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AUTHOR	Plympton, Patricia; Conway, Susan; Epstein, Kyra
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ABSTRACT

This document discusses evidence regarding daylighting and student performance and development, and presents four case studies of schools that have cost effectively implemented daylighting into their buildings. Case studies reveal that design and construction strategies that incorporate daylighting do not significantly increase costs over conventionally designed schools. Students do benefit in increased performance and general health when school designs incorporate daylighting in the schools. Design tips are included as are resources for information on daylighting and other renewable energy and energy-efficient technologies for schools. (Contains 27 references.) (GR)

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Patricia Plympton
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DAYLIGHTING IN SCHOOLS: IMPROVING STUDENT PERFORMANCE AND HEALTH AT A PRICE SCHOOLS CAN AFFORD

Patricia Plympton
Susan Conway
Kyra Epstein
National Renewable Energy Laboratory
901 D Street SW, Ste 930
Washington, DC 20024

ABSTRACT

Between 2000 and 2007, at least 5,000 new schools will be designed and constructed to meet the needs of American students in kindergarten through grade 12 schools. National efforts are underway to encourage the use of daylighting, energy efficiency, and renewable energy technologies in school designs, which can significantly enhance the learning environment. Recent rigorous statistical studies, involving 21,000 students in three states, reveal that students perform better in daylit classrooms as well as indicate the health benefits of daylighting. This paper discusses the evidence regarding daylighting and student performance and development, and presents four case studies of schools that have cost effectively implemented daylighting into their buildings.

1. BENEFITS OF DAYLIGHTING ON STUDENTS

Recent studies show that daylighting in schools may significantly increase students' test scores and promote better health and physical development—and can be attained without an increase in school construction or maintenance costs.

One study analyzed the test scores of more than 21,000 students in three school districts in California, Washington, and Colorado, using multivariate linear regression to control for other influences on student performance. (1) These are profound results, which have been carried out under rigorous statistical controls. In one school district, students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% faster on reading tests when compared to students in the least daylit classrooms. In the other two school districts, "students in classrooms with the most daylighting were found to have 7%–18% higher scores than those in the least." (2) Another study compared test scores for students in three daylit schools in North Carolina to scores in the county school system as a whole and other new schools within the county. (3) Test scores for over 1,200 students in daylit schools were compared to scores for the students in the county. The study showed that students who attended daylit schools outperformed the students in non-daylit schools by 5%–14%. (4)

Two studies suggest that daylighting in classrooms can promote overall health and physical development. In a study of 90 Swedish elementary school students, researchers tracked behavior, health, and cortisol (a stress hormone) levels over the course of a year in four classrooms with varying daylighting levels. "The results indicate work in classrooms without daylight may upset the basic hormone pattern, and this in turn may influence the children's ability to concentrate or cooperate, and also eventually have an impact on annual body growth and absenteeism."(5)

In another study in Alberta, Canada, over a two-year period, children attending elementary schools with full spectrum light were compared with children in classrooms with conventional lighting. (6) The results of the study suggest that the students in the full-spectrum lit classrooms had fewer days of absence per year as well as enhanced health effects. Daylighting allowed for the heating, ventilation, and air conditioning (HVAC) system to be downsized, which in turn reduced the noise levels in both the classrooms and library, thus enhancing the learning environment.

In addition, schools found that increasing the amount of daylighting in school design did not necessarily represent an increase in school construction and operation costs. Incorporating design components such as light sensors, and optimizing mechanical and electrical systems due to reduced cooling and lighting loads, can actually reduce the initial capital cost because of the reduced size and cost of HVAC equipment. Furthermore, the operations and maintenance costs are reduced due to a smaller electrical load and a smaller number of lighting fixtures to maintain. In a study conducted in daylit schools in North Carolina, investments in daylighting could be paid back within three to nine years. For five daylit schools in North Carolina, authors of the study state that "the cost of the daylighting components have added little to the first-cost of the projects." (7) Therefore, optimizing daylighting in the construction of new schools is an attractive option to potentially improve the performance and health of America's students.

2. CASE STUDIES

The following case studies describe schools that have successfully won approval from school boards and administrators to incorporate the benefits of daylighting into their learning environments.

