

DESIGNING SUSTAINABLE LEARNING ENVIRONMENTS: LOWERING ENERGY CONSUMPTION IN A K-12 FACILITY

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ABSTRACT

The construction industry is embracing sustainable building practices that boost the “triple bottom line”, namely the building’s ecological, social, and financial performance. Since more than 55 million US students spend a significant part of their day in K-12 schools, it is vital that these facilities should provide healthy, comfortable, and productive learning environments. Here we present an in-depth literature review of how educational facilities affect student school performance, comfort, and health, and we examine the role of sustainable design and construction strategies in influencing the physical learning environment in schools. Significant barriers to implementing sustainable strategies are examined, particularly the first cost premium of a sustainable building. A systematic decision strategy is described that incorporates sustainable design strategies, lowering energy consumption and improving indoor environments. A case study describes the process of incorporating sustainable strategies in a K-12 education facility in North Carolina to lower annual energy consumption and greenhouse gas emissions. Ways to reduce the first cost premium and minimize operating costs over the facility’s life while providing healthy and comfortable learning environments for students and teachers are discussed. The case study school also functions as an experimental learning tool for teaching sustainability to K-12 students, having the potential to improve their attitudes and behavior with respect to sustainability.

KEYWORDS

sustainable design and construction, K-12 facilities, energy consumption, greenhouse gas emission

INTRODUCTION

Twenty percent of the U.S. population, nearly 56 million individuals, spend a significant part of their day in K-12 school facilities throughout the United States (USEPA, 2005). Consequently, the quality and physical condition of U.S. school facilities have received considerable attention over the years (Kozol, 1991; Lewis et al., 1989; USDOE, 2000) and lawsuits challenging school funding for facilities have drawn attention to the poor conditions that many

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students encounter at school (USDOE, 2000). According to the U.S. Department of Education's National Center for Education Statistics, in 1999 around 33,800 (43%) of America's public schools reported at least one unsatisfactory environmental condition (typically lighting, heating, ventilation, indoor air quality, acoustics or noise control, or physical security of the building) (USDOE, 2000). Approximately a quarter of the public schools reported that ventilation was unsatisfactory, while indoor air quality (IAQ) was reported to be unsatisfactory in about 20% of schools. In 2000, the U.S. Department of Education reported that the average school building was 42 years old and those buildings had not been properly maintained and renovated over much of their building life. This situation has not improved, and many school facilities in the United States fail to provide a healthy, high-quality learning and teaching environment.

The physical condition of school facilities impacts students, teachers, and their families both directly and indirectly. For example, the physical quality of a school facility has been linked to the performance and health of all those who use the building (Berner, 1993; USDOE, 2000; O'Neill and Oates, 2001; Buckley et al., 2004). The quality of the school facility is dependent upon many factors including air quality, lighting quality (including daylighting), temperature, humidity and thermal comfort, acoustics, building age, school size, and classroom design (Plympton et al., 2000; USEPA, 2000; Olson and Carney, 2006; USEPA 2010). Poor IAQ adversely affects the comfort and health of students and teachers and is thought to be a major cause of 'sick building syndrome', where sufferers report irritated eyes, nose and throat problems, upper respiratory infections, nausea, dizziness, headaches and fatigue, or sleepiness. Poor IAQ negatively affects concentration, attendance, and student performance and has been shown to lower students' academic achievement with prolonged exposure (Berner, 1993; Cash, 1993; Hines, 1996; USEPA, 2010). The condition of a school facility also has an adverse impact on teacher performance and effectiveness, staff turnover rate, and the quality of teachers' lives (USDOE, 2000; O'Neill and Oates, 2001; Buckley et al., 2004).

In addition to the issues raised by the physical deterioration of America's school facilities, school systems spend over six billion dollars a year on energy and energy costs, second only to salaries in education budgets and far exceeding the costs of supplies and books (ASE, 2003). Energy prices continue to rise rapidly, increasing the pressure on already tight operating budgets and reducing the money available for hiring new teachers and purchasing textbooks, computers, and other instructional materials. Furthermore, many new schools are located at the edge of communities and consist of a single story structure on a large site (Olson and Carney, 2003). In addition to contributing to urban sprawl, building this type of school encourages automobile dependency, increases per-person infrastructure costs, raises energy and water consumption, and has an overall negative effect on the environment.

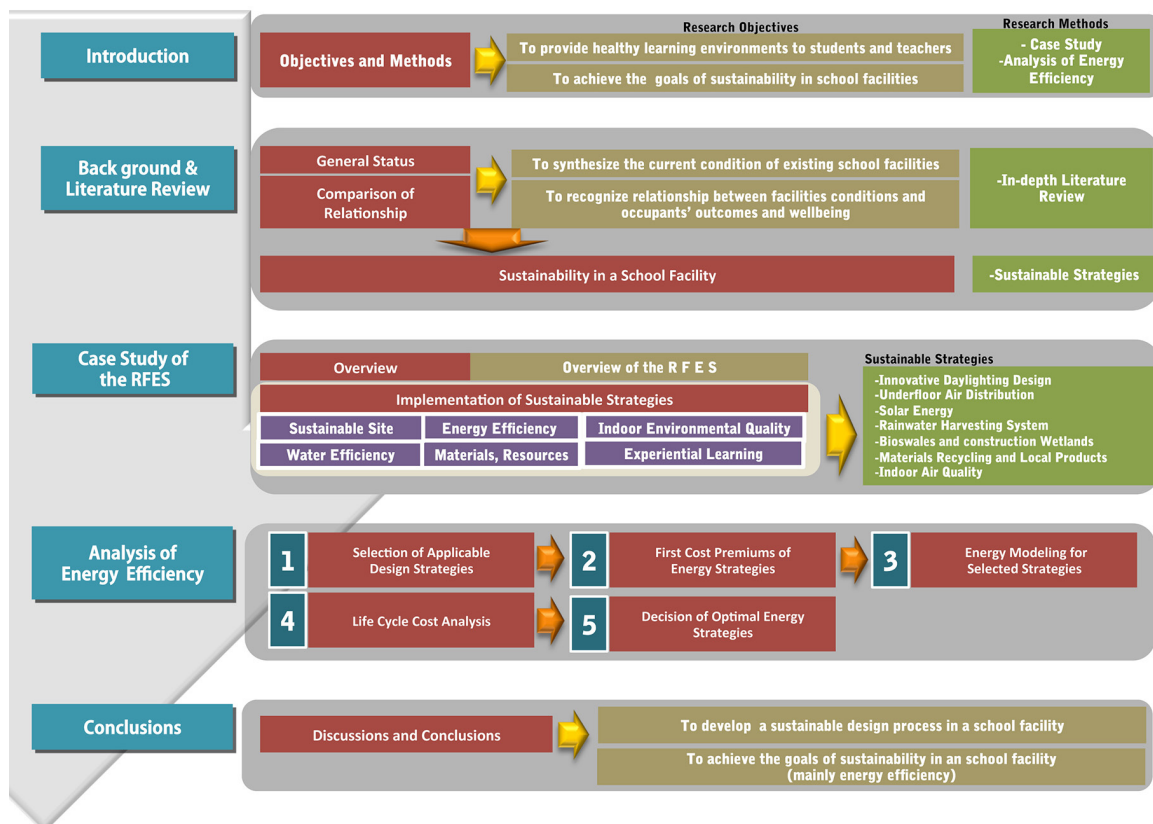
One way to address the current poor physical condition of school facilities is to replace them with high performance sustainable buildings that are specifically designed to meet their energy needs without compromising the future needs of the community. A sustainable school should provide an optimally safe, healthy, comfortable, and productive learning environment for students and a pleasant working environment for teachers and staff, while at the same time minimizing negative environmental impacts.

