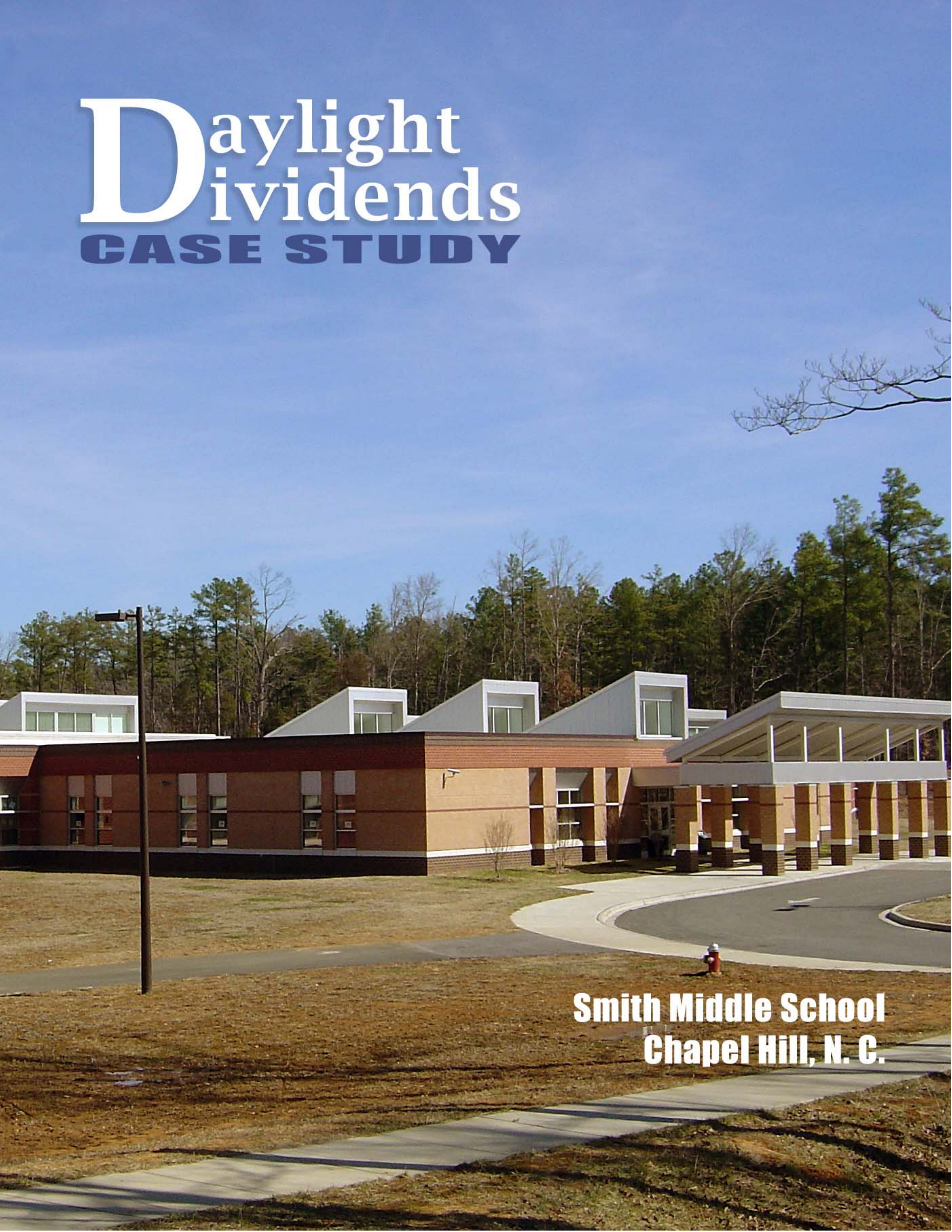
Daylight Dividends
CASE STUDY



Smith Middle School
Chapel Hill, N. C.

Image: Innovative Design

Daylight Dividends Case Study

Location .... R. D. & Euzelle P. Smith Middle School
9201 Seawell School Road
Chapel Hill, NC 27516

Completed 2001

Architect .... Corley Redfoot Zack, Inc.

Consulting Engineer .... Reece, Noland & McElrath

Daylighting Design .... Innovative Design

Daylight Dividends promotes the effective use of daylighting strategies in nonresidential buildings. Part of this effort focuses on impartially evaluating the use of daylight in different building types, reporting those results so that others considering daylighting can see what works and what does not.

