

# **Retro\_Fit: greening educational facilities for carbon neutrality and students' performance**

**Ihab M.K. Elzeyadi, Ph.D., FEIA**

University of Oregon, Eugene, Oregon

**ABSTRACT:** Existing classrooms and educational spaces are problematic. They approximately 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 green products and building strategies to produce high-performance sustainable schools, existing classrooms have been largely ignored. This is a problem of huge proportions because the amount of occupied classroom space in the US exceeds 20 billion square feet. These existing educational spaces, generally a product of the past 30-50 years, are not energy conscious, and many of the new building products and sustainable strategies are not applicable to existing classroom retrofits. This research project targets this problem by developing evidence-based design guidelines for retrofitting existing educational spaces through the Green Classroom Toolbox (GCRT) project. This paper gives a synopsis of this project and provides a roadmap for its future application and replication.

The objective of the GCRT project was to develop green design guidelines for retrofitting existing educational spaces based on carbon neutrality metrics and student achievement outcomes. These guidelines were generated from a list of best retrofit practices that were identified by practitioners in a baseline survey and a series of focus groups, in a collaborative effort with academics. The identified best practices were then analyzed for their impact on building energy use and carbon emission using computer simulations. This data was further analyzed together with an extensive meta-analysis of prior studies related to the impacts of the best practices on occupancy health and students' performance. One of the significant goals of this project is to link green retrofit best practices with their energy and carbon emission reductions as well as with their impact on human health and student achievements. The hope is to provide a comprehensive decisions support tool for practitioners and school principals that will help them prioritize and evaluate green classroom retrofit strategies in a holistic way.

Conference theme: Building performance studies, zero energy, and carbon-neutral buildings

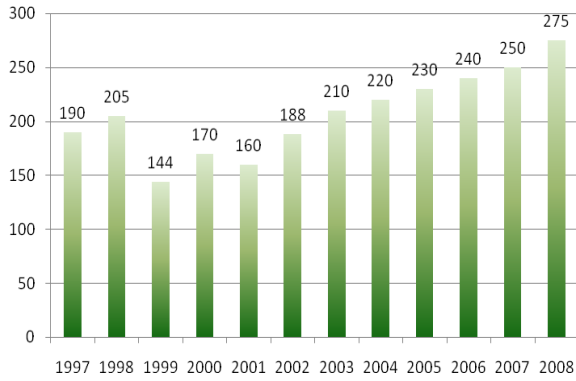
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## **INTRODUCTION: OVERVIEW OF EXISTING EDUCATIONAL ENVIRONMENTS**

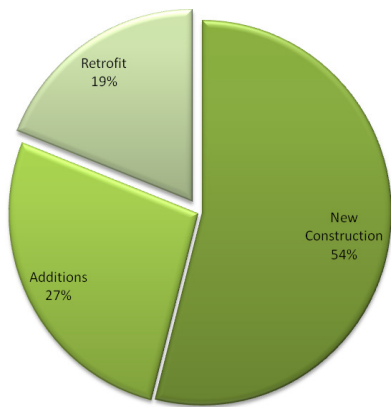
Every day, 55 million students attend schools in the US. Unfortunately, the EPA estimates that 40 percent of our nation's 115,000 schools and universities suffer from poor environmental conditions that may compromise the health, safety, and learning of more than 14 million of these students (USGBC 2008). In fact, according to the American Society of Civil Engineers, our aging educational buildings are in worse condition than any other infrastructure, including prisons. In addition, educational facilities have four times the number of occupants per square foot than most work environments.

A recent and rapidly growing trend is to design green schools with the intent of providing healthy, comfortable, and productive learning environments

(Fig. 1). While the new school construction sector of the building industry has incorporated green products and building strategies to produce high-performance sustainable schools, existing classrooms have been largely ignored. Given that the occupied classroom space in the US exceeds 20 billion square feet (this includes labs, lecture halls, and meeting spaces), this is a problem of huge proportions. These existing educational spaces, generally a product of the past 30-50 years, are not energy and environmentally conscious. In addition, many of the new building products and sustainable technologies are not applicable to existing classroom retrofits. This research project targets this problem by developing and implementing the Green Classroom Retrofit Toolbox (GCRT), which (1) quantifies the impact of green school retrofits on the triple bottom line of people, planet, and profit; and (2) ranks these retrofits to