The concept of 'sustainability' has begun to be more widely accepted by the construction industry in the past twenty years. It is broadly defined by the World Commission on Environment and Development as "meeting the needs of today without compromising the ability of future generations to meet their own needs." (WCED, 1987). To work toward this

goal of sustainability, a variety of high performance building techniques have been developed and implemented in the construction industry. Using these techniques, sustainable buildings are designed to optimize environmental, social, and economic performance; to mitigate demand on natural resource bases by saving energy, water, and other resources; to furnish satisfying, productive, healthy, and high quality indoor spaces; to use environmentally preferable materials; and to educate the building occupants about efficiency and conservation (Ahn and Pearce, 2007; Kibert, 2008; Ahn, 2010). Accordingly, in this study, we define a sustainable school building as a building designed and constructed using sustainable strategies that provides a healthy learning environment; minimizes the use of energy, water, and other valuable resources; educates the students and teachers that occupy it about efficient use of resources, environmental conservation, and sustainability; conveys financial benefits throughout the building's life; and improves student academic outcomes, health, and wellbeing.

To accelerate the adoption of the sustainable school concept, this study uses a case study research methodology to investigate a real context of sustainable school development in order to examine how a sustainable school facility functions. The structure of this study is depicted in Figure 1 and demonstrates how a sustainable K-12 school facility can address issues related to the current poor physical condition of many school facilities and provide optimal learning environments for students and teachers. In addition, this study demonstrates how the integrated design process inherent in energy-efficient design strategies can reduce first cost premiums and maximize life cycle cost savings while simultaneously providing healthier and better indoor environments to teachers and students, thus lowering absenteeism and further improving students' academic achievement.

FIGURE 1. Structure of the Study.



BACKGROUND STUDY & LITERATURE REVIEW

This study includes an examination of the current status of school facilities in the United States in order to establish the need for sustainable school facilities. The literature clearly supports the relationship between the condition of the school facility and users' health and comfort. The physical condition of a school facility is also known to have an impact on student academic achievement: poor quality facilities are reflected in the poor performance of the students attending those schools (Schneider, 2002). This section of the study concludes with a literature review that identifies sustainable best practices in K-12 school facilities.

Status of School Facilities

School bodies in the United States, both at the state and local level, spend billions of dollars annually on the construction, renovation, and maintenance of school facilities to ensure they provide healthy learning environments for both students and teachers (USDOE, 2000). However, concerns persist about the conditions of many school facilities in the United States and a number of studies have demonstrated the deplorable physical condition of many school buildings throughout the country. According to the U.S. General Accounting Office, every school district in the United States has identified facilities in their area whose condition is poor (GAO, 1995). The report notes that billions of dollars are needed for repairs to bring the facilities up to the federally mandated standard (GAO, 1995). The situation is especially serious in those schools located in urban and high-poverty areas, where conditions in some school facilities are so bad that students' and teachers' health and safety are at risk, and learning and teaching opportunities are very limited (USDOE, 2000). The federal government conducted a comprehensive study of school facilities in the United States in 1999, collecting data from 903 of the nation's K-12 school facilities via a survey questionnaire. The survey results indicated that (USDOE, 2000):

- Seventy-five percent of school facilities need repairs, renovations, and modernization to achieve good overall condition
- An estimated \$127 billion is needed to bring all school facilities into good overall condition
- One in four school sites include at least one type of building in less than adequate condition
- Eleven million students are enrolled in schools with at least one type of onsite building in less than adequate condition
- Forty-three percent of school facilities have unsatisfactory performance in at least one of six environmental factors (lighting, heating, ventilation, indoor air quality (IAQ), acoustics/noise control, and physical security of buildings)
- Ventilation is the environmental condition most likely to be unsatisfactory (26% of schools); 20% of schools experience unsatisfactory conditions in the areas of heating, IAQ, acoustics/noise control, and physical security; lighting conditions are unsatisfactory in 12 % of school facilities.
- In 1999, the average instructional facility was 40 years old, based on years since original construction
- The average functional age of instructional facilities in 1999 was 16 years, based on the year of the most recent renovation or construction if no renovation occurred
- The functional age of schools was found to be correlated to their conditions, with older schools more likely to report inadequate or unsatisfactory conditions

- Schools in areas with the highest concentration of poverty are more likely to report unsatisfactory environmental conditions than those with the lowest concentration of poverty
- About 25% of school facilities are overcrowded, based on the capacity of permanent instructional facilities and space.

These findings support those of other researchers. Benya (2001) and Phillips (1997) both found that over 21% of the teachers in their studies reported that the lighting in their school was inadequate, even though classroom lighting is known to play a critical role in student performance (ibid.). Lackey (1999) revealed that teachers also believed that noise in a school facility impairs academic performance and hinders teachers' instruction. In another study, 26% of Chicago public school teachers and more than 30% of Washington, DC, teachers interviewed reported health related problems caused by their school facility (Schneider, 2002). Most of these problems were related to poor indoor air quality, with teachers reporting that asthma and other respiratory problems were the main adverse health effect.

These studies, in conjunction with the reported problems with the existing school facilities in the United States, suggest the importance of this issue. The physical condition of the school facility affects students' and teachers' health and wellbeing, as well as influencing student academic achievement. Improving the quality of school facilities is vital if we are to provide an adequate and optimal learning environment for our students and teachers.

School Facility and Students' Outcomes and Achievements

Many previous studies have supported the notion that the physical condition of the school facility is significantly correlated with student academic performance and outcomes (Table 1).

The specific characteristics of the school facility also have an impact on student outcomes, including achievement, attendance, behavior, and health (Table 2).

The growing body of research in this field supports the notion that the physical condition of the school facility may significantly affect student academic achievement, health, and attendance rates. This literature review highlights the potential importance of developing school facilities that incorporate sustainable strategies that positively affect a school's physical condition, primarily lighting/daylighting and indoor air quality strategies, in order to provide a high quality indoor environment for students and teachers. An additional benefit of such a facility is reduction in energy and water utility bills and mitigation of adverse environmental impacts.

Sustainability in a School Facility

The sustainable building concept has been developed by the building sector to respond to the need to minimize environmental, social, and economical impacts in the building sector. The construction of sustainable buildings makes it possible to "meet the needs of today without compromising the ability of future generations to meet their own needs" (WCED, 1997). To achieve sustainability in a school facility, sustainable design and construction strategies must be incorporated into the development process from the earliest stages. A sustainable building relies upon a fully integrated "whole building" approach being applied throughout its design, construction, and operation (Olson and Carney, 2003). Incorporating the findings of several previous studies, Olson and Carney (2003) demonstrated that that sustainable school facilities that incorporate sustainable design and construction strategies offer several benefits that help minimize many of the issues and problems associated with current school facilities in the

TABLE 1. Physical Condition of the School Facility and Student Achievement.