The Lighting Research Center and Daylight Dividends sponsors express their sincere thanks to the principal, faculty, staff, and students of Smith Middle School as well as the staff of Innovative Design for their assistance in developing this case study.

In 2001, the R. D. & Euzelle P. Smith Middle School opened its doors, embracing not only a new student body, but also an environmentally conscious attitude. Part of the Chapel Hill-Carrboro City School District in Chapel Hill, North Carolina, the Smith Middle School exemplifies good daylighting practice. This case study documents that good daylighting design incorporated at a building's inception yields positive results in energy savings (64% reduction in lighting energy), comfort (teachers and students favor daylighting in the classrooms), and a reasonable return on the added investment (4.2 years).

Background

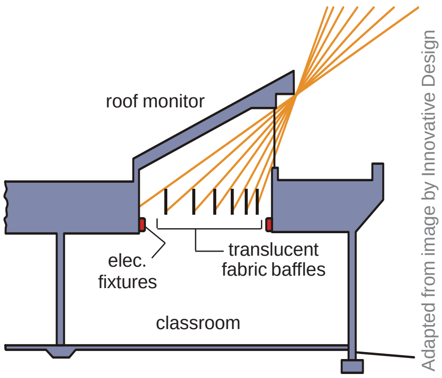
The progressive community of Chapel Hill lies within North Carolina's renowned Research Triangle—named for the triangle formed by the area's three major research universities: the University of North Carolina in Chapel Hill, Duke University in Durham, and North Carolina State University in Raleigh. This technology-focused business region is home to more than 140 organizations in a wide variety of fields such as biotechnology, telecommunications, microelectronics, and information technology.

Education and environmental conservation are of paramount importance to the Chapel Hill community. With those themes as a guide, the school district directed the design and construction of Smith Middle School to include daylighting features and other environmentally friendly attributes. Green features include a solar water heating system, 2-kilowatt photovoltaic panels, and a rainwater collection system that provides sufficient filtered and chlorinated water for all the toilets in the school, as well as the irrigation system for an adjacent athletic field. The water catchment system saves an estimated 2.6 million gallons of water yearly.

Since the completion of the building, the school district has required every new school to employ a daylighting strategy. This approach even includes performance goals for school principals to include sustainability in teaching and building performance.

Triangular-shaped roof monitors provide most of the daylighting within the classooms.

Fabric baffles help ensure uniform light distribution while eliminating potential glare from the roof monitors.



Roof monitor scheme.

Light shelves and angled soffits maximize and redirect daylight upward through the windows to light-colored ceilings.

Design Strategy

All classroom corridors run east to west, maximizing the southern exposure potential for the roof monitors. The design also minimizes east- and west-facing walls and windows to reduce difficult to control sun exposure.

