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Daylighting and Human Performance

By Lisa Heschong

Daylighting is the practice of using natural light to provide illumination in interior environments. Fifty years ago, practically all schools and workplaces used daylight as the primary illumination source. With the advent of inexpensive electricity and widespread use of fluorescent lighting in the 1950s and 1960s, states began to abandon requirements for minimum daylight illumination in their building codes. As energy costs soared, starting with the energy crises of the 1970s, the glazed areas of buildings came to be regarded by many as an energy liability, seen as increasing heating and cooling loads. Since cooling loads typically dominate in non-residential buildings, solar gain through windows became a driving concern.

New buildings, no longer optimized for daylight, were constructed with lower ceilings and lower skin to volume ratios. Older buildings were often retrofitted with dropped ceilings, heavily tinted glass or insulating panels designed to reduce heat gain from windows. The net result has been a dramatic reduction in the amount of daylight available in our schools and workplaces during the past half-century.

Two forces are working to reverse this trend. First, when lighting electricity consumption is considered along with heating and cooling as part of a whole building energy equation, daylighting typically provides a net energy benefit. Daylight is intrinsically more efficient than any electric source because it provides more lumens per unit of heat content. If appropriate daylighting techniques are used to displace electric illumination, the savings for lighting and cooling can be dramatic.

Secondly, a growing interest in the influence of indoor environments on health and productivity has resurrected interest in the potential health and productivity benefits of daylighting. Reductions in worker absenteeism, higher retail sales, and better student health were associated with increases in daylight in anecdotal reports. However, few formal scientific studies have addressed the relationship of daylight with these outcomes. Accordingly, we have been studying the association of increased daylight with student performance and retail sales. This summary article describes the methodology and findings from the study[1] in schools.

We identified three large school districts that had a range of daylighting conditions in their classrooms. We collected test scores and demographic information for all second through fifth graders in the districts, and classified their classrooms for the amount and quality of daylight available. We chose to work with data on elementary school children since they typically spend all year in one classroom. Thus, we could directly isolate the effects of that one classroom.

We also specifically selected districts that had a number of classrooms lit from above with skylights or roof monitors ("toplighting"). We reasoned that daylight provided through windows might have complicating factors, such as the quality of view, whereas daylight provided from above typically had fewer other qualities that might influence results. Thus, we would be more likely to be looking at a pure "daylighting" effect.

The three districts were located in San Juan Capistrano, Calif., Seattle, and Fort Collins, Colo. These three districts have very different climates, school building types, curriculums and testing protocols. The districts also provided us with information about student demographic characteristics, special school programs, size of schools, etc. We added information to these data sets about the physical conditions of the classrooms where these children were assigned. We re-

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Daylighting Conditions In Classrooms	Percent Average Improvement (Probability that Observed Association with Improved Test Scores is Due to Chance)	
	Reading	Math
Classrooms with most overall daylighting (from skylight and windows) relative to classrooms with least overall daylighting	26% (0.1%)	20% (0.1%)
Classrooms with most window area compared to classrooms with least window area	23% (0.1%)	15% (0.1%)
Skylight A (diffused illumination with manual operation for controlling illumination level) relative to no skylight	19% (0.3%)	20% (0.1%)
Skylight B (direct illumination with no controls) relative to no skylight	–21% (5.1%)	—
Operable windows, relative to classrooms without operable windows	8% (0.4%)	7% (0.1%)

***Table 1:** Improvements in test score (fall to spring in Capistrano School District) of students in classrooms with better daylighting.*

viewed architectural plans, aerial photographs and maintenance records, and visited a sample of the schools in each district to classify the daylighting conditions in more than 2,000 classrooms. Each classroom was assigned a series of codes on a 0 to 5 scale indicating the size and tint of its windows, the presence and type of any skylighting, and a daylighting code indicating the overall quality and quantity of daylight expected. Ultimately, the study analyzed test scores performance for 8,000 to 9,000 students per district. We looked at math and reading scores in all three districts, and analyzed data from each district separately, alternately using the holistic daylight code and the separate window and skylight codes, for a total of 12 statistical models.