Author and Year	School Facility Condition	Student Achievements and Outcomes	Selected Findings
Berner 1993	Condition of school building	Comprehensive Tests of Basic Skills score	A school in fair condition could be expected to have average achievement test scores 5.45 points higher than a school in poor condition, on a scale of 0 to 100.
Maxwell 1999	Whether schools had recent renovation projects	New York Pupil Evaluation Program reading and math scores	School facilities with recent renovations generally had better average math achievement test scores, but results showed no association with reading achievement scores.
Lewis 2001	Assessments of school condition by district staff and staff from the program architect	Wisconsin Student Assessment System test scores	Schools with better facility conditions generally had better average achievement test results for each of four tests in 3 years, but the association was statistically significant in only 11 of 36 tests after taking other factors into account (with a one-tailed test of significance.) These 11 tests were for 1996 and 1997. None of the tests for 1998 were statistically significant.
Schneider 2002	Teachers' survey response grading the condition of schools' facilities	Stanford Achievement Test in District of Columbia schools and Iowa Test of Basic Skills in Chicago schools	Schools with facilities in the worst condition had lower percentages of students performing in the two highest achievement categories—an estimated 3% fewer compared with school facilities in the best condition in the District of Columbia, and 3 to 4% fewer in Chicago.
Pricewaterhouse Coopers 2003	Amount of capital expenditures to improve the suitability of the facilities	The percentage of students meeting reading, writing, math, and science standards in the United Kingdom	Schools with additional capital investment in facilities generally had better pupil performance, particularly for community primary schools and for investment in science laboratories and technology.
Buckley et al. 2004	Overall building compliance level with health and safety standards	California State Achievement Tests	Schools in the best condition compared with those in the worst condition had an estimated 36-point higher average composite score on student achievement tests on a 200 to 1,000 point scale.
Picus et al. 2005	Building quality scores assessed by a consulting firm	Wyoming Comprehensive Assessment System scores	Facility conditions were not associated with better or worse achievement test scores, and results showed no association with reading achievement scores.
Durán-Narucki 2008	Condition of elementary school buildings based on independent consultant assessments	New York State and City mathematics and English achievement test results	Better school building conditions were associated with better student attendance rates, and these in turn were associated with better English and mathematics achievement.
Uline and Tschannen-Moran 2008	Teachers' perceptions of the quality of school facilities	Factor based on two Virginia standards of learning test scores	Schools with better quality facilities generally had better test scores, but not after taking into account school attitudes, such as whether students admire others who get good grades and whether teachers are committed to students' education. The authors concluded that better quality facilities affect achievement indirectly—through their effect on school attitudes.

TABLE 2. Characteristics of the School Facility and Student Outcomes.

Author and Year	School Facility Condition	Student Achievement and Outcomes	Selected Findings
Küller and Lindsten 1992	Amount of natural daylight and fluorescent light in classrooms	Student attendance, sociability, and sick leave use	Classrooms that lacked natural or simulated daylight had marked delays in rise of a natural hormone, cortisol. The ability to concentrate was higher in those classrooms with overhead daylight and artificial warm white tube light. Sociability was also higher with windows or fluorescent daylight tubes.
Hathaway 1995	Use of four different types of light fixtures in school classrooms	A comparison of scores on Canadian Test of Basic Skills taken in 1987, attendance rates, measures of physical development and dental health	Attendance, achievement, health, and development measures were better in schools with full-spectrum lights compared with those in schools with high-pressure sodium vapor lights.
Taskinen et al. 1999	The presence of moisture problems in elementary schools and indoor air quality	Parents' response to a survey concerning respiratory symptoms	In the schools with moisture problems, parents noted higher incidences of children with repeated wheezing and prolonged coughing, as well as more respiratory infections that led to emergency room visits and use of antibiotics.
Rosen and Richardson 1999	Indoor air quality as measured by levels of airborne particles in schools with an without electrostatic air cleaning systems in operation	Student attendance rate	When the electrostatic air cleaning systems were in operation, average attendance rates rose, although this was not statistically significant at the smaller day care center included in the study.
Berry 2002	Adequate natural light, classroom temperature, no VOC materials, and open and flexible use of all surfaces	Student attendance rate, teacher's retention, the Stanford 9 Math and Reading, parent involvement	The student attendance rate improved from 89% to 93%. The retention rate of teachers improved, with teachers from throughout the DC area applying for positions. Many parents began to use the school after hours to improve their own reading skills. Math scores dramatically improved as did reading skills.
Wargocki and Wyon 2007	Outdoor air supply rate and classroom temperature	The speed at which students completed various mathematics, reading comprehension, and proof reading tasks	Increasing the outdoor air supply rate and reducing elevated classroom temperature significantly improved student performance, primarily reflected in how quickly students completed tasks.

TABLE 3. Major Sustainable Practices and Their Benefits

Categories	Specific Benefits	Major Practices	Common Benefits
Sustainable Site	<ul style="list-style-type: none"> • Efficiency of site use • Heat island effect • Reduced need for civil infrastructure • Reduction in heat island effect 	<ul style="list-style-type: none"> • Sustainable site planning and landscaping • Southern orientation of building • Public transportation • Stormwater management 	<ul style="list-style-type: none"> • Provide optimal learning environment to students and teachers • Optimization of environmental and economic performance • Financial benefits over the building's life • Improved student academic achievement, health, and wellbeing
Energy Efficiency	<ul style="list-style-type: none"> • Energy saving • Greenhouse gas reduction • Operation cost saving 	<ul style="list-style-type: none"> • South orientation • High efficiency envelopes (efficient windows and high R-value insulation) • High efficiency HVAC system • Daylighting & high efficiency lighting • Onsite renewable energy sources (photovoltaics) 	
Water Efficiency	<ul style="list-style-type: none"> • Water saving • Reduced operating costs 	<ul style="list-style-type: none"> • Water saving fixtures and technologies • Rainwater harvesting system 	
Materials & Resources	<ul style="list-style-type: none"> • Resource saving 	<ul style="list-style-type: none"> • Green supplies and materials • Construction waste management • Recycled content materials • Regional materials • Rapidly renewable materials 	
Indoor Environment quality	<ul style="list-style-type: none"> • Productive and healthy indoor spaces • Improvement of students' academic outcomes, health, and wellbeing 	<ul style="list-style-type: none"> • Daylighting; high efficiency lighting • Adequate air filtration • Low VOC materials • Mold prevention • Enhanced acoustical performance 	
Experiential Learning	<ul style="list-style-type: none"> • Education of building occupants about efficiency, conservation and sustainability 	<ul style="list-style-type: none"> • Real time monitoring of sustainable strategies • Installation of a sundial • Integrative signage 	

United States and provide healthier school environments to students and teachers. The major benefits gained by adopting a sustainable building approach are listed in Table 3 (Plympton and Conway, 2000; Rittner-Heir, 2001; Olson and Carney, 2003; Gertel et al., 2005; Kats, 2005, 2006; USEPA, 2010; Chansomsak and Vale, 2010).

To achieve these benefits, a series of sustainable building practices are listed that can potentially be applied in the development of school facilities. These sustainable building practices for designing, operating, and maintaining schools offer not only potential economic benefits, but also have the potential for positive impacts on student health and learning if well-integrated as part of a holistic design.

One of the most widely accepted approaches to facilitating the use of sustainable strategies in construction is through the incorporation of green building rating systems such as Leadership in Energy and Environmental Design (LEED), GreenGlobes, Building Research Establishment Environmental Assessment Method (BREEAM), and Collaborative for High Performance Schools (CHPS) among others. These rating systems encourage the use of potential sustainable strategies that could improve the building's overall environmental performance; provide a way to help the construction market understand the standards expected of them and how to meet sustainable project goals; and provide guidelines that help project teams meet or exceed the stated performance thresholds (Pearce and Ahn, forthcoming).

CASE STUDY: REEDY FORK ELEMENTARY SCHOOL

This case study describes how a sustainable school facility not only benefits from lower energy consumption and greenhouse gas emissions, but also provides a healthy, comfortable, and productive learning environment for its students and teachers. The Reedy Fork Elementary School (RFES) in Reedy Fork, North Carolina, was chosen for this study because it incorporates many sustainable strategies and has successfully addressed the major challenges associated with the first cost premium.

Overview of Reedy Fork Elementary School

RFES is an 87,000 sq.ft school facility that includes classroom space for 725 students and 70 staff plus dining, gymnasium, auditorium, science, art, music, computer, library, and administration facilities (Figure 2). Construction on the project started in 2006 and was successfully completed in 2007. The school has been chosen as one of those in the top 10% of school facilities in the United States eligible for the Energy Star® label (Nicklas, 2008).

FIGURE 2. Reedy Fork Elementary School.



TABLE 4. Sustainable Strategies at Reedy Fork.