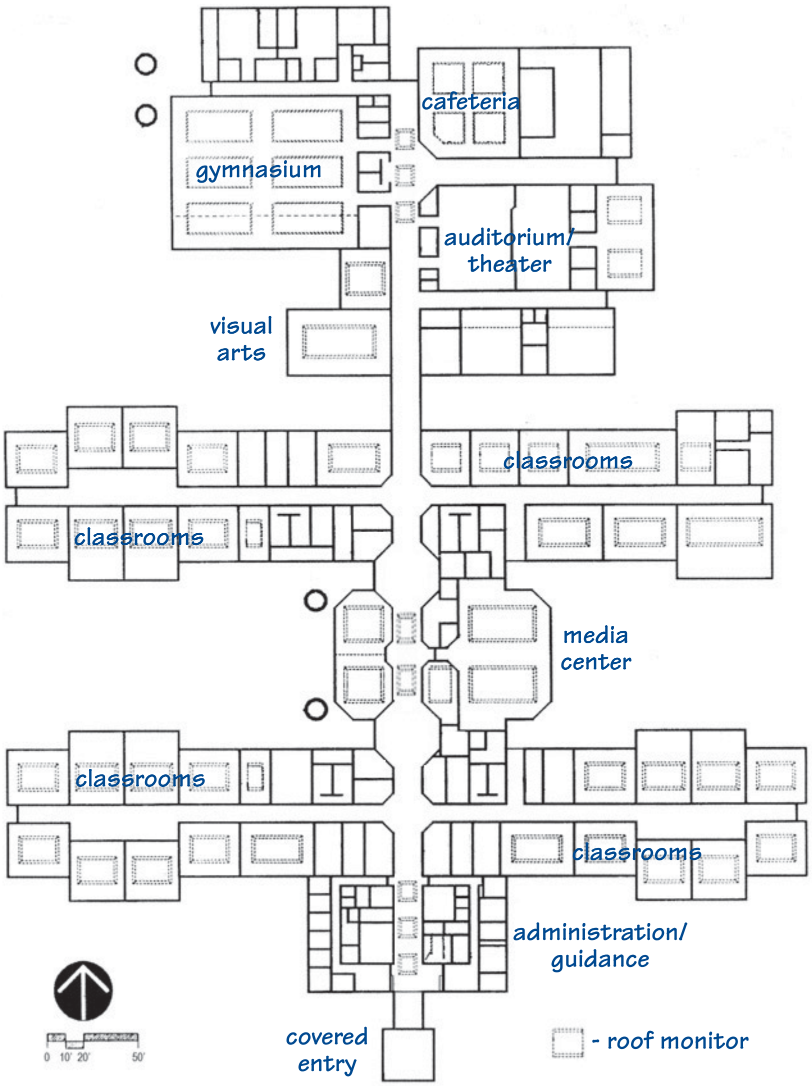
Daylighting provides enough natural light into the single-story school to minimize the use of electric lighting without creating glare. Further, daylighting reduces the internal heat gains from electric lights and reduces the overall cooling load. The key to successful implementation of these goals was to incorporate daylighting in the initial design concepts and integrate the daylighting strategy into the building's mechanical systems.

The building uses south-facing roof monitors to provide most of the daylighting within the classrooms, media center, gymnasium and main corridor. These monitors enable the electric lighting to be off most of the day, reducing peak cooling. Within the monitors are fire-retardant, UV-resistant, unevenly spaced cloth baffles that help distribute the light uniformly while eliminating any potential glare problems. Clear, double-glazed glass is used in the monitor windows. This glass was chosen to allow the most light into the room with the least amount of glass area. Optimizing the window size to distribute the correct amount of light across the room minimizes solar heat gain and reduces initial building costs. The monitor allows hot air to stratify, keeping this air from entering the conditioned space of the room. This strategy was incorporated in all larger classrooms, the media center, gymnasium, main hallway and the cafeteria.

Recessed windows on the exterior classroom walls are equipped with clear, low emissivity (low-e) double glazing. The south windows contain anodized aluminum light shelves that reduce glare without having to close the shades. The upper shelf surface reflects additional sunlight into the rooms. North-facing windows do not have light shelves.

East- and west-facing windows were avoided in the design, and were mostly used in the hallways.

The windows have blinds that can be closed to darken a room; the science rooms motorized shades on the roof monitor instead of blinds.



Adapted from original image by Innovative Design

Building plan view.

Window blind usage is only recommended when teachers present materials with overhead projectors or video monitors. Teachers are encouraged to reopen the blinds following their presentations.

A white roofing membrane reflects additional light upward through the roof monitors. Light-colored walls and ceilings diffuse and reflect sunlight within the classrooms.