**Figure 1:** Education construction (million SF)  
(source: McGraw-Hill Construction & Analytics, 2007)

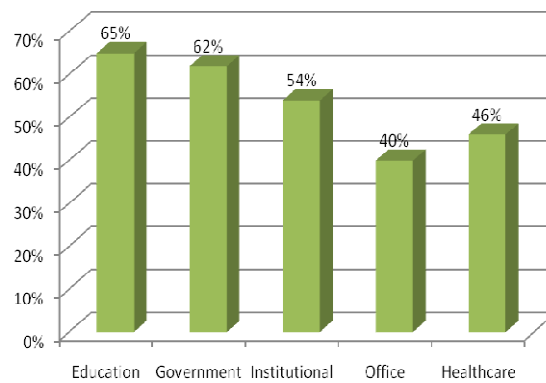


**Figure 2:** School project types by value  
(source: McGraw-Hill Construction, 2006)

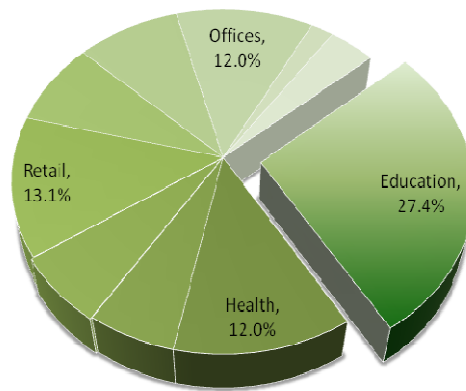
provide design guidelines for making existing schools more sustainable and better learning environments. This project has huge potential benefits for school districts and tax payers due to the fact that more than 46% of all future schools' construction is either planned additions (27%) or retrofits (19%) (Fig. 2).

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), with a projected increase of 65% in the next five years (Fig. 3). It is expected to capture 27.4% of the commercial market construction (Fig. 4), topping the other market sectors in both value and number of projects. Although green schools provide a range of benefits, there is a current gap in information regarding their energy and CO2 performance, as well as their impact on sick days, operations and maintenance, life cost, insured and uninsured risks, power quality and reliability, state competitiveness, social inequity, and educational enrichment (National Research Council, 2007). The lack of evidence-based design guidelines for this building sector could lead to a devastating missed opportunity in directing that building momentum in the most effective way.

Based on a national review of 30 green schools, a study by Capital E (Kats, 2006) reported that green schools cost less than 2% more than conventional schools - or about \$3 per square foot (\$3/ft<sup>2</sup>) - but provide financial benefits that are 20 times as large. Kats also pointed out the lack of documented studies that evaluate and compare different scenarios for green retrofitting existing schools in terms of how well and how cost effectively they enhance student learning, reduce health and operational costs, and, ultimately, increase school quality and competitiveness. This gap in the existing literature was the main driver for the Green Classroom Retrofit Toolbox (GCRT) research project, which focuses on the impact of green retrofit scenarios for classrooms on the triple bottom line of, people, planet, and profit (3P).



**Figure 3:** Top five sectors expected to have growth in green construction (source: Green Buildings Smart Market Report, McGraw-Hill Construction, 2007)



**Figure 4:** Commercial construction activity by value  
(source: McGraw-Hill Construction & Analytics, 2007)

## 1. AN ACTION RESEARCH APPROACH TO GREEN CLASSROOM RETROFITS

This interdisciplinary project targets the research problem by developing actionable green classroom retrofit guidelines. As reported by Ahrentzen (2006), the

design and building professions have not established an agenda for organizing, disseminating, and advancing the state of knowledge on how good design is best employed to create long-term economic and social value. Typically, examples of “best practices” provide little evidence or criteria for what make them “best.” For this reason, we developed our tools and tested them based on a deductive approach. First, in a collaborative effort between academia and local building professional organizations, we conducted a base-line survey to identify the best school green retrofit scenarios. This effort resulted in a check list of best practices of classroom retrofits collected from interviews and focus groups with designers, facility managers, and school principals. Second, this list of best practices was systematically evaluated using the 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.