Categories	Major Strategies
Sustainable Sites	<ul style="list-style-type: none"> • Bioswales and construction wetlands
Water Efficiency	<ul style="list-style-type: none"> • A holistic water cycle approach (rainwater for toilet flushing)
Energy Efficiency	<ul style="list-style-type: none"> • Innovative daylighting design
	<ul style="list-style-type: none"> • Energy efficient building shell, with radiant barriers and solar reflective roofs • Underfloor air distribution system • Indirect lighting with photocells and occupancy sensors • Solar water heating and photovoltaic systems
Materials and Resources	<ul style="list-style-type: none"> • Recycled materials • Local products • Waste management
Indoor Environmental Quality	<ul style="list-style-type: none"> • Innovative daylighting design • Translucent fabric baffles • Indoor environmental quality management during construction • Low VOC products and materials
Experimental Learning	<ul style="list-style-type: none"> • Computer based real-time monitoring of sustainable systems. • Integrative signage • Installation of a sundial

The school incorporated multiple sustainable strategies to lower energy consumption and greenhouse gas emissions and to provide a healthy, comfortable, and productive learning environment for its students and teachers. The major sustainable strategies ultimately implemented in its construction are listed in Table 4.

Sustainable Sites: Bioswales and Construction Wetlands

A series of bio-retention swales and constructed wetlands (Figure 3) capture all of the rainfall that does not fall onto the roof areas of the school, thus minimizing nitrogen runoff in the stormwater before it is absorbed into the soil. No stormwater is discharged into local storm sewers, which significantly reduces infrastructure costs because the existing central sewer line is located some miles from the site. Special soils and a variety of aquatic plants such as Pickerel Weed, Soft Rush, and Spike Rush reduce pollutants from the storm water, again returning clean water to the aquifer. Photovoltaic-drive aerators are used in the constructed wetland to move surface water and to minimize mosquito problems.

FIGURE 3. Bioswales and Constructed Wetland.

Water Efficiency: Rainwater Harvesting System

Reedy Fork uses a rainwater harvesting system to reduce consumption of potable water from municipal systems throughout the school. The school's unique rainwater harvesting system collects rain from one-half of the roof area of the school and sends it to a 45,000-gallon underground storage tank (Figure 4). The collected rainwater is then pumped from the tank to the school, filtered, chlorinated, dyed light blue, and used for flushing each toilet in the school. By using rainwater for toilet flushing, the school is able to save over 767,000 gallons of water that would otherwise be purchased from the City of Greensboro, representing 94% of the water used for toilet flushing in the school each year. By diverting and treating stormwater that would otherwise be directed from the site's roof into the storm sewer collection system, the rainwater harvesting system also reduces the generation of wastewater requiring treatment. This rainwater harvesting system therefore reduces the burden on the municipal water supply and wastewater systems, protecting the natural water cycle.

Energy Efficiency

Innovative Daylighting Design

Natural daylighting is a primary strategy that not only reduces energy consumption but is also a significant factor in improving students' performance, comfort, and wellbeing (Michael, 2002). Consequently, Reedy Fork has adopted several daylighting design strategies. The preferred daylighting design adopted for this building consists of two south-facing clerestories that incorporate curved, interior, translucent light shelves. These light shelves filter sunlight down into occupied areas, bouncing the light deep into the classroom (Figure 5). Highly reflective ceiling tiles enhance this effect. Together, these two strategies require 40% less glass than typical side-lit glazing solutions. Furthermore, as a result of the 20% visible light transmittance of the translucent panel used in the light shelves, glare is reduced and the resulting soft light is well distributed within the space. The curved translucent light shelves provide light immediately under each shelf and bounce diffuse light back into the space, ensuring that the glazing at the wall clerestory aperture maximizes the visible light transmission. In addition, because the white single ply roofing and the curved translucent light shelves provide adequate daylight by themselves, the glass-to-floor ratio is considerably lower than for conventional side-lit solutions. An interior dropped soffit shades the projection screen area and television monitors in classroom spaces without blocking views and without the need for operable clerestory window shading devices.

FIGURE 4. Rainwater Harvesting System.

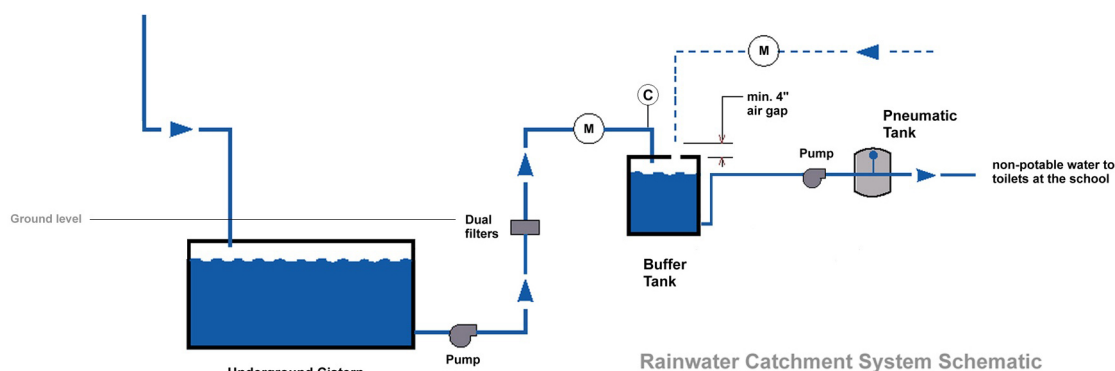
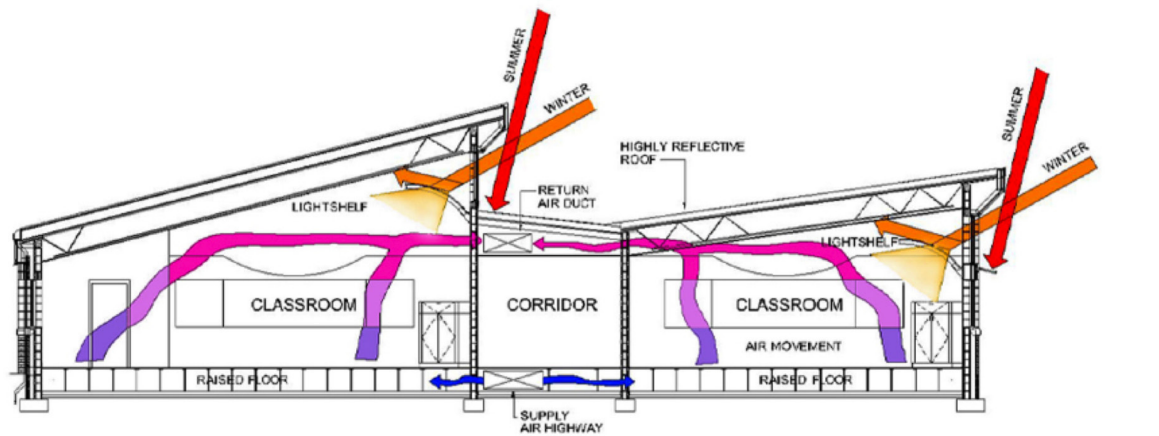


FIGURE 5. Innovative Daylighting Design in Two Classrooms.



South-facing roof monitors with translucent fabric baffles in the light wells provide daylighting in the gymnasium, dining, and multi-purpose areas of the school. These features eliminate direct glare and effectively diffuse light throughout the spaces. Clear, double-glazing is used to maximize visible light transmittance and minimize the glass-to-floor ratio. Overhangs over the monitor windows protect the spaces from direct light during peak cooling periods during the summer. This approach was adopted because of the large room dimensions and because the ceiling cavity is limited due to the thickness of the roofing system, which is shallower than conventional systems using dropped ceilings. As a result, the reflective losses generally associated with deep ceiling cavities were eliminated.

To light the building during periods when daylighting is insufficient, energy efficient indirect fluorescent lighting has been installed throughout the building. The lighting is dimmable and controlled by occupancy and photocell sensors in order to minimize the need for artificial light.