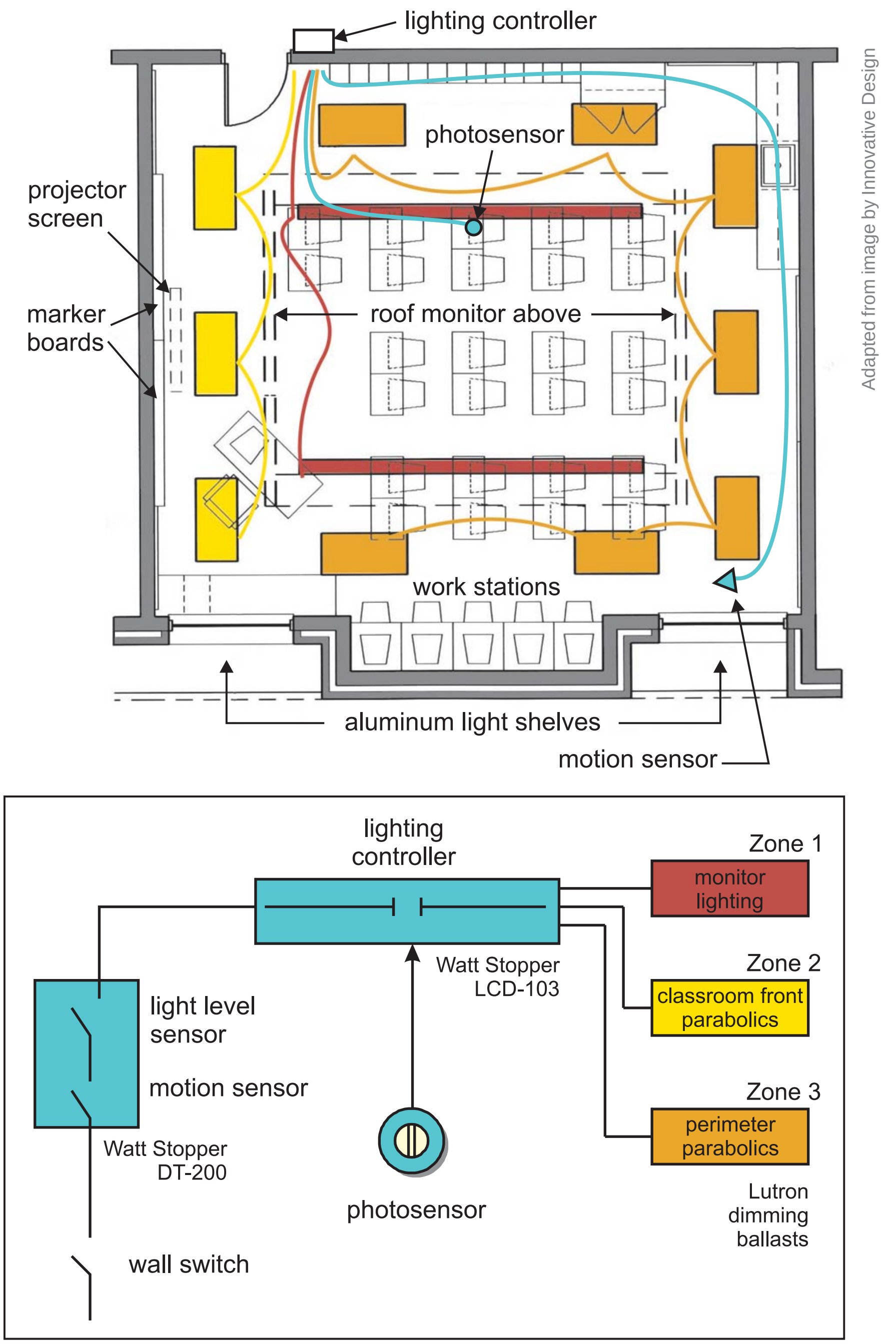
The daylighting strategy was integrated with the building's HVAC systems. As a result of lower internal heat gains from the electric lighting system, designers were able to reduce the size of the cooling system by 78 tons (19%). The cost savings on cooling helped to justify the additional daylighting installation cost.

Solar panels for the hot water system take advantage of north-facing roof monitors in the cafeteria because the sloping monitor roof provides an ideal panel-mounting surface toward the south.

Electric Lighting Strategy

The classrooms employ two types of lighting fixtures. In each room, eight fluorescent fixtures are installed on the monitor wall where it meets the classroom ceiling. Each luminaire contains two T8, 4100 K lamps and a Lutron dimming ballast. Additionally, ten 2' x 4' fluorescent fixtures are installed in the drop ceiling. Each recessed fixture includes three T8, 4100 K lamps in an 18-cell, 4" deep, parabolic troffer with a Lutron dimming ballast.

The cafeteria, which also takes advantage of daylighting, uses the same wall-mount, dimming fluorescent fixtures where the monitors meet the drop ceiling. Dimmable compact fluorescent downlights, each with two 18-watt lamps, are mounted in the ceiling. The cafeteria's perimeter has non-dimming 2' x 4' fixtures with two T8, 4100K lamps in a 4" deep parabolic troffer.



Lighting controls installation diagram.

The media center's daylighting scheme employed the same type of fixtures found in the classrooms. In addition, compact fluorescent downlights are used where supplemental light is needed.

While the main hallway makes use of roof monitors, the electric lighting is non-dimming and may be switched on or off manually. The gymnasium also is equipped with monitors, and like the hallway, its 400-watt metal halide fixtures cannot be dimmed.