### 1.1. Conceptualizing the Green Classroom Retrofit Toolbox (GCRT)

This project conceptualized the school environment from a place-based experience perspective, which assumes 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). While “people” in a school setting includes students, faculty, and staff, we are focusing our investigation primarily on the students (Fig. 5).

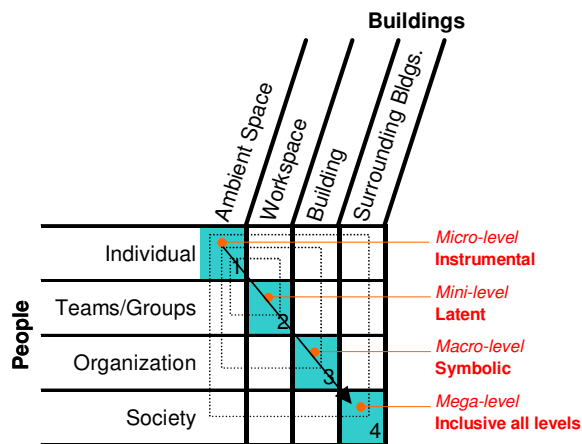


Figure 5: GCRT Conceptual framework

The project’s conceptual framework treats students and their school environment as interdependent elements of a system. This systems epistemology rests on the idea that the environment is an organic structure; its parts are connected to each other by complex interactions in such 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).

### 1.2. GCRT objectives and the triple bottom line

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

- Develop tools that will analyze the impact of separate green retrofit strategies while also acknowledging the larger effect of the interrelationship among these strategies on the building and its occupants’ performance.
- Identify not only design retrofit strategies and best practices but also operations and maintenance ones, which have typically been neglected by 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 and Resources (Site construction, Structural and non-structural); (3) Environmental Quality (IAQ, Comfort, and Acoustics); (4) Sustainable Sites (Density, Light Pollution, and Transportation), and (5) Water and Waste (Building fixtures, Landscaping, Recycling).

### 2. GCRT PROCESS AND PHASES

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

1. Surveyed and classified existing classroom types and typologies.
2. Held focus groups with school building designers, operators, principals, and contractors to generate a check list of best practices of green retrofit scenarios and products for classrooms.
3. Performed energy and carbon performance simulation analyses of the best practices (identified in the focus groups) for a prototypical K-12 school. This analysis simulated the 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.
4. Reviewed and analyzed previous studies linking the identified green design strategies to students’ health and performance outcomes.

### 2.1. Methods and approach

This project was planned in three phases. The first phase researched and identified green classroom retrofit best practices (BP) based on a survey of opinions from school principals, 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 the BPs based on their impact on occupants’ performance relying on meta-analysis of previous studies.

**2.2. Project phases and tools**

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

**2.2.1. Phase 1: survey of best practices**

A cross-sectional survey was designed to elicit responses from K-12 school owners and principals (O&P), architects and engineers (A/E), and facility managers (FM) on their views of best practices for green retrofitting of classes. The survey participants were chosen to represent a sample of each of the groups involved in decisions regarding school and classroom energy and environmental upgrades. Data was collected using focus groups and interviews across building professions and geographical locations. This enhanced our analysis of the various opinions by subgroups and helped achieve 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 on average. The stratified sample of respondents was theoretically weighted to include a larger number 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 group. Building owners/principals comprised the second most important category, and it included an equal number of respondents from those two groups (Table 1). From the results of this phase of the research we compiled a checklist of best practices for classroom retrofits and green remodel strategies, which are available in a previous report (see Elzeyadi, in press).