Underfloor Air Distribution

An underfloor air distribution system has been incorporated in classrooms, the media center and administration offices (Figure 6). This raised floor system improves thermal comfort, indoor air quality, flexibility, and energy consumption. At the same time, the system lowered the initial construction costs by reducing the need for expensive steel ductwork. Several courses of masonry were also eliminated by slimming down the ceiling cavity by 2–3 ft throughout. The underfloor strategy also eliminated scaffolding costs and eased the installation and coordination problems usually associated with overhead ductwork, plumbing, electrical, and control wiring.

Solar Energy

A photovoltaic (PV) system was incorporated as a demonstration project into the entry canopy to feed 1.75kW of electricity (3,000KWhs/per year) into the computer lab, entrance sign, and PV pond aerator. This on-site renewable system reduces the environmental and economic impact associated with using fossil fuel energy while improving outdoor environmental quality.

FIGURE 6. Underfloor Air Distribution System.



Figure 7 shows the PV systems installed at Reedy Fork. This figure also shows the solar thermal system installed to provide approximately 75% of the hot water for the school, the majority of which is used by the kitchen. Both systems were incorporated for demonstration purposes.

Materials and Resources: Materials Recycling and Local Products

Materials with recycled content used on the project include carpeting, metal roofing, and acoustic ceiling tiles. A construction waste management plan was required by the G3-Gulford Green Guide during construction to minimize the waste going to local landfills. 60% of the total construction waste was diverted for recycling during construction, helping to establish a market for new vendors in this previously underserved area. The school has also implemented a program for daily recycling on an ongoing basis.

Locally manufactured masonry products were the predominant structural and finish materials for the school. The specifications for these products were developed to encourage the use of local products and manufacturers and preference was given to local manufacturers during the bidding process.

FIGURE 7. Photovoltaic and Solar Hot Water Heating Systems.



Indoor Environmental Quality

Since poor indoor environmental conditions are known to affect the health, safety, and comfort of students, Reedy Fork implemented the following strategies to mitigate potential problems:

- Low VOC adhesives were used for carpet tiles
- No VOC paints and low VOC adhesives were used throughout
- High MERV filters were used throughout
- Xeriscaping was used to minimize use of pesticides and irrigation
- An Indoor Air Quality Management Plan was required during construction
- Rigorous air quality testing was conducted prior to occupancy
- Increased ventilation that uses outdoor air was installed
- CO₂ sensors were installed to determine the need for outside air
- 100% daylighting was provided in all classrooms.

As discussed in the literature review section, reducing indoor air contaminants is associated with increased comfort levels, reduced absenteeism, and increased student productivity and performance.

Experiential Learning

Since Reedy Fork is an elementary school, implementing sustainable features at the school offers a significant opportunity to enhance experiential learning. The entry area at the school features a large sundial, which allows students to connect seasonal changes with the different positions of the earth and sun (Figure 8). Integrative signage is installed throughout the school buildings and site, helping to educate students, staff, the community, and visitors about sustainable features (Figure 8). Reedy Fork also facilitates real-time monitoring of the sustainable design features in the building, enabling students to use their computer monitoring systems



FIGURE 8. Experiential Learning Opportunities at Reedy Fork Elementary School.



to compare the performance of their system with those of similar sustainable systems in other schools across the country and around the world.

One of the major challenges facing those charged with implementing sustainable strategies is the high first cost compared to the cost of conventional strategies. However, many sustainable strategies, particularly the energy saving strategies, can lower operational costs, thus minimizing the total cost of ownership of the school facility over the building's life. These sustainable strategies must be considered at an early stage of the design phase in order to not only achieve the goals of sustainability but also reduce the building's total cost of ownership. Such were the challenges faced by the design team for Reedy Fork Elementary School as part of their design process, discussed next.

DETAILED CASE STUDY: DESIGN PROCESS NEEDED TO ACHIEVE SUSTAINABILITY AND MINIMIZE THE FIRST COST PREMIUM

Implementing a higher degree of sustainable strategies in K-12 facilities is often a struggle due to their relatively higher first costs, even though many sustainable strategies reduce operational costs considerably compared to conventional approaches. The first cost premium of the sustainable building itself is the first barrier to implementing sustainable strategies in the construction industry (Ahn and Pearce, 2007; Ahn, 2010). Therefore, this study examined the issue of how best to achieve the highest possible level of sustainability within a constrained budget in K-12 school facilities, using the RFES as a case study. The sustainable design process related to energy efficient strategies adopted by the Reedy Fork project is depicted in Figure 1 as "Analysis of Energy Efficiency".

Overview of Design Process

The Reedy Fork project team considered a number of different strategies to minimize energy consumption in the building while minimizing first cost premiums. Initial goal setting was undertaken during preliminary design for energy use, water use, and other factors. The project team conducted an energy-efficiency charrette at the early schematic design phase to identify and prioritize applicable energy saving alternatives for the school. Performance modeling was conducted for both energy and water systems during subsequent phases of design to explore various scenarios and identify potential consequences. Before conducting energy simulations for the chosen energy efficient alternatives, the project team developed a model of a base case school. The base case school, designed to serve as a comparison for various scenarios using sustainable design features, was assumed to meet the levels of energy efficiency outlined in the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 90.1-2001 standard. The total construction cost of this base case building was estimated, allowing the incremental first costs for sustainable features to be estimated in turn. The annual energy consumption was simulated using DOE 2.1 based on energy simulation models, eQUEST 3.63, and other daylighting simulation tools, after which the annual energy-use estimates of the sustainable school in several different scenarios featuring different sustainable design features were compared with those for the base case building, and the estimated energy savings and associated incremental costs were calculated. A Life Cycle Cost Analysis was then conducted to calculate the Net Present Value (NPV) and payback periods in order to compare the base case school building with the actual design incorporating various energy efficient features.

Base Case Building and Alternatives

The base case building was constructed of materials based on the minimum requirements set forth by ASHRAE Standard 90.1. No daylighting glass was included. The building in this model was oriented with the front facing east (Figure 9). The central plant in the base case building consisted of a standard efficiency air-cooled screw chiller using a $10^{\circ}\Delta T$ and two 80% efficient condensing type boilers. Classroom wings, media center, and administration areas were served by Variable Air Volume (VAV) systems. The VAV air handlers were equipped with constant volume fans, chilled water coils for cooling and hot water coils for preheating. Air was distributed overhead (mixing ventilation). Each classroom and all the major spaces were served by variable air volume terminal boxes equipped with hot water heating. Multi-purpose, dining, kitchen, and music/art areas were served by overhead constant volume air systems. These constant volume air handlers were equipped with constant volume fans, chilled water coils for cooling, and hot water coils for preheating and reheating. Ventilation (outside) air was provided through the central air-handling units. An air side economizer cycle was used to take advantage of free cooling when the outside air temperature was at 55°F or lower.

Alternative 1: Daylighting

The “Daylighting” alternative was one of the most beneficial of the scenarios in that it was very cost effective while having the potential to improve both the health and productivity of the students and teachers at the school. As previously discussed in the case study, daylighting strategies included improving glazing, south-facing clerestories, white single ply roofing and curved translucent light shelves, highly reflective ceiling tiles, and shading devices.

Alternative 2: Improving Insulation

Increasing the levels of insulation in wall, roof, and floor would reduce energy consumption in the building and improve occupant thermal comfort. Accordingly, the second alternative was to improve insulation values from the ASHRAE Standard 90.1 to a wall insulation level of R-38 and a roof insulation level of R-32.