Dual technology passive infrared and ultrasonic occupancy sensors enable classroom lighting in combination with a manual light switch. For the electric lighting in the room to come on, three conditions must exist: the manual switch must be on; motion must be detected; and the lighting level within the room must be below the determined setpoint. Once these conditions are met, the lights come on and a photosensor adjusts the lighting down to 10 percent in response to daylight.

The media center and cafeteria use similar lighting control schemes, except no motion sensors are employed.

Watt Stopper DT-200 energy-saving motion and light sensors are installed in the classrooms.

Survey Response

More than 130 students, faculty and the school principal participated in a lighting survey conducted by the Lighting Research Center (LRC). The general summary can be proclaimed in three simple words—they like it. A teacher wrote, "When I came to work at this school, I thought I had died and gone to heaven."

Teachers favor the amount and quality of light provided by the daylighting scheme and the electric lights. They like having the ability to control the amount of light via the window shades and the lighting controls. Often the teachers do not even turn the electric fixtures on

The media center supplements daylighting with recessed and wall-mounted T8 fluorescent luminaires as well as CFL downlighting.

because their lighting needs are met by the daylight. Teachers believe the lighting at Smith Middle School is much better than other schools where they have taught.

Teachers and students alike experience a feeling of spaciousness within the classrooms, caused by the added volume of the roof monitors. They only complain about too much darkness when viewing TV monitors. For this activity, all shades are closed and the lights are off. Most students rarely find the room too bright; this only occurs on very sunny days.

The principal uses the school building to attract prospective teachers to Smith. She gives tours of the school to candidates. The building's unique daylighting style and feeling of openness are factors in recruiting new teachers.

Maintenance Issues

The LRC interviewed the maintenance staff at Smith Middle School and from the school district. Some maintenance issues exist that should be considered when integrating daylighting within a building.

Replacing failed dimming ballasts is expensive. When purchased in small quantities, these ballasts generally cost approximately $90 each. A typical instant-start, non-dimming electronic ballast may be replaced for approximately $20.

Cleaning and maintenance of the additional windows is not a problem. However, cleaning the cloth baffles in the roof monitors is difficult. The chief electrician for the school district complained that there were too many parts to the lighting control system, making it harder to calibrate and maintain. Some teachers lodged minor complaints about the lighting levels on cloudy days.

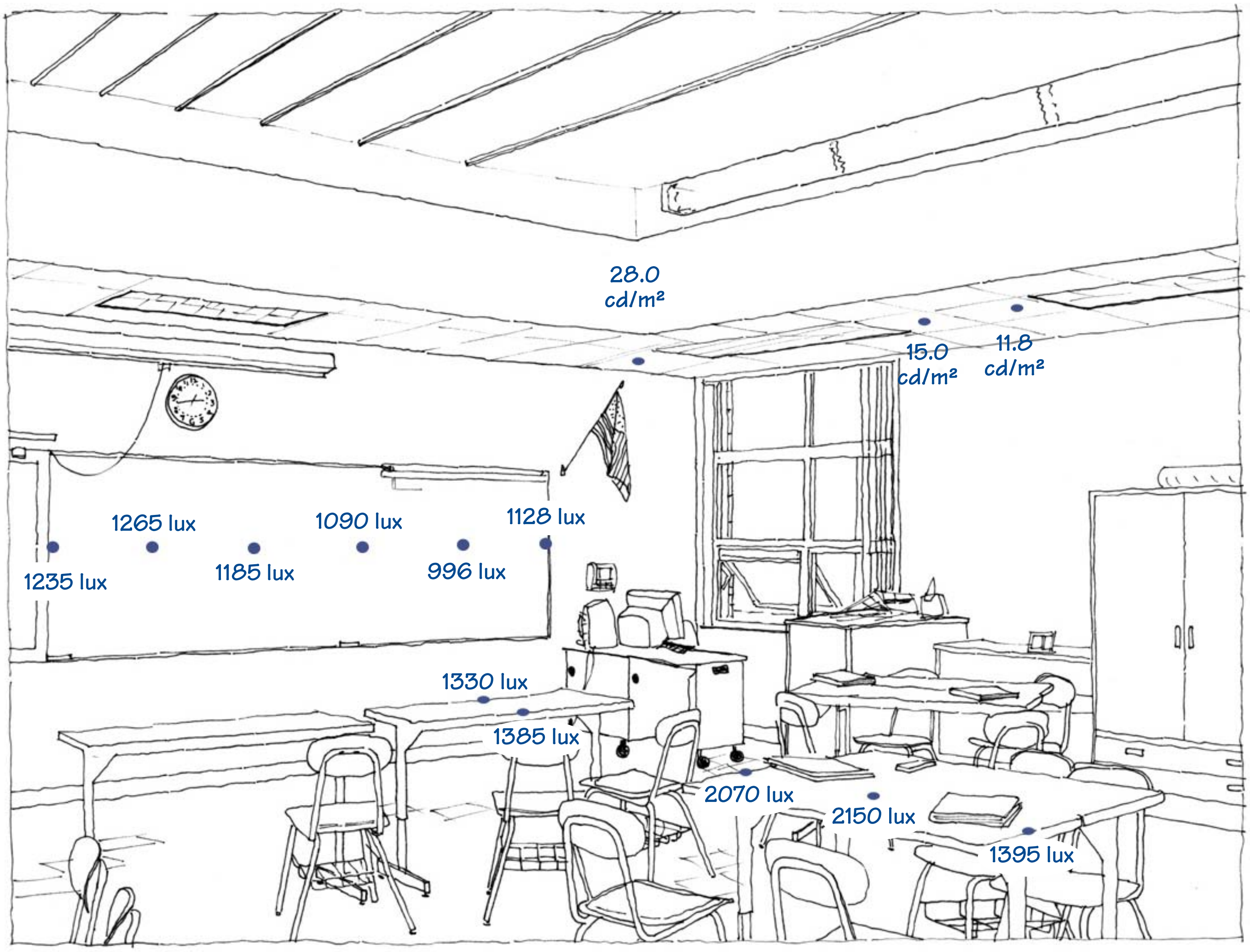
Manually operated vertical blinds on the roof monitor windows can be drawn to darken rooms for audio-visual presentations.

