

THE EVOLUTION OF DAYLIGHTING IN OUR SCHOOLS: CHALLENGES AND SOLUTIONS

Umesh Atre
Michael Nicklas
Jon Zubizaretta
Innovative Design, Inc.
850 W Morgan St.
Raleigh, NC 27603
umesh@innovativedesign.net
mike@innovativedesign.net
jon@innovativedesign.net

ABSTRACT

Most designers engaged in daylighting design understand how daylighting saves energy and influences the architecture. But there are many secondary issues related to daylighting, which are less understood by building designers that can have a significant impact on performance. Failures and successful aspects from past designs must be fully appreciated and lessons learned should be used to modify future designs. New technologies are also coming into the market, which can be utilized by designers to greatly improve their designs. Over the years, our firm has learned many important lessons, both positive and negative. This paper details the important advances our firm has made over the past three decades in daylighting design. The paper explains how the whole-building design and human factors were particularly influential in our progression and, by staying focused on energy, our designs evolved in ways different than many other designers.

1. INITIAL DAYLIGHTING DESIGNS

Daylighting has always been the focus of all our school designs. It has helped define the form taken by different spaces in a school design. Our school designs have sought to provide daylighting illuminance levels that are superior to normally experienced conditions, mainly in the well-utilized spaces (classrooms, labs, libraries, cafeteria, and gymnasium), for at least two-thirds of the occupied time. Our initial classroom spaces used roof monitors as the primary daylighting strategy. Roof monitors were located centrally in a classroom and provided uniform daylight throughout the space. Translucent fabric baffles in the roof monitor well helped prevent direct beam radiation to enter

the space and created a practical, diffused daylighting design. Fluorescent lighting fixtures with appropriate dimming controls and daylight sensors were provided to supplement the daylighting. Daylighting glazing design (glazing type, sizing, orientation, and position) has a direct influence on the energy consumption of the spaces. Early case studies and building energy modeling confirmed the suitability of vertical, south facing glazing to balance daylighting and energy use in our cooling-dominated southeastern climate. This allowed us the ability to control the high sun angles that lead to summer time cooling peaks, while taking advantage of passive heating from the low angle sun that is allowed to enter the spaces.



Fig. 1: South-facing roof monitors at a middle school

Over time, each one of our school designs using roof monitors helped refine and optimize the entire roof assembly, including the glazing, the overhangs, roofing materials, monitor sizing, and ceiling designs. We

appreciated the need for optimization through a daylighting-energy balance, since an increase in the glazing area affected all other building components of the daylighting assembly, thus increasing overall construction costs. The following are significant design refinements resulting from our efforts to continually improve daylighting in schools.

1.1 North facing monitors

In case the design did not permit south-facing roof monitors, north-facing roof monitors were used. Due to their orientation, the glazing area required was more than the south-facing monitors, thus this design cost more. On the energy side, in our climate, there was the concern of heat losses through the north glazing, leading to an increase in building energy use. North monitor design was maximized by using the back-side (south-facing) to mount solar collectors, wherever applicable. This combined approach helped cut down on overall costs, while providing adequate daylighting.



Fig. 2: Solar collectors mounted on north roof monitors

1.2 Exterior roofing systems

When selecting roof membranes, it is important to look at 2 to 3 year aged reflectance values. Recent experiments by North Carolina State University graduate students at one of our schools show that white roofing in front of our roof monitors increased the interior daylight illuminance levels by as much as 40%, as compared to a similar roof monitor with a dark roofing material in front. Though the reflected component from the roof had always been accounted for in our daylighting designs, the actual percentage daylighting benefit had not yet been tested in an existing building.

1.3 Interior colors and finishes

The effects of interior wall and ceiling surface finishes were also evaluated through daylighting computer simulations, and are being used in our current designs. A study we conducted for the Ohio School Facilities Commission suggests that the glass-to-floor-ratios could be reduced by up to 1.0% for a blinds-between-the glazing strategy, and up

to 0.5% for a roof monitor strategy, through the use of lighter interior finishes alone. All building materials usually lose their reflectance values and original colors over time. Interior paint colors should be light, but should not be glossy or reflective, as this might create hotspots and glare conditions. Fissured or perforated ceiling tiles should be avoided as they can trap daylight and reduce reflectance. Choose bright colors, if demanded by the classroom aesthetics, by actual reflectance values, as most often color names do not equal reflectance.

1.4 Interior Baffles

Translucent fabric baffles were used inside the monitor well to diffuse daylight and prevent glare and discomfort issues from direct beam radiation. The baffle design was traditionally arranged in a linear way, but was remodeled so that the baffles could be arranged in an ascending manner, thus reducing the number of baffles required, and cutting costs. The daylighting quality in the spaces with this new baffle arrangement was similar to the earlier design. In gymnasium-like spaces with no ceiling cavity, the baffles had to be located entirely inside (recessed baffles) the monitor cavity (over the top of the roof structure) to avoid conflict with the truss framing system.