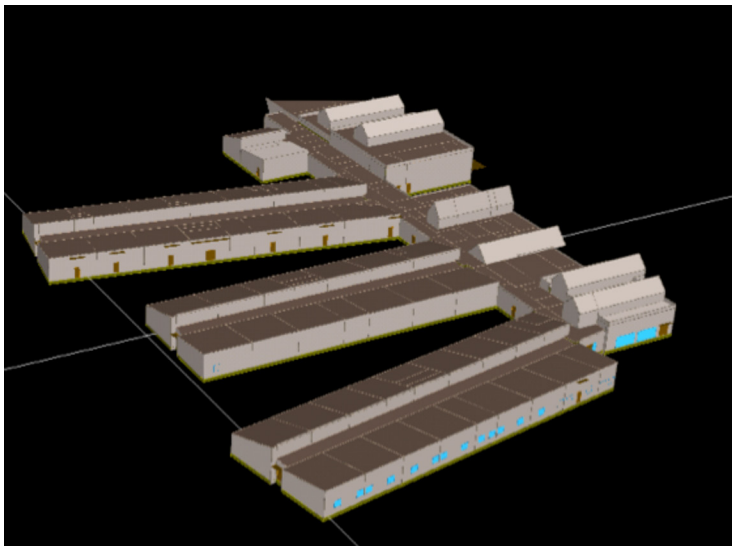


FIGURE 9. Rendering of the base case school building.

Alternative 3: Underfloor Air Distribution Systems

In alternative 3, underfloor air distribution systems were added. As in the base model, the central plant consisted of a standard efficiency air-cooled screw chiller using a $10^{\circ}\Delta T$ and two 80% efficient condensing type boilers. Classroom wings, media center, and administration areas were served by standard Underfloor Air Distribution (UFAD) systems. The UFAD air handlers were equipped with variable air volume fans, chilled water coils for cooling, and hot water coils for preheating. Air was distributed underfloor (mixing ventilation). Each classroom and major space were served by underfloor air terminal boxes equipped with a control damper and hot water heating. Multi-purpose, dining, kitchen, and music/art areas were served by overhead constant volume air systems. Constant volume air handlers were equipped with constant volume fans, chilled water coils for cooling, and hot water coils for preheating and reheating. Ventilation (outside) air was provided through the central air-handling units. An air side economizer cycle was used to take advantage of free cooling when the outside air temperature was 60°F or lower.

Alternative 4: Premium Underfloor Air Distribution System

In the fourth alternative, the building would be served by an upgraded underfloor air distribution system. The central plant consisted of a standard efficiency air-cooled screw chiller using a $10^{\circ}\Delta T$ and two 80% efficient condensing type boilers, as in the other cases. Classroom wings, media center, and administration areas were served by premium UFAD systems. UFAD air handlers were equipped with variable air volume fans, chilled water coils for cooling, and hot water coils for preheating. Air was distributed underfloor (mixing ventilation). Each classroom and major space was served by premium underfloor air terminal boxes equipped with a constant volume fan and hot water heating. Air was supplied through the floor by varying the geometry of the floor outlets. Multi-purpose, dining, kitchen, and music/art areas were served by overhead constant volume air systems. Constant volume air handlers were equipped with constant volume fans, chilled water coils for cooling, and hot water coils for preheating and reheating. Ventilation (outside) air was provided through the central air-handling units. An air side economizer cycle was used to take advantage of free cooling when the outside air temperature was 60°F or lower.

Alternative 5: Premium Efficiency Air Cooled Screw Chiller

Here, the school building was constructed of materials based on the proposed design requirements. The central plant consisted of a premium efficiency air-cooled screw chiller using a $14^{\circ}\Delta T$ and two 94% efficient condensing type boilers. Classroom wings, media center, and administration areas were served by premium UFAD systems. UFAD air handlers were equipped with variable air volume fans, chilled water coils for cooling and hot water coils for preheating. Air was distributed underfloor (mixing ventilation). Each classroom and major space was served by premium underfloor air terminal boxes equipped with a constant volume fan and hot water heating. Air was supplied through the floor by varying the geometry of the floor outlets. Multi-purpose, dining, kitchen, and music/art areas were served by overhead constant volume air systems. Constant volume air handlers were equipped with constant volume fans, chilled water coils for cooling and hot water coils for preheating and reheating. Ventilation (outside) air was provided through the central air-handling units. An air side economizer cycle was used to take advantage of free cooling when the outside air temperature was 60°F or lower.

TABLE 5. Input Parameters and Energy Consumption

	BASE CASE	ALTER. 1	ALTER. 2	ALTER. 3	ALTER. 4	ALTER. 5
WALL INSULATION	R-6.6	R-6.6	R-38	R-38	R-38	R-38
ROOF INSULATION	R-15.4	R-15.4	R-32	R-32	R-32	R-32
GLAZING	View Glass: ASHRAE 90.1 No daylighting	View Glass: Low-e insulated Daylight: clear insulated	View Glass: Low-e insulated Daylight: clear insulated	View Glass: Low-e insulated Daylight: clear insulated	View Glass: Low-e insulated Daylight: clear insulated	View Glass: Low-e insulated Daylight: clear insulated
COOLING PLANT	Air Cooled Screw Chiller (10° ΔT)	Air Cooled Screw Chiller (10° ΔT)	Air Cooled Screw Chiller (10° ΔT)	Air Cooled Screw Chiller (10° ΔT)	Air Cooled Screw Chiller (10° ΔT)	Air Cooled Screw Chiller (14° ΔT)
HEATING PLANT	80% Efficient Hot Water Boiler	80% Efficient Hot Water Boiler	80% Efficient Hot Water Boiler	80% Efficient Hot Water Boiler	80% Efficient Hot Water Boiler	94% Efficient Hot Water Boiler
AIR HANDLING UNITS	Variable Air Volume Air Side Economizer Cycle & Constant Volume Systems	Variable Air Volume Air Side Economizer Cycle & Constant Volume Systems	Variable Air Volume Air Side Economizer Cycle & Constant Volume Systems	Standard Underfloor Air Distribution Air Side Economizer Cycle & Constant Volume Systems	Premium Underfloor Air Distribution Air Side Economizer Cycle & Constant Volume Systems	Premium Underfloor Air Distribution Air Side Economizer Cycle & Constant Volume Systems
AIR DISTRIBUTION	Overhead Air Distribution	Overhead Air Distribution	Overhead Air Distribution	Underfloor & Overhead Air Distribution	Underfloor & Overhead Air Distribution	Underfloor & Overhead Air Distribution
COOLING LOAD PEAK	257 Tons 3,081 kBtu/hr	209 Tons 2,510 kBtu/hr	201 Tons 2,415 kBtu/hr	200 Tons 2,403 kBtu/hr	197 Tons 2,364 kBtu/hr	197 Tons 2,364 kBtu/hr
HEATING LOAD PEAK	(2,536) kBtu/hr	(2,509) kBtu/hr	(2,362) kBtu/hr	(2,398) kBtu/hr	(2,398) kBtu/hr	(2,398) kBtu/hr
ENERGY PERFORMANCE	46.3 kBtu/sqft/yr	38.9 kBtu/sqft/yr	36.8 kBtu/sqft/yr	36.8 kBtu/sqft/yr	36.5 kBtu/sqft/yr	32.7 kBtu/sqft/yr
ELECTRIC END USE	673,835 kWhr	508,371 kWhr	491,206 kWhr	459,487 kWhr	454,562 kWhr	439,961 kWhr
NATURAL GAS END USE	17,420 Therm	16,601 Therm	15,415 Therm	16,413 Therm	16,382 Therm	13,563 Therm
LIGHTING END USE	258,977 kWhr	131,611 kWhr	131,611 kWhr	131,611 kWhr	131,611 kWhr	131,611 kWhr

Table 5 summarizes the detailed input parameters of the five alternatives presented above plus the base case. The next step was to simulate the energy consumption for each using the DOE 2.1E-based energy simulation engine, eQUEST 6.3, to calculate the cooling peak load, heating peak load, energy performance, and end-use consumption of electricity, natural gas, and light. All simulated data is also summarized in Table 5.