2.1 Durant Road Middle School, Raleigh, North Carolina

Capacity	1,300 students
Grades	6-8
Size	149,250 sq.ft.
Budget	$16 million
Award Cost	$12.3 million
Completed	1995
Estimated annual savings	$21,000

The energy saving features used at the Durant Road Middle School have reduced the energy use for lighting, ventilation, and heating by 50%–60%. Typically, these three energy costs are the greatest energy expenses for a school district. Moreover, Durant is a year-round school, thus the summer cooling costs were a major concern for school board members and administrators. To reduce these costs, the radiant barrier on the roof reflects up to 90% of the radiant heat in the summer. (8)

According to the principal, Tom Benton, "The daylit classrooms have increased the well being of the students and the teachers and it is at least partly responsible for the record high attendance rates. We are running about 3% ahead of the rest of the county in attendance. We stay around 98%. It is a model school and students are proud to show it off."(9)

Fig. 1 Durant Road Middle School saves the district $21,000 annually.

Design features include:

- Orientation of the building is lengthwise on an east/west axis to optimize placement of the north and south facing daylighting monitors and to reduce heat gain.
- South-facing and north-facing roof monitors provide daylighting to classrooms, cafeteria, gymnasiums, and hallways with a corresponding 30% overall increase in glazing for daylighting and an absence of glazing on the east and west sides.
- The roof is equipped with a radiant barrier that reflects more than 90% of the radiant heat. There is low-e glazing throughout, including the roof monitors.
- The reduced cooling load required a 370-ton chiller instead of a 400-ton chiller needed for a similar school, saving initial and energy operation costs.
- High-efficiency lighting equipment and controls are used, including motion sensors and light-level sensors to automatically adjust energy-efficient fluorescent lighting as needed.
- An energy management system controls the amount of outside air circulation to correspond with the occupancy level of the school, rather than constant operation, which is typical of school buildings.(10)

Durant's energy savings translate into monetary savings of $21,000 annually. (11) The school's natural daylighting is supplemented by electric lights controlled by automatic dimming controls that activate or dim lights as daylight levels fluctuate. In 1997, the American Institute of Architects voted the design of Durant Middle School as one of the top ten most environmentally friendly buildings in the United States. (12) "We've created a healthier learning environment that uses a lot less energy and costs about the same to build."(13)

2.2 Dena Boer Elementary School, Salida, California

Capacity	819 students
Grades	K-5
Size	47,000 sq.ft
Budget	$4.7 million
Completed	February 1997
Minimum estimated annual savings	$9,000 or 1.85 kWh/sq.ft-yr. (14)

Completed in 1997, Dena Boer Elementary School uses daylighting in all the classrooms. Although this feature costs an additional $2,500 per room (including the skylights and the cost of designing the ceiling around them), the school maintained a standard construction budget. To achieve this end, the architect, Ken Kaestner of Ken Kaestner and Associates, designed the school "from the inside out," concentrating on the classrooms.

"You have to make the most of the funds you have by taking away from certain areas and putting it towards the good stuff such as the skylights. It is a matter of how you want to spend your money—in the classroom or on the outside. We spent more money on the daylighting features, but we made up for those costs by cutting down on outside elements. For example, we made the exterior of the building very simple. Instead of brick, you build with concrete."(15)

Fig. 2 Dena Boer Elementary School diverted funds from hallway and exterior construction to enhance the learning environment through daylighting.

Funds were diverted from hallway construction as well as from the exterior of the building and redirected to the classrooms to enhance the learning environment. The daylighting design uses four 4-ft x 4-ft skylights in each classroom. With daylighting, fewer lighting fixtures were required; the cost of electric lighting was reduced and the savings applied towards the cost of daylighting the learning spaces.