The Capistrano Unified School District proved to be the most interesting study site for many reasons. The district administers standardized tests in fall and spring, allowing us to compare the change in students' math and reading test scores while they spent the year in one classroom environment. Because the district, like most in California, has nearly identical portable classrooms at every elementary site, we were able to use these portables as a standardized condition controlling for the influence of individual school sites or neighborhoods. We also collected additional information at this district about the HVAC and ventilation conditions of the classrooms, which was also included in the statistical models used for data analyses.

> Students in classrooms with the most window area or daylighting were found to have 7% to 18% higher scores on the standardized tests than those with the least window area or daylighting.

Results

In Capistrano, using a regression equation that controlled for 50 other variables (socio-economic status, special programs and school size) that might affect student performance, we found that students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% on reading tests in one year than those with the least daylight. Similarly, students in classrooms with the largest window areas were found to progress 15% faster in math and 23% faster in reading than those with the least window areas. Students that had a well-designed skylight in their room, one that diffused the daylight throughout the room and allowed teachers to control the amount of daylight entering the room, also improved 19% to 20% faster than those students without a skylight. Classrooms with a skylight that allowed direct beam sunlight into the classroom and did not provide the teacher with a way to control the amount of daylight were actually seen to have a negative association with student performance. In addition, in three of the four Capistrano models, the presence of an operable window in the classroom was also seen to have a positive effect on student progress, associated with 7% to 8% faster learning. In statistical analysis of this type, variables of interest will sometimes be associated with the outcome variable only by chance. However, statistical tests indicated that a probability of 1% or less that the observed associations (of daylight and operable windows) to improved student performance was the result of chance.

The Seattle and Fort Collins school districts administer only one standardized test at the end of the school year. In these districts, the study used the final scores on math and reading tests at the end of the school year. We also had less detailed information about the schools; thus, the statistical models used to analyze the data had only 20 variables. In both districts, we also found improved test scores associated with increased daylighting. Students in classrooms with the most window area or daylighting were found to have 7% to

18% higher scores on the standardized tests than those with the least window area or daylighting. The analyses indicated that the probability that these associations were chance associations was less than 1%.

Conclusions, Limitations and Further Work

The three districts have different curricula and teaching styles, different school building designs, and climates. And yet, the results of the studies show consistently positive associations of increased daylighting with improved test scores with a very low probability that the associations are the result of chance. This consistency across such diverse school environments persuasively argues that there is a valid and predictable effect of daylighting on student performance or that some other unidentified factor consistently linked with daylighting improves student performance.

There are also important limitations that should be considered. The models used to analyze the data explained about 25% of the natural variation in student performance. Thus, the other 75% of unexplained variation might be purely random or explained by other factors not included in our models, such as teacher quality, home life, health, nutrition, individual talents and motivation, etc. There always remains the possibility that some other variable left out of the equation is influencing results.

Reviewers of the school study asked if "better" teachers were more likely to be assigned to the more daylight classrooms, thus influencing the results. To answer this question, we collected additional data about the teachers in our Capistrano study that might be a measure of "better" teachers, such as years of experience, education level, and special awards. We found that these teacher characteristics only explained 1.4% of the variation in the assignment to daylit classrooms. Adding this information about the teachers to the original analysis did not significantly change the daylight effects in magnitude or significance, and only increased the models' explanation of variation (R^2) in student progress by about 2%.

Finally, these types of statistical studies show strength of association between variables, but cannot prove a causal relationship, such as between daylight and improved human performance. Other types of studies are necessary to prove a causal mechanism. Daylight is actually quite a complex phenomenon, involving variations in the intensity, spectrum, distribution, duration, and timing of light exposure. A number of potential mechanisms (alone or combined) that may have been responsible for the positive association between daylight and improved performance of students are:

- Improved visibility due to higher illumination levels;
- Improved visibility due to better light quality;
- Mental stimulation; and
- Improved mood, behavior or well-being.

A more exhaustive discussion on these issues can be found in the original report.[1] The potential energy savings from daylighting can be substantial. While 25% of the existing non-residential building stock in the United States is amenable to side-lighting from perimeter windows, an additional 60% could potentially be reached from above, via skylights or roof monitors. If the link between increased daylight and improved human performance holds true with additional studies, it strongly suggests that we should act to reverse our current building trends that are reducing the presence of daylight in the workplace.

Acknowledgments

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