Data Logging

To understand the daylighting design effects on energy use at Smith Middle School, the LRC installed data loggers to collect typical classroom lighting levels, indoor temperature, and lighting energy use. Data was collected and recorded from March 3 to March 31, 2004.

Light loggers were placed on the teacher's desk approximately five feet from the view window. Light levels and temperatures were recorded at two-minute intervals. To collect lighting energy levels, a recording ammeter was placed on an electrical circuit which fed two classrooms: the subject classroom and a similar, adjacent classroom. The two rooms' electric lighting was the only load on the circuit. The recording intervals were six minutes apart, with the logger averaging the usage every minute between recordings.

Classroom Daylighting 101



Illuminance and luminance information was recorded in a classroom with all electric lighting off and window shades open, on a sunny day at 1:45 p.m. The side windows face north. Measurements reflect only daylighting contributions to ambient light.

Illuminance measurements in lux (1 lux = 0.09 footcandle); luminance measurements in cd/m² (candelas per square meter).

A weather station was also erected outdoors to collect temperature and solar intensity data. Researchers placed the station in a location where nothing would block or shade the radiometers from sunlight at any time during the day. Solar intensity and temperatures were recorded in one-minute intervals.

Averaged Data, One Classroom

Weather	Avg. Daily Lighting Energy (w/ daylighting) kWh	Avg. Daily Lighting Energy * (w/o daylighting) kWh	Avg. Daytime Room Lighting lux	Avg. Hourly Solar Intensity μ mol/m²/sec
Sunny	1.0	8.8	550	1093
Partly cloudy	2.6	8.4	320	306

* - Energy use based on connected lighting load.

The chart, left, shows an average sampling of the recorded results. Three days of sunny and three days of partly cloudy conditions, selected randomly, indicate significant lighting energy savings due to the daylighting strategy employed.

Energy Simulation Modeling

Prior to construction, the schools' designers used the DOE-2 energy simulation model to estimate energy usage for a base case (no daylighting) and for the daylighting strategies employed. They estimated that the lighting energy reduction using daylighting was 64%. Data logger measurements confirmed this estimate by measuring 85% lighting energy reduction on sunny days and 60% on cloudy and partly cloudy days. The energy simulation also predicted a peak cooling load reduction of 19% (78 tons) due to the reduction of internal heat from the lighting system. Similarly, heating energy increases by an estimated 20% when using the daylighting strategy as a result of the reduction in the heat generated from the lighting system.

