture 2030 challenge.

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