COMPARISON OF DAYLIGHTING STRATEGIES FOR SCHOOLS

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ABSTRACT

This paper will describe the overall process and key factors considered by our architectural firm during a recent whole-building analytical process to develop a new, more cost-effective daylighting strategy for classroom daylighting. The analysis evaluated the cost and efficiency impacts of key factors that impact good daylighting design for K-12 school design. Our firm has previously designed, implemented and later analyzed many classroom daylighting strategies that have employed south- and north-facing room monitor and lightshelf strategies on similar K-12 classrooms. The goal of this effort was to develop a strategy that would improve energy efficiency and reduce initial construction cost while still maintaining a high quality daylighting solution that would minimize glare and maintain reasonable light level uniformity within the classroom.

1. CONTEXT

The daylighting design was originally developed for the new Northern Guilford Middle School in Greensboro, North Carolina. The daylighting design was slightly modified and used for a second school within the same Guilford County School System.

Like most schools, the middle school had a fixed budget that was developed by the school system without regard to green design features. In addition to daylighting, the overall school design incorporated an extensive rainwater harvesting strategy, a Living Machine to treat the waste water, constructed wetlands, several PV systems, a solar water heating system, a greenhouse off the sixth grade science classroom, numerous green products, and real-time monitoring of the sustainable features. The school was designed and constructed at the same time as another middle school in the same county with the exact same program and budget. The 140,000 square foot daylit school, which also included many other green features, was completed for $.07 per square foot more than the other school.

2. COMPUTER SIMULATIONS AND MOCK-UPS

To analyze various daylighting options we constructed physical daylighting models and utilized the “Daylite” daylighting computer program to simulate and compare the physical model to the computer model. We felt that because we were implementing a new daylighting strategy, this verification was necessary. We then took the daylighting simulations, modified to reflect the physical model results, and used this as input into a DOE-II simulation to see the impact on the entire classroom wing’s energy consumption and peak conditions.

Once the final design was determined analytically, our firm had an aluminum fabrication company construct a full-scale mock-up of the final interior and exterior lightshelf design to verify the constructability and aesthetics and to better determine cost implications.

3. IMPORTANCE OF WHOLE BUILDING APPROACH

Simply adding a daylighting strategy to a conventional design will likely result in higher construction costs. Incorporating an under-floor air distribution system by itself will certainly cost much more, and selecting indirect lighting costs more than lay-in fluorescent fixtures. When looked at as individual systems added to a conventional design, it may easily be assumed that these systems would add $15 to $20 per square foot. The goal of our process was to capture the energy, health, productivity and quality benefits of these strategies without the high cost.

In evaluating cost-benefit relationships we tried to consider all the key issues that would ultimately impact the daylighting strategy's viability. These issues were:

- Site issues, most important being orientation
- Architectural systems
- Mechanical systems
- Electrical systems
- Controls systems
- Acoustical systems

We believe that successful school design also considers the benefits of implementing sustainable solutions that, in addition to their energy and environmental benefits, are linked to the curriculum. Real-time monitoring systems can reinforce the experiential learning opportunities provided by incorporating daylighting.

4. KEY PROBLEMS AND SOLUTIONS TO MULTIPLE INTER-RELATED ISSUES

When initiating this process we identified past problems associated with daylighting of classrooms. For our new design to be successful, we knew that we would have to successfully address these issues. Several of these issues are unique to schools while others are common among a variety of building types.

The first group of these issues relate to human factors.

1. Strive to achieve in excess of 50 foot-candles from daylighting, two-thirds of the time. To prevent teachers and students from overriding the controls and turning on the lights the norm must be superior lighting from daylighting.
2. Don't count on view glass. Students and teachers too easily control low windows. They also serve as good display areas and can't be counted on as a component of a good daylighting strategy.
3. Eliminate direct beam radiation. If sunlight is getting into the teacher's face, they will find a way to block the light from entering the space.
4. Minimize contrast within spaces.
5. Provide a way to intentionally shade or darken the TV monitor and projection screen at the teaching wall without darkening the entire room. This eliminates the need for manual shades that require teacher interaction and are often left shut.
6. Employ a separate lighting and control strategy at teacher's desk area and teaching wall.

The second group of factors deals with more technical issues that can enhance or hinder the performance of a daylighting strategy.

