DAYLIGHTING *initiative*

Design tools and information from The Pacific Gas and Electric Company

Daylighting in Schools

An Investigation into the Relationship Between Daylighting and Human Performance

Condensed Report

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Submitted to:

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on behalf of the
California Board for Energy Efficiency Third Party Program

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EXECUTIVE SUMMARY

This study looks at the effect of daylighting on human performance. It includes a focus on skylighting as a way to isolate illumination effects from other qualities associated with daylighting from windows, such as view and ventilation. In this project, we established a statistically compelling connection between daylighting and student performance, and between skylighting and retail sales. This report focuses on the school analysis.

We obtained student performance data from three elementary school districts and looked for a correlation to the amount of daylight provided by each student's classroom environment. We used data from second through fifth grade students in elementary schools for two reasons: because there is extensive data available from highly standardized tests administered to these students, and because elementary school students are generally assigned to one teacher in one classroom for the school year. Thus, we reasoned that if the physical environment does indeed have an effect on student performance, we would be mostly likely to be able to establish such a correlation by looking at the performance of elementary school students.

We analyzed test score results for over 21,000 students from the three districts, located in Orange County, California, Seattle, Washington, and Fort Collins, Colorado. The data sets included information about student demographic characteristics and participation in special school programs. We reviewed architectural plans, aerial photographs and maintenance records and visited a sample of the schools in each district to classify the daylighting conditions in over 2000 classrooms. Each classroom was assigned a series of codes on a simple 0-5 scale indicating the size and tint of its windows, the presence and type of any skylighting, and the overall amount of daylight expected.

The study used multivariate linear regression analysis to control for other influences on student performance. Regressions were compared using data from two separate tests, math and reading, for each district. Each math and reading model was also run separately using first the window and skylight codes, and then the overall daylight code. We reasoned that if daylight effects were truly robust the variables should perform similarly in all models. Thus, we created a total of twelve models for comparison, consisting of four models for each of three districts.

The daylighting conditions at the Capistrano school district were the most diverse, and the data from that district were also the most detailed. Thus Capistrano became our most precise model. In this district, we were able to study the change in student test scores over a school year. Controlling for all other influences, 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. 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. And students that had a well-designed skylight in their room, one that diffused the daylight throughout the room and which allowed teachers to control the amount of daylight entering the room, also improved 19-20% faster than those students without a skylight. We also identified another window-related effect, in that students in classrooms where windows could be opened were found to progress 7-8% faster than those in rooms with fixed windows. This occurred regardless of whether the classroom also had air conditioning. These effects were all observed with 99% statistical certainty.

The studies in Seattle and Fort Collins used the final scores on math and reading tests at the end of the school year, rather than the amount of change from the beginning of the year. In both of these districts we also found positive, and highly significant, effects for daylighting. Students in classrooms with the most daylighting were found to have 7% to 18% higher scores than those in rooms with the least.

The three districts have different curricula and teaching styles, different school building designs and very different climates. Yet the results of the studies show consistently positive and highly significant effects. This consistency supports the proposition that there is a valid and predictable effect of daylighting on student performance.

The results of this study of student performance, when considered along with those of the companion study showing the positive effect of skylighting on retail sales, also strongly support the thesis that these performance benefits from daylighting can be translated to other building types and human activities.

1. DAYLIGHTING IN SCHOOLS

This report is part of a study that looks at the effect of daylighting on human performance. This part of the study looks at how daylighting, from windows or skylights, affects the test scores of students in three elementary school districts. Another part of the study reports on how the use of skylighting affected the sales of a large chain retailer. We found a statistically compelling connection between daylighting and student performance, and between skylighting and retail sales. The study was supported by the California Board for Energy Efficiency, and administered by Pacific Gas and Electric Company.

Schools and retail stores were chosen as the subject of the study because we could obtain extensive data on occupant performance for nearly identical buildings. We believe that the conclusions may be transferable to other types of buildings, such as offices and factories, since it is really human performance that we are investigating. If daylighting enhances the performance of children in schools, it is not too large a stretch to suppose that it might also enhance the performance of adults in office buildings. If daylighting motivates buyers at a retail store, it is not too large a stretch to presume that it might also motivate workers in a factory.

This Condensed Report is intended for the non-specialist reader. It is a summary of a more extensive report that details the study methodology and statistical analysis. If you have questions about the study that are not answered here, we recommend reading the Detailed Report.

1.1   Background

The impact of daylighting on the performance of school children has been a subject of interest for many years. Before fluorescent lighting became prevalent, it was generally assumed that all school rooms would be daylit as a matter of course. The California Department of Education had a rigorous review process for the architectural design of classrooms to ensure that daylighting standards were met. As a result, California classrooms built in the 1950's and early 1960's remain excellent examples of daylighting practice. The "finger" plan with multiple rows of single classrooms, each with windows on two sides, became a standard for California K-12 campuses.

However, starting in the late 1960's a number of forces came into conflict with the daylit design of classrooms. Engineers, asked to provide air conditioning in classrooms, argued against the use of large expanses of glass and high ceilings. Construction economists argued that schools could be built more inexpensively on smaller sites if the classrooms could be built back to back or grouped together, without constraints on solar orientation. Educational theorists argued that a more flexible arrangement of classrooms, with open walls between them, would encourage team teaching and creative learning. And educational planners,

trying to meet the needs of an exploding school age population, required that at least one-third of all new classrooms be portable, so that, if the need arose, they could be moved to new areas with an overpopulation of new students.

As a result of these various pressures, the finger plan school was largely abandoned in California, and a vast experimentation in school design was undertaken. Many of the classrooms built since the 1960's have little daylighting. Windows are commonly built with "black glass" that allows a view out, but no useful daylight in. Numerous schools have been built with no windows at all.