School design enhancements include:

- Louvers controlled from an electronic switch on the walls are installed at the top of the skylight wells to manually modulate daylight levels.
- Skylights are triple-glazed with a prismatic, spectrally-selective acrylic material that refracts light throughout the room, eliminating direct-beam sunlight.
- High-efficiency fluorescent lights—T-8s with electronic ballasts—are recessed in the horizontal ceiling bands between the skylight wells. (16)

2.3 Roy Lee Walker Elementary School, McKinney, Texas

Capacity	680 students
Grades	K-5
Size	70,000 sq.ft
Budget	$9.3 million
Completed	July 2000
Estimated Payback	
Daylighting	3-5 years
Other energy efficient and renewable technologies	10-15 years

In 1997, Texas' McKinney Independent School District was awarded a $200,000 grant from the Texas State Energy Conservation Office for the design and engineering of a sustainable school. (17) As the architects developed the design, they estimated that the construction cost of the school would be 15% more than an elementary school of the same size built in the district at the same time as Roy Lee Walker Elementary School. To convince the school board of the value of incurring the additional costs, the design team at SHW Group Inc. divided incremental costs to reflect the amount of money that would be spent per child over the next 50 years (the expected life of a school in McKinney), which was less than $30 per child. The number is the result of dividing the increased cost, by the number of students, by the number of years that the school will be open: $1 million/ 680 students/ 50 years. This method of analyzing the budget showed the initial costs in a different perspective, and made the enhancement seem less cost prohibitive.

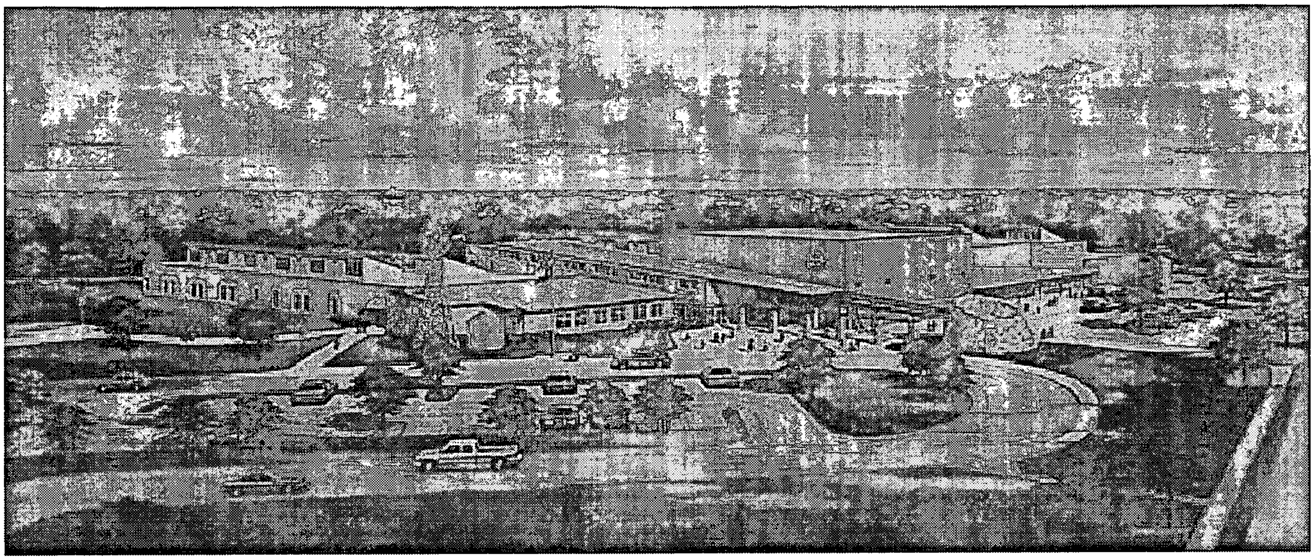

Fig. 3 Estimated payback for daylighting, one of many sustainable features at Roy Lee Walker Elementary School, is three to five years.

"The design team also presented the findings of various studies on student performance and daylighting. These findings convinced school board members that daylighting would improve education for children and also appealed to the board members' sense of responsibility," said Scott Milder of SHW Group. (18)

In addition to the benefits that daylighting will provide to each child, there will also be a monetary payback through the saved energy. The projected savings of the school will result from downsizing the HVAC system since daylighting has less heat gain than fluorescent lights. The HVAC system is a highly efficient air cooled mechanical split system—which will allow greater occupant control. (19)

The lighting system will also be downsized, which will result in reduced maintenance costs since staff will not have to replace light bulbs as often. Daylighting will be the main feature of this school, which will incorporate other technologies such as rainwater collection; solar water heating; a windmill for circulating the water in the building; energy-efficient lighting; and thermal pane glass to reduce heat gain. An "eco-pond" in the back of the school allows students as young as kindergartners to learn about freshwater ecology. (20) Wherever possible, materials selected are recycled—such as the carpeting—and are manufactured or quarried in Texas.