1. Optimize the glazing by maximizing visible light transmission. By utilizing clear double glass the visible light transmission was at least 10% to 25% better than low-E glass.
2. Improve light reflectance within the classroom to enhance the performance. This is particularly true on the ceiling where the textured finishes and holes in acoustical ceiling tiles often significantly reduce the reflectance of light deep into classrooms.
3. Focus primarily on south-facing glass. Passive heating benefits are important and south glazing requires 25% less glass area to achieve the same annual contribution as north-facing glazing.
4. Incorporate white, single-ply roofing in front of clerestory glass. This results in needing 10% less glass area to produce the same daylighting results.
5. Minimize or eliminate the ceiling cavity if using roof monitors. A 7-foot deep cavity with a white painted light well coming down from a south-facing roof monitor will lose 50% of the light.
6. Lightshelves and shading devices should be extended beyond each side of the opening to account for early morning and afternoon azimuth conditions.
7. Recognize the limits of side lighting with just low, view-glass windows. There needs to be a fail-safe means of blocking direct beam and bouncing light to the back of the classroom.
8. Consider the limitations of interior lightshelves. Typical interior lightshelves are flat and solid. Since south-facing windows are impossible to control in terms of glare, the blinds on these windows are typically closed. The result is that right under the lightshelf it is dark.
9. Incorporating blinds-between-glass in south-facing clerestories is a good option but it cuts visible light transmission by 40%.
10. Sloping the ceiling down from clerestory areas improves side lighting by 5 to 10%.

The final set of issues deals specifically with how daylighting can be enhanced or hurt by lighting control strategies.

1. Indirect lighting is a good solution to creating a lighting scheme that is visually consistent with daylighting.
2. Install 1/6 fewer lights in classrooms that are not used for teaching at night. In classrooms with good daylighting schemes there will be at least 10 footcandles of daylight in the space during the day.
3. If not daylighting the halls, implement an indirect lighting scheme. Lay-in fixtures produce a glare that makes the space seem brighter than the classrooms.

4. Dimming provides improved performance, but controls, lamps and ballasts must all be compatible. Controls should not kick in at a "high" dimming level but start at full light/full power and dim down to appropriate level.

5. THE RESULTING DAYLIGHTING STRATEGY

The daylighting design we sought needed to address all of the above issues in a positive manner but also needed to cost less than our previous strategies, which were mostly south-facing roof monitors. The ultimate solution, shown below, did just that. In comparing the cost of various daylit classroom wing designs, we broke down the construction cost of every component in a typical wing design. This was compared to rather conventional flat roof and pitched metal roof designs with no daylighting, lay-in lighting, and a VAV mechanical system. The cost estimates initially utilized when designing the Northern Guilford Middle School were updated with actual unit prices we received from the general contractor on the middle school. These costs are included in the analysis presented here. They also served as the basis of our system evaluation of the Reedy Fork Elementary, a second school we designed in the same county for the same school system.

The preferred daylighting design featured two south-facing clerestories that utilized a curved, interior, translucent lightshelf that both filtered light down under the lightshelf as well as bounced light deep into the classroom. Indirect lighting complemented the approach and an under-floor air distribution system provided superior indoor air quality and further reduced energy consumption.

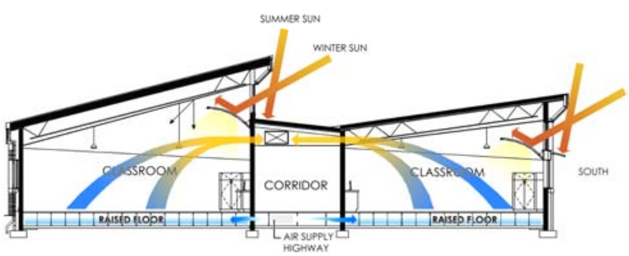

Fig. 1: The resulting daylighting strategy

The biggest drivers in the design were:

1. The single sloped ceiling that eliminated the ceiling cavity and sky well.
2. The curved translucent lightshelf that provided light immediately under the lightshelf, bounced light back into the space, and diffused the light. This also allowed us to use clear-double glass (maximum visible light transmission) and reduce the glass-to-floor ratio to the lowest we have experienced.
3. By going to an underfloor strategy, the high-end finishes on the exterior of the ceiling cavity spaces and several masonry courses are eliminated.
4. Through the incorporation of the daylighting, cooling peak loads are significantly less, resulting in reduced chiller capacity.
5. The indirect lighting that, by itself, saved 6" to 8" in ceiling cavity.
6. The simple construction framing.
7. The underfloor strategy eliminates many overhead construction problems including scaffolding costs while easing the installation and coordination problems associated with typically implemented overhead ductwork, plumbing, electrical, and control wiring.
8. The white single-ply roofing provided increased benefit in the north-side classroom. This allowed glass areas to be reduced even further.