Incremental First Costs for the Five Alternatives Based on the Base Case Cost

Each of the different alternatives considered to reduce annual energy consumption would incur different design and construction costs if adopted. Thus, it was necessary to estimate the incremental costs of each of the energy efficient features that could be implemented to enhance the facility's energy performance. The cost of each feature was estimated based on drawings and construction documents based on input from the architecture firm and the general contractor. To estimate the incremental first costs of energy efficient features, it was necessary to estimate the first cost adjustments based on the base case because the cost involved in implementing energy efficiency features should be offset by a corresponding reduction in the size of HVAC system needed. Thus, the final incremental first cost for each of the energy efficiency features was estimated by combining the changes in the construction costs and the HVAC costs. The incremental first costs related to energy saving features are summarized in Tables 6 and 7.

TABLE 6. Incremental First Cost Related to HVAC Systems (in US dollars)

ECONOMIC COMPONENT	BASE	ALTER. 1	ALTER. 2	ALTER. 3	ALTER. 4	ALTER. 5
Cooling Equipment	90,000	80,000	80,000	78,000	78,000	85,000
Heating Equipment	20,000	20,000	20,000	15,000	15,000	30,000
Hydronic Pumps	28,000	28,000	28,000	25,000	25,000	20,000
Hydronic Piping & Accessories	220,000	215,000	215,000	215,000	215,000	200,000
Air Handling Units	200,000	200,000	200,000	225,000	225,000	225,000
VAV Boxes w/ HW Coil	85,000	85,000	85,000	100,000	100,000	100,000
Ductwork & Accessories (Air Hwy. incl.)	350,000	350,000	350,000	350,000	300,000	300,000
Air Distribution Equipment	55,000	55,000	55,000	55,000	90,000	90,000
Exhaust Fans	5,000	5,000	5,000	5,000	5,000	5,000
Unit Heaters	5,000	5,000	5,000	5,000	5,000	5,000
Breechings and Vents	5,000	5,000	5,000	5,000	5,000	5,000
Controls and Instrumentation	175,000	175,000	175,000	175,000	200,000	200,000
Test & Balancing	25,000	25,000	25,000	25,000	30,000	30,000
Miscellaneous	50,000	50,000	50,000	50,000	50,000	50,000
Architectural Cost	0	0	0	0	0	0
Total First Cost for HVAC	1,313,000	1,298,000	1,298,000	1,328,000	1,343,000	1,345,000
Incremental First Cost for HVAC	0	(15,000)	(15,000)	15,000	30,000	32,000

TABLE 7. Summary of Incremental First Costs (US Dollars)

	Incremental First Cost (\$/ ft ²)	Incremental First Cost (\$)	HVAC Cost Adjustment (\$)	Total Accumulated Incremental Cost (\$)
Base Case	\$0/ft ²	\$0	\$0	\$0
Alternative 1	\$2.77/ft ²	\$240,990	(\$15,000)	\$225,990
Alternative 2	\$1.28/ft ²	\$111,765	(\$15,000)	\$337,755
Alternative 3	\$1.37/ ft ²	\$119,190	\$15,000	\$486,945
Alternative 4	\$1.37/ ft ²	\$119,190	\$30,000	\$501,945
Alternative 5	\$1.37/ ft ²	\$119,190	\$32,000	\$503,945

Annual Energy Cost Savings Due to Energy Efficient Features

In order to determine the best, most cost effective energy saving strategies for the Reedy Fork project, annual energy consumption for the five alternatives and the base case building were simulated using the DOE 2.1E-based simulation tool. To estimate annual energy consumption costs, the unit prices for electricity and gas were based on data from local electricity and gas providers, including Duke Energy and Piedmont Natural Gas. The electricity unit price used in the simulation was \$0.09725/kWh and the gas unit price was \$1.080130/therm. Total energy cost was equal to the cost of electricity plus the cost of gas.

Based on these prices for energy, the total annual energy cost of the five alternatives was estimated. Table 8 shows the total annual energy savings for each of the five alternatives compared to the base case design. The annual energy cost of the base case was \$84,346, combining the electricity cost of \$65,530 and the gas cost of \$18,816 (Figure 10 and Table 8). The following subsections compare each alternative with the base case as well as the previous alternatives. Note that the alternatives are considered to have a cumulative effect on energy consumption, with each alternative including the features of all previous alternatives.

Alternative 1: Daylighting

Implementing the daylighting system would reduce annual energy consumption within the building and thus reduce annual energy costs. Since the proposed daylighting strategy reduced electrical lighting use from 258,977kWh to 131,611kWh based on the simulation result, it would be possible to reduce annual electricity cost by \$12,386 for lighting, from \$65,530 to \$49,439. Daylighting strategies also reduced the gas cost by \$885, from \$18,816 to \$17,931 by reducing the building's heating load in winter. Thus, the total reduction in the energy costs achievable by implementing this option was about \$16,976 (Figure 10 and Table 8).

Alternative 2: Improving Insulation

Improving the level of insulation would reduce both the heating and cooling loads of the building. Based on the energy modeling, improving the insulation should reduce annual electricity costs by \$1,670 compared to Alternative 1 (Table 8). In addition, better insulation would also reduce the annual gas cost by \$1,281 compared to Alternative 1. Therefore, improving insulation could reduce the annual energy cost by \$19,926 compared to the base case building (in conjunction with Alternative 1), an improvement of \$2,950 compared to Alternative 1 alone (Figure 10 and Table 8).

Alternative 3: Underfloor Air Distribution Systems

The underfloor air distribution system was estimated to additionally reduce the annual electricity cost by \$3,084 compared to Alternative 2, although the annual gas cost went up by \$1,078 (Table 8). Since the annual electricity cost saving exceeded the increased annual gas cost, adding underfloor air distribution to the previous two alternatives would reduce the annual energy costs of operating the facility by \$21,933 compared to the base case, or by \$2,007 more than that achievable by implementing Alternative 2 (Figure 10 and Table 8).

Alternative 4: Premium Underfloor Air Distribution System

Upgrading the underfloor air distribution to a premium system should further reduce the annual electricity cost by \$479 and the gas cost by \$33 compared to Alternative 3. The premium underfloor air distribution system takes the total savings in the annual energy cost to \$22,445 compared to the base case, \$512 more than that for Alternative 3 (Figure 10 and Table 8).

Alternative 5: Premium Efficiency Air-Cooled Screw Chiller

The addition of a premium efficiency air-cooled screw chiller should reduce the annual electricity cost by another \$1,420 and the annual gas cost by \$3,045 compared to Alternative 4, lowering the annual energy cost by \$57,436 compared to the base case cost of \$84,346 (Figure 10 and Table 8), potentially saving \$26,910 every year at current prices.

Life Cycle Cost and Payback Period

Life cycle cost is a very important decision making criterion because it considers all the costs associated with a facility, from construction costs to operation, maintenance, repair, and replacement costs throughout the facility's life span. Thus, calculating a Net Present Value (NPV) by Life Cycle Cost Analysis (LCCA) for all alternatives compared to the base case

FIGURE 10. Annual energy costs for alternatives.