Fig. 3: Linear and ascending baffle designs in monitors

1.5 Ceiling depth

The ceiling cavity in roof monitor applications should be kept to a minimum, as percentage of daylight reaching the working plane decreases with increase in ceiling cavity

application, the glass-to-floor-ratio can increase by as much as 3-4% points, if the ceiling depth is increased from 5'-0" to 10'-0". Many of these issues led our firm to realize the significance of a whole-building approach to daylighting design, which includes equal emphasis on space-efficient mechanical and electrical design.

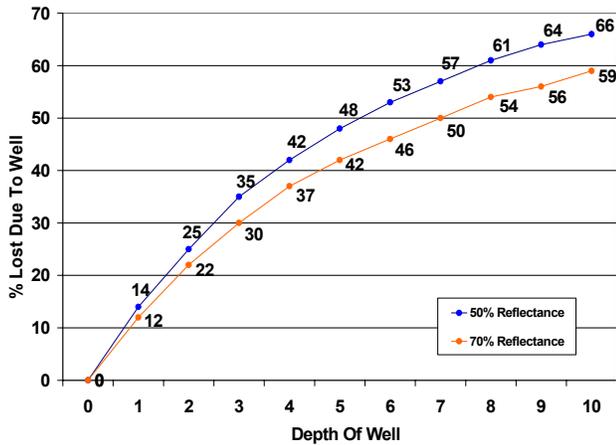


Fig. 4: Percentage of light loss as a factor of well depth

1.6 Ceiling Transition

In order to create a uniformly daylit space, interior soffits of the roof monitors transitioned from the original right-angled design to a 45-degree splay and a rounded or curved condition. The angled or curved soffits reduce ceiling contrast, making the daylighting more fluid. In certain school designs, the monitor glazing areas were reduced due to the fact that the daylight could now reach the work plane with minimum ceiling obstructions.

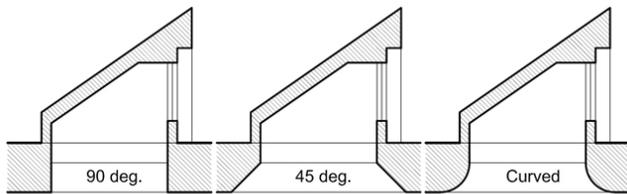


Fig. 5: Transition from a right-angled (90 deg.) soffit to 45-deg. and curved designs

Though excellent, quality controlled lighting could be achieved through proper use of the roof monitor design, rising costs and the need for multi-storey building applications led us to start looking at side-lit daylighting solutions.

2. CHANGING PERSPECTIVES

As the daylighting design of spaces moved to side-lit solutions, we had to find a strategy that would prevent direct beam radiation, while providing potential for daylight to reach deep into classroom-type spaces. Clerestory windows with blinds integrated in-between the glazing were found to be a good fit for this application. Though this design could provide for the direct beam prevention, this was found to be good enough only up to a limited room depth. The first step in the evolution of this strategy was the addition of an exterior light shelf that helped direct more daylight on to the ceilings and deeper in to the rooms. The light shelf also acted as a shading element for the lower view glazing. The daylighting distribution was further enhanced by locating the clerestory glazing as high up as possible, and sloping the ceiling from the top of the glazing to the back of the daylit spaces. A combination of all these elements was found to work well in classroom-like spaces. Also, the plenum space above the sloped ceiling was adequate to accommodate all the mechanical and electrical requirements.



Fig. 6: Sloped ceiling with high clerestories



Fig. 7: Exterior light shelves with blinds between glazing

This side-lit daylighting design works well in schools, but the daylighting glazing area required to provide adequate illumination was at least 30%-40% more than the earlier south-facing roof monitor designs being used in similar classroom applications. This led to increased glazing costs

and a rethinking of the side-lit daylighting strategy in classrooms.

2.1 A Whole-Building Approach to Daylighting

We started exploring radically different whole-building designs that could satisfy all the daylighting goals while controlling costs. The result was a new kind of curved, translucent interior light-shelf design that could provide glare-free daylighting, and has proved more effective than our earlier blinds between the glazing designs. The daylighting glazing area requirement could be reduced even further than the roof-monitor designs, and the locally manufactured light-shelf keeps costs within budget. This design does not require any additional control strategy like interior blinds or shades. An exterior light shelf and a sloped ceiling help bounce light deeper in to the classrooms.