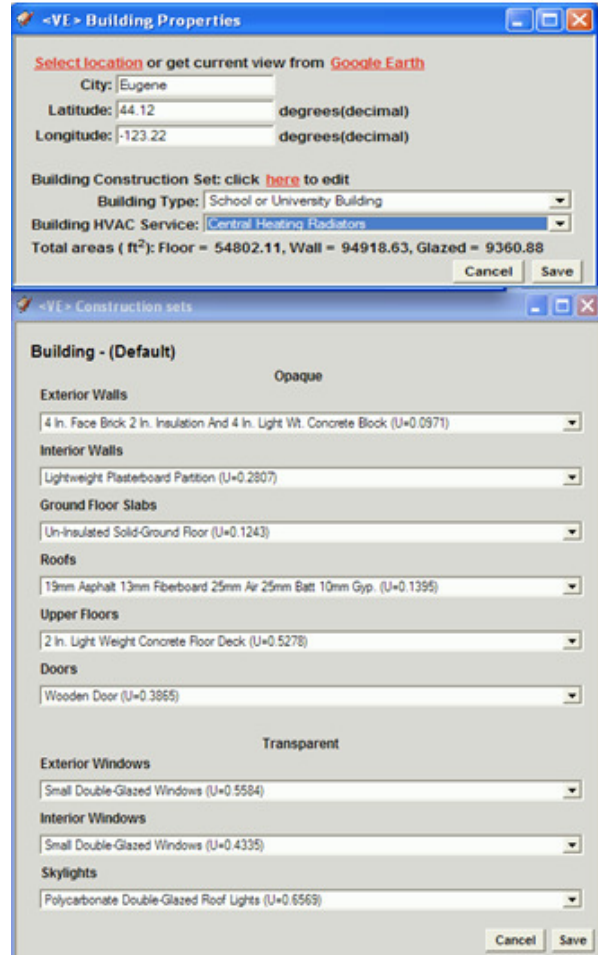
**Table 1:** Survey participants and locations of focus groups

Location	A/E	F. M.	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

**2.2.2. Phase 2: Experimental simulations**

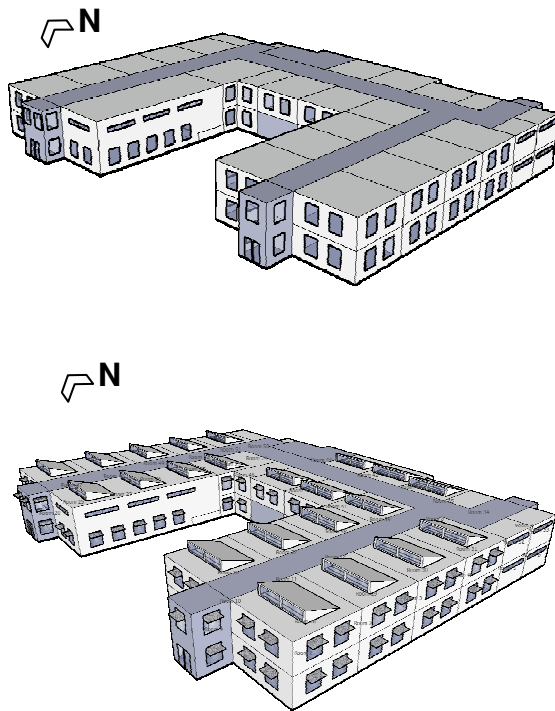
Energy analysis computer simulations were conducted for each best practice strategy identified in phase 1. These simulations were run using Integrated Environmental Solutions Virtual Environments™ (IESVE, see www.iesve.com) ApacheSim module. ApacheSim is a rigorous building thermal simulation approach that conforms to ANSI/ASHRAE Standard 140. The simulations were conducted on a two-story 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 (Fig. 6). For experimental purposes, all best practices were compared to a base

case model using one geographic climate location, Eugene, OR (44.12° North Latitude, 123.22° West Longitude and elevation of 357 ft). Every 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™ model in conjunction with IESVE sustainability tool kit plug-in modules (Fig. 7).



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

Each of the identified best practices was run separately to determine its specific impact on the building energy use and carbon generation, 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 CO2 emissions performance of the building. The detailed energy and emissions analysis included: Energy consumption (MMBtu), Carbon emissions (lbCO2), 2030 Challenge Targets (kBtu/ ft2), Thermal Comfort (%PPD limits), Peak HVAC loads (btu/h.ft2), Ventilation rates (cfm), and daylighting analysis (avg. fc/h operation).



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

### 2.2.3. Phase 3: Meta-analysis of health and performance impact

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). Likewise, a published document by the American Federation of Teachers notes low IAQ 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 have failed to acknowledge linkages between specific design strategies and occupant outcomes. This limits the relevant data available to understand and quantify the benefits of high-performance, healthy design in schools in general and retrofits in particular. To overcome this limitation, we conducted a meta-analysis of 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 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.