The main feature, daylighting, has a payback of three to five years; the total payback for all the features is 10-15 years. According to Scott Milder of SHW Group, "School boards will be recognized for innovative thinking. Districts that want to design similar schools throughout the country have contacted Walker's architects. The school board members who approved this approach in design are in the spotlight." Walker has been selected by the American Institute of Architects' Committee on the Environment as one of the 1999 Earth Day Top Ten Buildings, recognized for its "viable architectural design which protects and enhances the environment." (21)

According to Wyndol Fry, assistant superintendent of the McKinney Independent School District, all of Walker's sustainable features were intended to not only provide health benefits of daylighting, but to cultivate students' interest in energy and environmental issues. The idea seems to be popular.

"The McKinney School District just redrew the attendance zones for our district that affected more than 11,000 students, and so many parents wanted their children to attend Walker that the school board committeed to build two more sustainable schools," Fry said. (22)

2.4 J.J. Pickle Elementary School/St. Johns Multipurpose Facility, Austin, Texas

Capacity	720 – 800 students
Grades	Pre-K - 5
Size	115,000 sq. ft (68% school use/32% multipurpose facility use)
Budget	$ 13.4 million

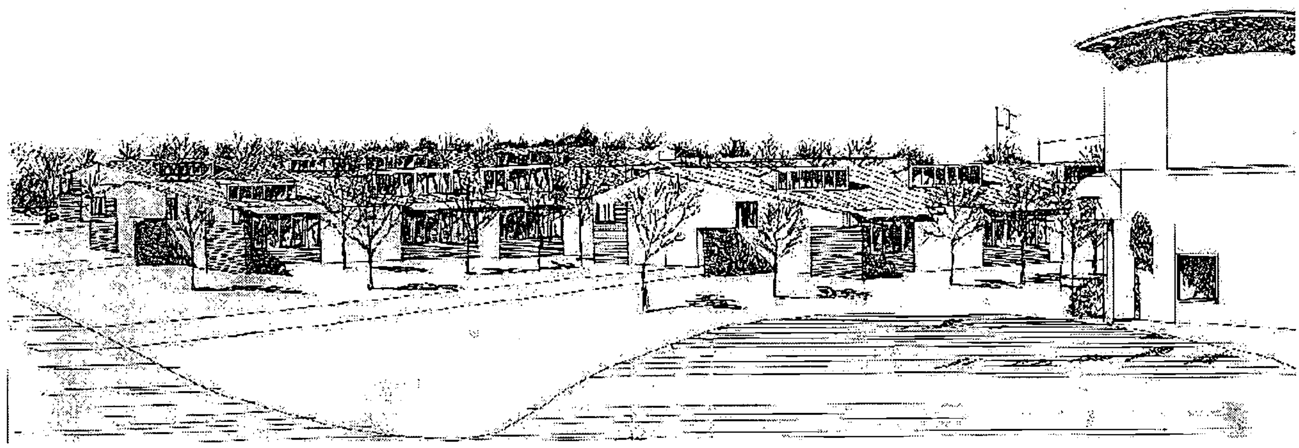

Fig. 4 J.J. Pickle Elementary School/ St. Johns Multipurpose Facility incorporated daylighting into the design while saving an estimated $32,000 annually in operation costs.

Anticipated Completion	August 2001
Estimated annual savings	$32,000

The Austin Independent School District identified a need for a new neighborhood elementary school in an area of ongoing neighborhood revitalization. Part of the neighborhood revitalization included a desire to have a facility that would engage students after school hours. Because of the benefits of constructing a facility to meet both needs, the city passed a bond for the additional funds needed to construct a "full service school," which included the multipurpose facility elements operated by the city. (23) In 1997, the Austin Independent School District also received a $200,000 grant from the Texas State Energy Conservation Office to hire a team to study and incorporate sustainable design features for a combined school/multipurpose facility. City of Austin policy mandates that all city projects incorporate some sustainable features, as the budget will allow. Austin Independent School District projects have had some "green" features, but not as many as a typical city project.