Fig. 8: Interior light shelf in an elementary classroom

Another important element in the whole-building approach was the use of an underfloor air distribution system. This improved human comfort and indoor air quality in the school spaces, while reducing utility costs. This approach practically eliminated the ceiling cavity and helped reduce the overall building height and cost. A detailed building cost comparison revealed that this new whole-building approach would be economical than past daylighting designs for similar sized spaces.

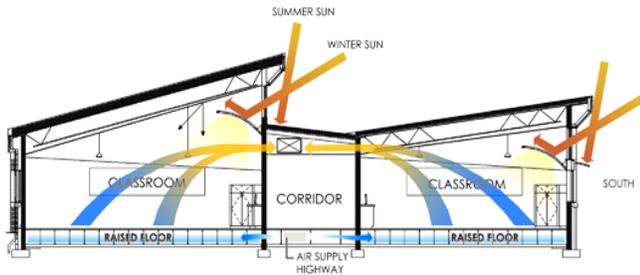


Fig. 9: A whole-building approach to daylighting

This whole-building approach is not limited to single-story school buildings, and is being currently implemented in our multi-story designs. Figure 10 shows an example of this strategy being used one of our new elementary schools.

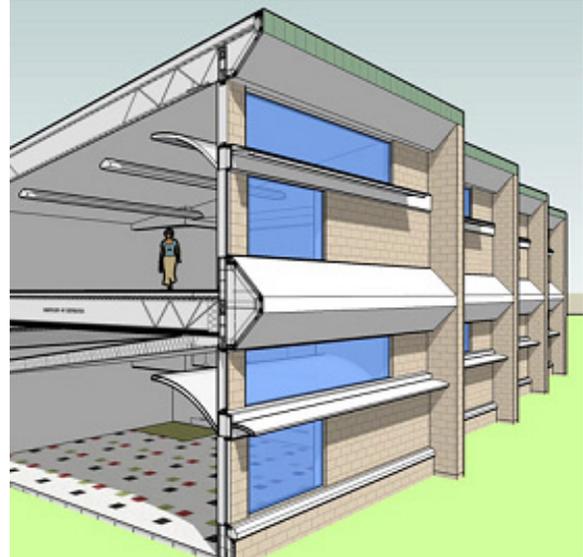


Fig. 10: Whole-building approach in a multistory design

3. HUMAN COMFORT & TECHNOLOGY

A typical challenge for the daylighting designer is the need to darken certain areas in classroom spaces to aid students clearly see projected images and information displayed on teaching boards, without sacrificing darkening the entire space. This need was not as acute in the past, but changes in teaching methods and audio-visual (AV) equipment used in schools have made it an important factor in the design of controlled daylighting. At the same time, it is important to prevent any unwanted/excessive contrast in the classroom spaces. Except the darkened areas, the daylighting needs to be as uniform as possible in the remaining space. Initially, interior shades/blinds were being used in some of our roof monitor designs to provide human control on the amount of daylight. These blinds failed in a number of projects due to the fact that they were hard to reach and operate, were kept closed for extended periods of time once closed, or were not fixed or replaced when broken. School systems often bought AV equipment after the schools were built, and without the knowledge of the architects. More often than not, this equipment was not mounted in the right places, making it difficult to read. The resultant design changes were to create an architectural shading element that would intentionally darken a specific area of the space while allowing the remaining space to be kept fully daylight. This eliminated the human control issues,



Fig. 11: Unwanted contrast at ceilings & AV location

and has been successfully implemented in many of our newer school designs. The design of the architectural shading element changed from a curved, eyebrow like shape to a linear shape, as daylighting strategies graduated from roof monitors (for single-story spaces) to side-lit light shelf strategies for multi-story schools. These design changes brought us closer to our goal of providing dark areas only where essential, while still maintaining a daylit space, and without blocking occupant views. Figures 14 and 15 show the variation in the hourly footcandle levels at a horizontal sensor placed at working plane height in the center of a classroom space, and at a vertical sensor placed at 5'-0" from the finished floor level below the shaded drop soffit area of the classroom.



Fig. 12: Curved architectural shading element & splayed soffit design in a classroom with roof monitor

To further increase human comfort levels, we started exploring technical specifications of the projection equipment, and realized that there were projectors with controls and projection screens designed to work



Fig. 13: Linear architectural shading element for AV equipment in a side-lit classroom with interior light shelf