## 3. 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 school designers as well as school principals make informed decisions about green retrofitting their classrooms. To that end, we have developed three main decision support tools. The first is a checklist of best practices compiled from the focus groups and interviews of 24 school building designers, facility managers, and principals. The second tool is a prioritization guide that provides some comparative analysis and ranks the best practices 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 occupant health and performance in schools. These tools 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 should be noted that the tools were 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 in other contexts and climates of the US and to develop a series of case studies of school retrofits that demonstrate the application of these guidelines.

### 3.1. Best practices survey

The focus groups and interviews of the 24 school building architects and engineers (A&E), facility managers (FM), and school owners and principals (O&P) in the three largest cities in the state of Oregon yielded a comprehensive checklist of best practices. In addition, these professionals were asked to identify and rank the primary reasons for adopting such practices (as well as limitations to adopting them). The reasons they identified were organized into categories meaningful for designers and practical for future adoption. On 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%) and to provide “connections to nature - Biophilia” (63%). The other three reasons reported were “Global warming – Environment” (45%), “Right thing to do” (28%), and “Recycling” (7%). A breakdown of the reasons by each group is displayed in Fig. 8.

Professionals in the focus groups also 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 for their applicability for retrofits projects, it is not surprising to see fewer items identified in categories that pertain to site choices, orientation, outdoor conditions, and building form, which are categories more applicable to new construction rather than retrofits (Fig. 9).

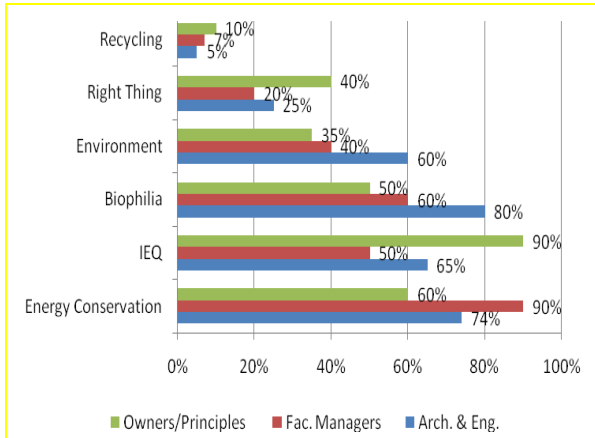


Figure 8: Reasons to adopt green classroom retrofits identified by different focus groups

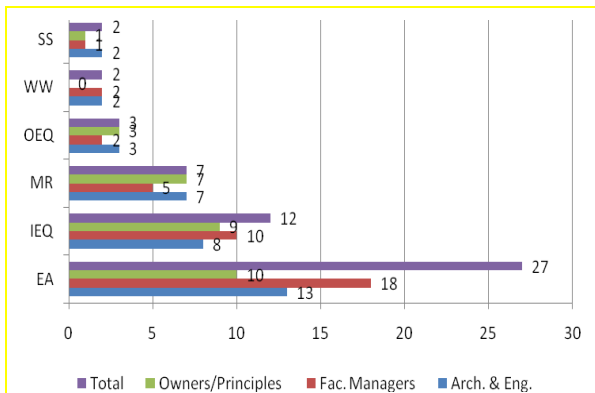


Figure 9: Number of best practices identified by different focus groups sorted by categories

### 3.2. Energy and CO2 analysis of best practices

One of this project's objectives is to evaluate and analyze the best practices identified earlier for their impact on school buildings' and classrooms' energy conservation as well as carbon (CO2) 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](http://www.iesve.com)). The simulations were conducted on a prototypical two-story 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 (Fig. 10a). Similar to national trends

of school buildings' energy use (McGraw-Hill 2007), the current simulation model predicted that 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 (Fig. 10b).