This overall systems approach made our goal achievable. The costs of the new daylighting strategy, in comparison to the typically implemented strategies, are as follows:

TABLE 1: BASE BUILDING DESIGN

Design type	Additional Cost/sq.ft.
Base Building Design, Non-daylit, Flat Roof	$0.00

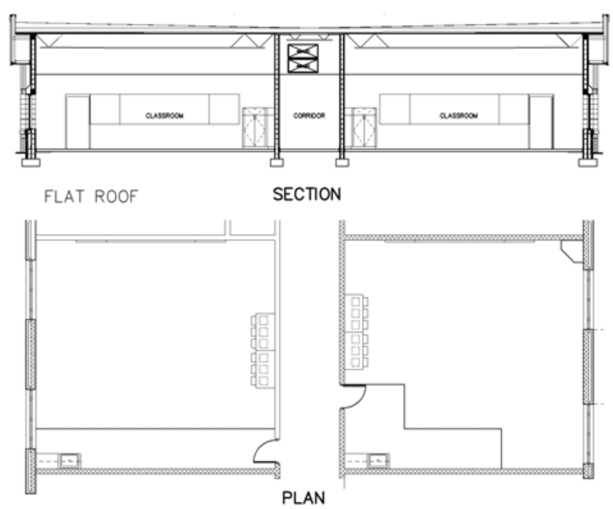

Fig. 2: Base building design

Figure 2 shows the plan and section for the base building design. A two-classroom unit was selected for this analysis.

Every classroom is 980 sq.ft. in area, with an 8’-0” wide corridor in between the two classrooms. The base case has a flat roof with no daylighting. The overall plan for all the alternatives is similar to the plan shown in Figure 2. Typical sections are shown for the remaining cases in the next set of figures.

TABLE 2: TYPICAL ALTERNATIVE 1

Design type	Additional Cost/sq.ft.
Base Building Design, Non-daylit, Sloped Roof	$0.04

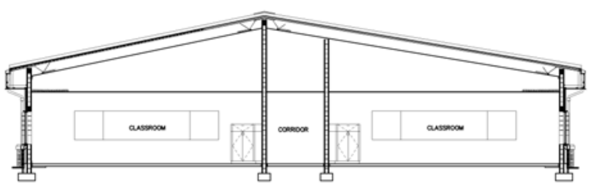

Fig. 3: Typical Alternative 1

TABLE 3: DESIGN CASE

Design type	Additional Cost/sq.ft.
Northern Guilford Middle School design with underfloor, daylighting, indirect lighting	$2.73

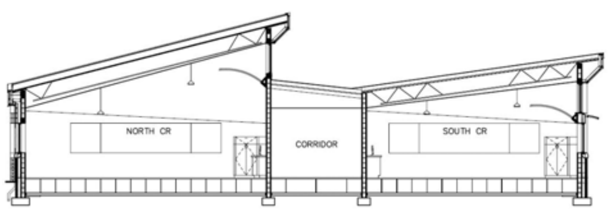

Fig. 4: Design Case with daylighting and underfloor system

Fig. 5: Design Case typical classroom showing daylighting

TABLE 4: DAYLIGHTING BUT NO UNDERFLOOR

Design type	Additional Cost/sq.ft.
Northern Guilford Middle School design with daylighting, indirect lighting, NO underfloor	$5.53

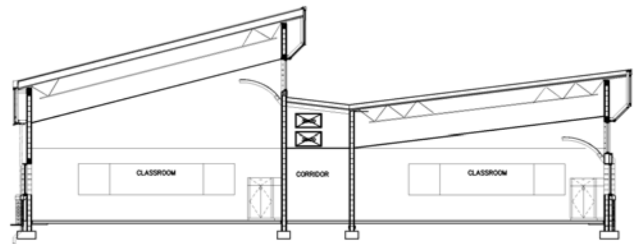

Fig. 6: Daylighting with no underfloor system

TABLE 5: DAYLIGHTING WITH MONITORS

Design type	Additional Cost/sq.ft.
Daylighting with south facing roof monitors, no underfloor	$3.29

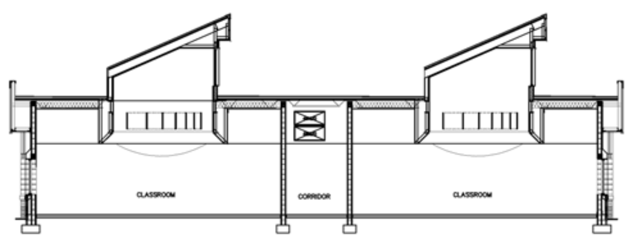

Fig. 7: Daylighting with south facing monitors

6. CONCLUSION

Whole building thinking is critical to advancing any building technology, particularly daylighting. Daylighting impacts so many building components and these components likewise impact daylighting.