An awareness program uses posters reminding students, faculty, and visitors of the school's daylighting qualities.

Cost Data

Daylighting strategies are not cost-free. In the case of Smith Middle School, the added cost of daylighting was estimated at $158,098, or $1.23 per gross square foot. Innovative Design, Inc., Smith's daylighting design firm, provided these data based on detailed net cost estimates and the actual bids for the work. This cost includes additional bracing, framing, wall and insulation for the roof monitors, additional glazing, lighting controls and dimming fluorescent ballasts, light shelves, and wall finishes and cloth baffles to eliminate glare. However, since the daylighting design reduces the cooling load, a smaller air conditioning system helps to offset these costs. In addition, a reduced electrical cost is attributed to the lower capacity chiller.

For daylighting to be considered economically viable, the energy savings must offset the additional cost in a reasonable amount of time. Although there may be other reasons to justify daylighting such as comfort, productivity, and student learning ability, this analysis focuses on the more widely accepted justification for daylighting—energy cost reduction.

Results of energy simulation modeling in terms of energy reduction seem reasonable and acceptable when compared with actual findings of data logging and energy bill assessment. The simulation identified a reduction in total electrical usage by 26% when using the daylighting strategies. With daylighting, the annual electrical usage is 13.54 kilowatt hours per square foot (kWh/ft²), compared to a base case (no daylighting) calculation of 18.30 kWh/ft². The cost for electricity at Smith is \$0.07/kWh. By reducing the electrical usage, the annual cost savings is \$0.33/ft²:

$$(18.30 \text{ kWh} - 13.54 \text{ kWh}) \times \$0.07/\text{ft}^2 = \$0.33/\text{ft}^2.$$

The added energy necessary to heat the building slightly offsets this savings. The energy simulation model indicates that it will take 20% more natural gas to heat the building, attributed to the reduction in heat gain from lower wattage of the dimmed lighting. The calculated additional energy required for heat is 0.048 therms/ft². With fuel cost based on \$0.81/therm, the result is an additional \$0.04/ft². Therefore, the total daylighting savings is the electrical savings minus the additional heating energy cost:

$$\$0.33/\text{ft}^2 \text{ (lighting + cooling)} - \$0.04 \text{ (heating)} = \$0.29/\text{ft}^2 \text{ (total savings)}$$

Simple payback on the daylighting investment is 4.2 years.

Image: Innovative Design

Summary of Lessons Learned

- Fixed baffles in roof monitors are effective at direct sunlight control (elimination of glare).
- To reap the benefits and maximize the use of daylighting while minimizing costs, daylighting design must be implemented from the start.
- Good daylighting design produces overall energy savings (lighting, cooling, and heating combined) while achieving a high degree of acceptance from school staff, teachers, and students.
- Dimming ballasts cost more to replace than expected. Maintenance budgets and financial analyses should incorporate this additional cost for a daylit building.
- Although no empirical data from this study proves an improvement in student achievement or learning ability, anecdotal information from the instructors attributed fewer behavioral problems to the quality of the light and a feeling of spaciousness brought forth by the roof monitors. The principal concluded that the students respond to their lessons better in the morning than in other schools she had worked. One teacher remarked that the daylighting provided a "natural upper" for the students.
- South-facing, clear glass reduces the size of the windows in the monitors, thereby reducing material costs.
- Reflective finishes on the ceiling, walls, and light shelves increases daylighting's effectiveness.
- An administration effort to educate and encourage the proper use of daylight is an important element to success.

More information on this daylighting approach can be found in *"Guide for Daylighting Schools,"* developed for Daylight Dividends by Innovative Design.

About the program...

Daylighting, employed properly, reduces the need for electric light by introducing natural light into a building. ***Daylight Dividends*** *was established to build market demand for daylighting as a means of improving indoor environmental quality; to overcome technological barriers to effectively reap the energy savings of daylight; and to inform and assist state and regional market transformation and resource acquisition program implementation efforts. More information can be found at:*

www.daylightdividends.org

The following organizations sponsor Daylight Dividends:
California Energy Commission
Connecticut Light and Power Company
Iowa Energy Center
Lighting Research Center
New York State Energy Research and Development Authority
North Carolina Daylighting Consortium
Northwest Energy Efficiency Alliance
U. S. Department of Energy

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