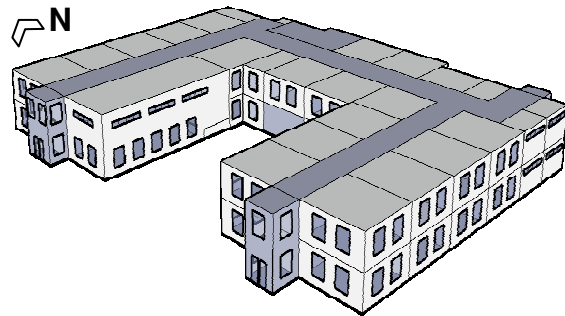


Figure 10a: Simulation base model used for energy analysis

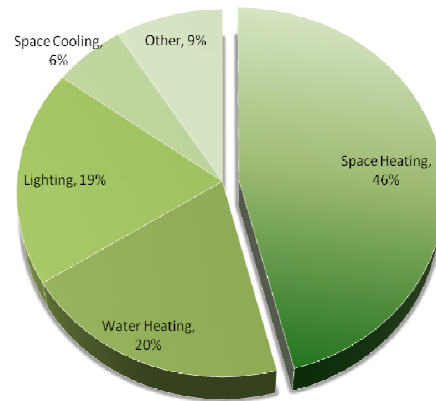
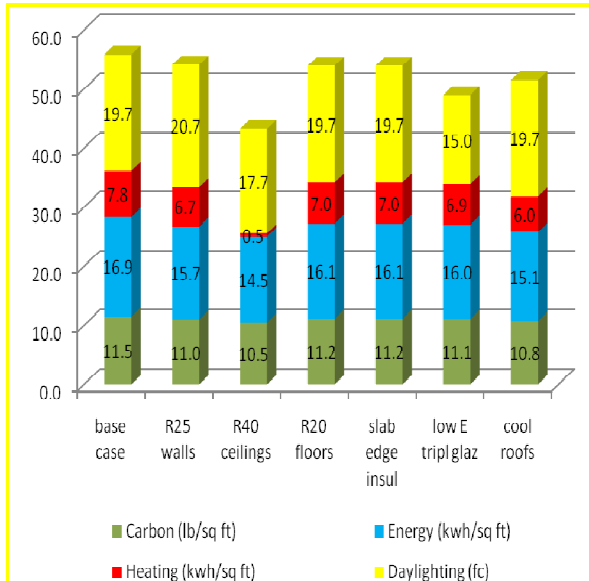


Figure 10b: Breakdown of energy use by building system category (base case usage)

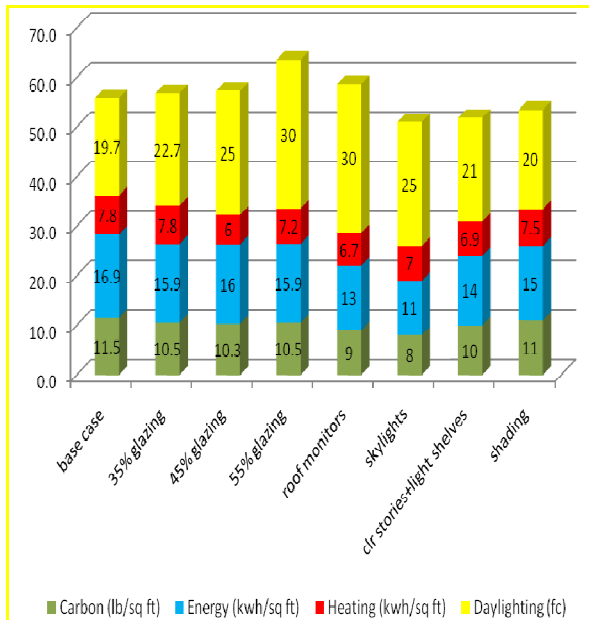
The total yearly energy consumption calculated for the simulations was converted to kwh/ft2/year from kbtu/ft2/year to normalize for the different sources of power supplied to the building. Figures 11 and 12 compare the impact of different envelope best practices on the yearly total building energy consumption (kwh/ft2), heating energy (kwh/ft2), CO2 emissions (lb/ft2), and average daylight levels in foot candles (fc) for the classrooms schedule. Fig. 11 shows ceiling insulation (R40), as well as cool roofs with radiant barriers, 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.