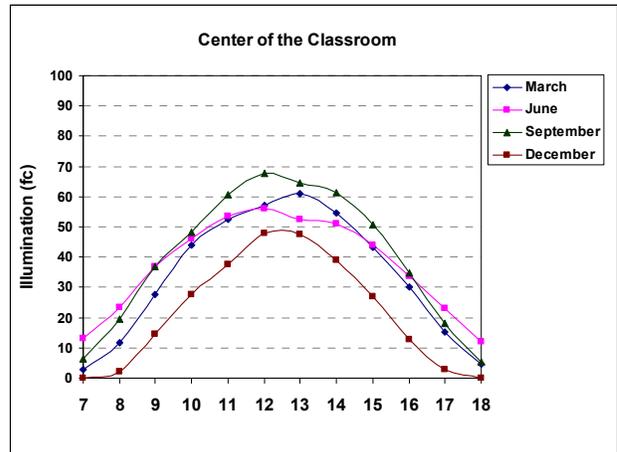


Fig. 14: Illuminance levels at the Center of a classroom

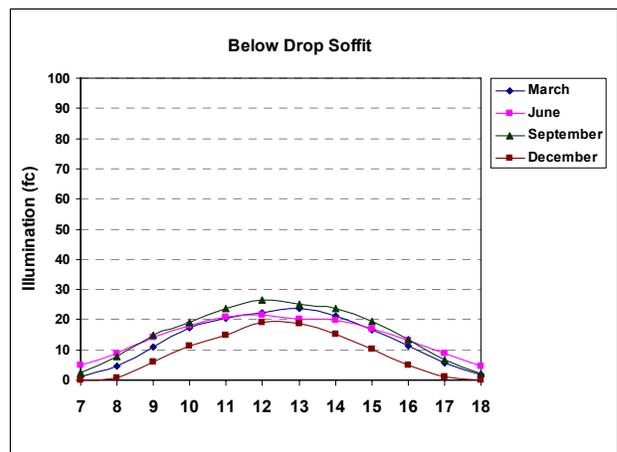


Fig. 15: Illuminance levels below the shaded drop soffit

specifically in daylit spaces with high ambient lighting. The two most important factors while selecting a video projector to work effectively in daylit classrooms were the lumen output and the contrast ratio. Projectors with lumen outputs of 3000-3500 and contrast ratios of 1000:1 or higher were successfully tested in our schools, and became part of our recommendations. Depending on the classroom design and occupant viewing angles, keystone correction and lens shift functions in projectors were also found to be factors to be considered. Equipment with low-power/power-saving modes was preferred over others. The video projectors can also be chosen based on qualities like size and throw distances, that will allow them to be mounted behind the architectural shading element.

4. LIGHTING CONTROLS

For successful daylighting, we had to make the daylighting and artificial lighting controls an integral part of our daylighting schemes. To take full advantage of daylighting, continuous or stepped dimming controls had to be specified and installed in all the daylit spaces. Due to premature lamp failures in a few of our schools, we conducted third-party commissioning, and came up with conclusions and recommendations for future projects, some of which are mentioned below.

- The lamps, ballasts, and dimming controls must be compatible
- Check with manufacturers' specifications for any information on effects of dimming on lamp life
- Make sure that the lamps are wired properly – series vs. parallel, since parallel creates a high voltage
- Do not kick in the controls at a 'high' dimming level; always start at full-light and full-power and then dim down to the appropriate levels
- 6 feet should be the maximum distance between the lamp and the ballast
- Check lamp seating in the sockets, as improper seating can create arcing and shortening of lamp life or failure
- Limiting the dimming to 20% may prevent lamp failure
- Use a manufacturer that can provide an integrated lighting system design that has been verified and tested in other similar projects
- Locate daylight and occupancy sensors at easily visible and reachable locations
- Arrange indirect linear fluorescent fixtures parallel to the exterior walls (assumed with daylighting glazing) to facilitate row-by-row dimming and enhance daylighting
- Commissioning of the entire daylighting systems (architectural and electrical) is a must at the completion of the project to confirm maximum advantage of the daylighting strategies

5. DAYLIGHTING SOFTWARE

Our method of choice in the past was building scale models to calculate the daylight illuminance levels in a particular space. Though accurate, this method was time-consuming, and was expensive in case one had to simulate detailed building elements. A number of daylighting analysis software are available today that assist us in optimizing our daylighting strategies. The daylighting analysis software are used in conjunction with building energy analysis tools that allow us to estimate the effect of the daylighting on the building cooling, heating, lighting, and overall energy use. This has helped us take more accurate, calculated decisions in our school designs.

We have been using the software program 'DAYSIM', developed by the National Research Council-Canada for most of our daylighting simulation work.

6. REAL-TIME MONITORING & EDUCATION

Another significant advance, particularly in our school designs has been the implementation of real-time monitoring; allowing students to instantaneously see the energy and environmental benefits associated with the daylighting strategies. The monitoring station displays real-time data on a large screen in a common school space (like a central lobby), while the staff and students can also access the same via their school's internal computer network. Sustainable design ideas are being made part of the school curriculum, and easy-to-understand graphic displays make it easy for students to better grasp the principles. Graphic signage is also displayed in school lobbies and common areas to expose students to the daylighting ideas more effectively.