As a result of the funds received from the State Energy Conservation Office, the architectural team has been able to reaffirm the school district's commitment to sustainability. According to Chris Noack, project manager/project architect from TeamHaas Architects, which designed Pickle Elementary School/St. Johns Multipurpose Facility, "When we were hired for the job, the district was committed to some energy-efficient features. Austin Independent School District current prototype elementary school buildings have some energy-efficient features; ground source heat pumps are the standard HVAC system. We have improved on the standard practice by incorporating daylighting, improved lighting, and rainwater collection. Due to Pickle's size and hours of operation, a central plant has proved to be the most energy efficient HVAC system."(24)

The school design incorporates the following features:

- Building is oriented such that maximum light will be allowed in from the north and south faces, which is easier to control, rather than from the east and west faces, which results in excessive heat gain.
- To optimize daylighting, clerestory windows are used on the south-facing classrooms. The clerestory windows are made of a polycarbonate material that provides a translucent surface for the sunlight to pass through, yet is lighter than glass and less susceptible to breakage. A sloping metal roof will improve daylighting by bouncing light into the clerestories.
- All windows at eye-level use a ¼-inch green-tinted, infrared-absorbing glass, which is very effective in Austin's climate.
- The north-facing classrooms have tall "studio" style windows to let daylight penetrate deep into the space.
- Optimized mechanical system is designed specifically for the building to increase energy efficiency and reduce operations and maintenance costs.
- Currently in conceptual design, the sloping metal roof will also be used for rainwater collection for the cooling tower; water is typically purchased from the city—representing significant cost savings. (25)

The joint use of the building has saved the city and school district money, since they can share features, such as the gym, bathrooms, parking and building support staff, which would otherwise be duplicated in two separate buildings. The multipurpose facility will include a city branch library, health and human services offices, a community policing office, and a parks and services recreation center, which shares the gym with the school. These neighborhood services also share meeting space among themselves. The gym will use daylight supplemented by fluorescent lighting, which is superior to the metal halide lights often used in gyms because it has less glare, better color, more flexible (via dimmer switches), and is more energy efficient. (26)

The energy costs for Pickle are estimated to be 31% less than standard schools, resulting in $32,000 of annual savings (energy use will be 18% lower and peak will be 46% lower). (27) The consultant team used DOE-2 to model the school.

3 CONCLUSIONS

Through inventive and resourceful design strategies, construction costs for schools do not represent a significant cost increase over conventionally designed schools. And, students who attend these schools benefit from daylighting, both in terms of increased performance (as measured by test scores) and general health and well being.
Design strategies include:

- Diverting funds away from building exteriors and hallways and applying them to daylighting features in classrooms.
- Orienting the building to maximize the daylighting potential while minimizing the undesired heat gain.
- Downsizing the cooling system, lowering utility and operations and maintenance costs, both of which represent a major cost savings, offsetting most or all of the cost increases associated with the daylighting features.
- Promoting whole-building design by optimizing mechanical system sizing and coordination of building systems (e.g. motion sensors and light-level sensors shut off or dim electric lights when there is sufficient daylight).

4 RESOURCES

Information on daylighting and other renewable energy and energy-efficient technologies for schools can be found on the U.S. Department of Energy's EnergySmart Schools web site: www.eren.doe.gov/energysmartschools and the Department of Energy's Rebuild America web site http://www.eren.doe.gov/buildings/rebuild/. Information can also be obtained by calling the Energy Efficiency & Renewable Energy Clearinghouse (EREC) at 800-DOE-EREC or TDD, 1-800-273-2957.

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Over the next seven years, at least 5,000 new schools will be designed and constructed to meet the needs of American students in kindergarten through grade 12 schools. National efforts are underway to encourage the use of daylighting, energy efficiency, and renewable energy technologies in school designs, which can significantly enhance the learning environment. Recent rigorous statistical studies, involving 21,000 students in three states, reveal that students perform better in daylit classrooms and indicate the health benefits of daylighting. This paper discusses the evidence regarding daylighting and student performance and development, and presents four case studies of schools that have cost effectively implemented daylighting into their buildings.

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