Fig. 12 shows the strong impact of top lighting strategies such as roof monitors and modular skylights on energy and emissions reductions. The same figure also shows that effective side lighting ranges between 35%-45% wall-to-glazing ratio for this climate and

specific building typology. Fig. 11 and 12 together provide a comparison of thirteen of the envelope and daylighting best practices upgrades with the base case school as well as with an optimized best practices model with most of the green upgrades. The optimized best practices model is shown to reduce energy consumption for the school by an average of 50% in lighting and heating energy and an associated 59% reduction in carbon emissions.



**Figure 11:** Energy and CO2 yearly emissions simulated by applying envelope insulation retrofits to base case



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

### 3.3. Occupants' performance related to best practices

Data used in the following meta-analysis is partially based on a literature review published by Capital E (Kats 2003 and 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, and occupants' outcomes, such as productivity and health (Lofness, et al. 2002). In addition, our analysis included data from a study conducted by William Fisk (2000) linking health and productivity gains of building occupants to better indoor environments and energy efficiency. We have also conducted a separate meta-analysis of more than 150 studies that link indoor environmental quality and comfort issues to occupants' performance in green buildings (see Elzeyadi, 2002; 2008). For simplicity and because of space limitations, we grouped results related to health, productivity, task performance, and test scores under the general heading of "human performance." Summaries of the conclusions from these reviews are given below under Green Retrofits related to three categories: Indoor Air Quality, Temperature Control, and Day/Lighting Quality.

*Green Retrofits Related to Indoor Air Quality Positively Impact Occupants' Performance by 5-20%:* The BIDS program identified 17 substantial studies that document the relationship between improved air quality and health. The health impacts include asthma, flu, sick leaves, sick building syndrome, respiratory problems, and other building-related illnesses. These 17 separate studies all found positive health impacts correlated with improved indoor air quality ranging from 13.5% up to 87% improvement, with average improvement of 41%. In a study of Chicago and Washington, DC schools, better indoor air quality in school facilities was correlated to a 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 health impacts that were documented are related to many of these practices, such as increased ventilation rates, natural ventilation, increased insulation, and HVAC pollutants control. Based on the above results, we can very conservatively estimate that the better indoor quality afforded by the different best practices results in a 5-20% improvement in occupants' performance.

*Green Retrofits Related to Temperature Control Positively Impact 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 acceptability and occupant satisfaction. Teachers perceive 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 the temperature in classrooms is very important to student performance (Heschong, Elzeyadi and Knecht 2001). A review of 14 studies by Carnegie Mellon on the impact of improved temperature control on productivity found a positive correlation between both perceived and experienced control and productivity improvements of up to 15% and with an average (mean) of 3.6% (Loftness, et al. 2005).

*Green Retrofits Related to Day/Lighting Quality Positively Impact Occupants' Performance by 5-20%:*

Green school design typically emphasizes providing views and ambient daylight for classrooms and educational facilities. These strategies have been associated with improvements in performance on students' standardized test scores of 10-20% on average (Heschong Mahone Group 2003; Heschong, Elzeyadi and 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).

## **CONCLUSION: 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, which lacks verification and external validity. Second, computer simulations of energy use and carbon emissions have 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 a specific design strategy on human performance in a cause-effect relationship. The other limitation of this study that should be noted is that the tools were developed based on opinions, contexts, and climates in the Pacific Northwest, specifically Eugene, OR, and also based on a specific K-12 school typology. We hope to replicate this study in the future in other contexts climate zones, with other school districts and classroom typologies. In addition, we intend to develop a series of case studies of school retrofits that demonstrate the application of these guidelines. In terms of achieving our objective of documenting the triple bottom line benefits of these green classroom retrofitting best practices for the planet (CO2 reductions), profit (energy savings), and people (health and performance), 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 health and learning of our children. It is the goal

of this study to reduce the gap in existing knowledge related to the availability of design analyses that target green school retrofits. Most important is the development of the check list as an evidence-based tool readily available for architects, designers, and school principals. The best practices list and guidelines identified earlier are available upon request (see Elzeyadi, in press). We hope this information will aid school designers, facility managers, and principals in making informed decisions for retrofitting existing classrooms to meet the Architecture 2030 challenge.

## **ACKNOWLEDGEMENTS**

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