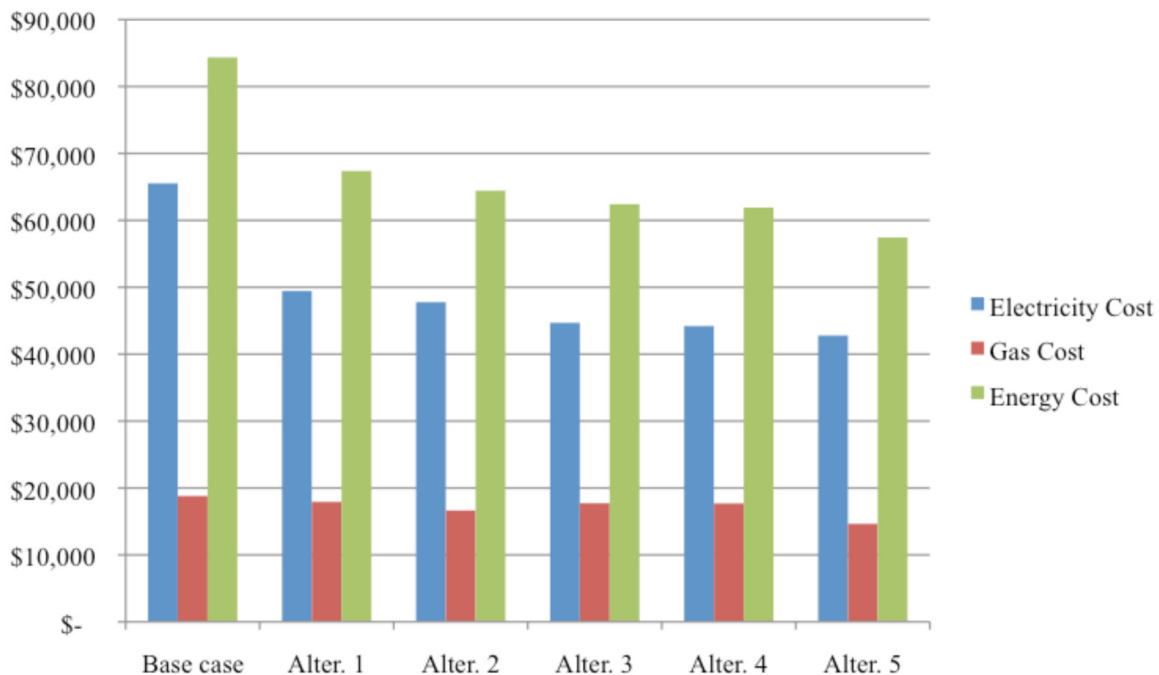


TABLE 8. Annual Energy Cost Saving by Energy Efficient Features

	Measure	Electricity (kWhr)	Elec. Cost (\$)	Total Elec. Savings (\$)	Gas (therms)	Gas Cost (\$)	Total Gas Savings (\$)	Total Cost (\$)	Total Savings (\$)	Incremental Savings (\$)
Base case		673,835	65,530		17,420	18,816		84,346		
Alter. 1	Daylighting	508,371	49,439	16,091	16,601	17,931	885	67,370	16,976	16,976
Alter. 2	Insulation	491,206	47,770	17,761	15,415	16,650	2,166	64,420	19,926	2,950
Alter. 3	Underfloor	459,487	44,685	20,845	16,413	17,728	1,088	62,413	21,933	2,007
Alter. 4	Premium Air Distribution	454,562	44,206	21,324	16,382	17,695	1,121	61,901	22,445	512
Alter. 5	Premium Air Chiller	439,961	42,786	22,744	13,563	14,650	4,166	57,436	26,910	4,465

TABLE 9. First Cost Premium and Life Cycle Costs

Alternatives	First Cost Premium	Life Cycle Cost
Base case	\$0	\$1,659,670
Alternative 1	\$225,990	\$1,557,746
Alternative 2	\$337,755	\$1,611,390
Alternative 3	\$486,945	\$1,721,105
Alternative 4	\$501,945	\$1,726,005
Alternative 5	\$503,945	\$1,581,147

would help decision makers evaluate the financial effectiveness of energy efficiency strategies in the Reedy Fork project because it reveals the relationship between the first cost premiums of energy efficient strategies and their potential O&M savings during the operation phase. For the LCCA, the following assumptions were applied:

- Real discount rate for the analysis: 3.0% (OMB Circular No. A-94)
- Length of analysis: 25 years
- Energy price escalation: 3%

Table 9 shows both the first cost premium over the base case and the total life cycle cost for each alternative obtained from this analysis.

The LCCA revealed that the daylighting strategy (Alternative 1) resulted in the lowest LCC of \$1,577,746, \$101,924 lower than the base case. However, Alternative 5 had the second lowest LCC of \$1,581,147 and resulted in the lowest annual energy consumption in the building, even though it required a greater first cost premium. After assessing the first cost premiums and LCC of all the energy efficient alternatives, the project team, in particular the architecture firm and the owner, chose to implement alternative 5 because it would not only minimize annual energy consumption but also reduce operating costs over the building's life. As a result, Reedy Fork consumes less than half the energy of a typical American school; its position in the top 10% of school facilities in the United States has led to it being awarded the Energy Star designation. This business case illustrates how integrating holistic and sustainable energy efficiency strategies can contribute to the goal of sustainability in the building industry while at the same time reducing or eliminating first cost premium barriers.

DISCUSSION AND CONCLUSION

The RFES project team sought to implement sustainability strategies designed to reduce energy and water consumption and costs; improve the learning environment in the school through daylighting, better temperature and thermal control, better acoustic control, and better indoor air quality, along with other elements related to the school facility; and increase student, teacher, and community awareness of energy, water and related issues such as financial management, air quality, climate change, and new sustainable technology. One of the most significant barriers to the construction of a sustainable building is the initial cost premium incurred by incorporating sustainability strategies. However, the actual bid price for Reedy Fork (\$151/ft²) was only slightly higher than the average bid for an elementary school (\$147/ft²) in North Carolina (NCDPI, 2010). This low initial construction cost premium primarily resulted from the whole-building design approach adopted in the early design

process. In addition, the energy efficiency strategies that were built in to the new Reedy Fork school facility are expected to reduce the annual electricity demand from the estimated base case consumption of 673,835 KWh to 439,961KWh, with a corresponding savings of \$22,744 (from \$65,530 for the Base Case to \$42,786 for Alternative 5). The reduction in the annual electricity consumption would also reduce greenhouse gas emissions, thus reducing contributions to global warming. In addition, the energy efficiency strategies would reduce annual gas consumption from 17,420 therms to 13,563 therms, reducing the annual gas bill by \$4,166. Water saving strategies, including the rainwater harvesting system employed in the final design, are estimated to reduce the estimated annual potable water demand by 765,565 gallons (94% of required water volume). These water saving strategies will also reduce the stormwater discharge from the site by 89,765 gallons (90% reduction).

In addition to the literature review and case study described above, this study examined how an integrated design process at the design phase could be utilized to minimize annual energy consumption while at the same time minimizing the first cost premium. This integrated design process started by recruiting project team members including architects, owner's representative, consulting mechanical and electrical engineers, and others to work together from the project outset to develop sustainable solutions that had multiple benefits including energy and life cycle cost savings. This study demonstrates how an integrated design approach using a energy simulation tool and LCCA at the design phase can help project design teams make intelligent decisions during design development that minimize both life cycle costs over the building's life and the first cost premiums of implementing energy efficiency strategies, resulting in healthier learning environments for teachers and students. This integrated design process could usefully be applied to other school facility development projects to create more sustainable educational facilities that contribute to efforts to address the often severe budget constraints that limit many school districts in the United States.

Other benefits to Reedy Fork School that have resulted from integrated design and sustainability strategies include both indoor environmental benefits and improved learning opportunities. Due to the various indoor air quality strategies adopted for the school, Reedy Fork can provide a healthier, safer learning environment for its students and teachers than it would otherwise have done. This is expected to enhance student performance and improve teacher and support staff satisfaction and retention. The school has also implemented a real-time monitoring system for its sustainable strategies and a computer monitoring system that enables students to compare the performance of their system with that of similar sustainable systems in other schools across the country and around the world. This system will allow the performance of the building to be incorporated as part of the curriculum in various types of classes by interested teachers. To support experiential learning, Reedy Fork also incorporated a sundial and interactive signage to educate students, staff, teachers, the community, and visitors about the facility's sustainable features. These tactics for experiential learning can help all participants in Reedy Fork improve their attitude and behavior toward sustainability.

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