Similar trends occurred nationally, and internationally, though perhaps without such a dramatic shift in design practice as in California. Concerned about the trend towards schools, and all types of buildings, without windows, Belinda Collins of the National Bureau of Standards conducted a major literature review on the study of windows in 1974[1]. At that time there was an ongoing debate about the desirability of windows in classrooms.

In a compilation of studies on windowless classrooms published in 1965, the editor, C.T. Larson, concluded that windowless classrooms should have no adverse effects upon their users. Larson stated, "The educational value of such a view [that windows are necessary for student learning] should be assessed against the cost of installing and maintaining classroom windows.[2]"

Collins also quotes from a later book on the behavioral aspects of design, which also concluded that windows were not needed in classrooms. "At present the pro-window forces still lack behavioral data in support of their case and argue on the basis of metaphor and supposition, but their arguments must be weighed against statistics…from the windowless schools…reported to have 40 percent greater efficiency in heating and cooling, constant light to prevent eye strain…35 decibels or more noise reduction, and reduced maintenance costs." The author went on to claim that the experience of completely underground schools provided evidence that claustrophobic reactions were extremely rare. He stated further that, "Opponents [of windowless schools] now take recourse in the need for communion with nature, contact with the outside and stimulus variation, which are more difficult to measure, and whose importance is not readily apparent."

Collins herself found that the research that had been done as of 1974 was suggestive of the importance of windows, but inconclusive:

> *"Much, though not all, of the evidence from the windowless classroom studies is inconclusive, or inadequate, while that from windowless factories is circumstantial, based on hearsay, rather than research. As a result, only tentative conclusions can be drawn about the qualities of windowless spaces that make them somewhat less than desirable."*

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[1] Collins, B. "Windows and People: a Literature Survey, Psychological Reaction to Environments With and Without Windows", National Bureau of Standards, June 1975

[2] Larson, C.T. (ed), *The Effect of Windowless Classrooms on Elementary School Children*, The Architectural Research Laboratory, Department of Architecture, University of Michigan, 1965.

Since Collins' study, other research on the importance of windows has been done, but primarily in hospitals. The most rigorous studies have been conducted in Europe. One interesting study in Sweden in 1992 looked at the impact of daylight on the behavior of elementary school children.

The Swedish researchers followed the health, behavior, and hormone levels of 88 eight-year-old students in four classrooms over the course of one year. The four classrooms had very different daylight and electric light conditions: two had daylight, two had none; two had warm white (3000K) fluorescent lamps, two had very cool (5500K) fluorescent lamps. The researchers found significant correlation between daylight levels, hormone levels, and student behavior, and concluded that windowless classrooms should be avoided[3].

Recent, more informal studies in the United States claiming a relationship between daylighting and enhanced student performance have generated considerable excitement among daylighting advocates.[4] These studies, along with a rising interest in "natural" and "healthy" environments, have contributed to a resurgent interest in daylighting in schools. All three districts that we worked with in this study reported that daylighting in classrooms is currently a concern for their school boards, driven largely by parent activism. However, without credible evidence of relationship between the design of schools and the performance of students within them, classroom design issues remain subject to architectural and educational fads, just as in the past. We hope that this study provides a contribution towards more durable understanding of how the physical environment affects student performance.

1.2   The School Data

We obtained student performance data from three elementary school districts and looked for a correlation between test scores and the amount of daylight provided by each student's classroom environment. We used data from second through fifth grade students in elementary schools because there is extensive data available from highly standardized tests administered to these students, and because elementary school students are generally assigned to one teacher in one classroom for the school year. Thus, we reasoned that if the physical environment does indeed have an effect on student performance, it would be most apparent in populations of elementary school students.

We analyzed test score results for over 21,000 students from the three districts, located in Orange Country, California; Seattle, Washington; and Fort Collins, Colorado. The three districts have different curricula, administrative and teaching styles, different school building designs and very different climates. Yet the

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[3] Kuller, R and Lindsten, C., "Health and Behavior of Children in Classrooms with and without Windows", Journal of Environmental Psychology, (1992) 12, 305-317. Further discussed in Conclusion.

[4] Nickas, M. and Bailey, G., "Analysis of the Performance of Students in Daylit Schools," Proceedings of the American Solar Energy Society, 1997. The study reports positive results for children moving to daylit schools. However, the analysis does not provide any certainty that this was not a random effect.

results of the studies show consistently positive and highly significant effects. This consistency supports the proposition that there is a valid and predictable effect of daylighting on student test scores.

The districts provided us with a wide variety of data sets, with many different student test scores and student demographic characteristics, for a two year period. In order to achieve consistency between districts, we chose to use the data from just two test scores, reading and math, in our analysis. We also endeavored to keep the demographic variables consistent between districts.

Individual student identities were masked by substituting false student record numbers for all data sets. In addition, some districts decided to provide some demographic data at a classroom level to further mask individual student records. Similarly, in our reporting, we have scrambled the identification numbers for school sites, and renamed the specific demographic variables in this report to make them generic.

A second data set was created describing the physical characteristics for each classroom in the three districts. This data allowed us to take into account the age and size of the classroom and school, the type of the classroom, (open, cluster or pod, portable or traditional) as well as the presence and size of windows and skylights.

We reviewed architectural plans, aerial photographs and maintenance records and visited a sample of the schools in each district to classify the daylighting conditions in over 2000 classrooms. Each classroom was assigned three codes on a simple scale indicating the size and tint of its windows, the presence and type of any skylighting, and the overall amount of daylight provided.

2. ANALYSIS AND FINDINGS

In this section we report on the findings for each of the three school districts in turn. First we describe the relevant characteristics of each district, so that the reader can understand the context and better evaluate the results. Then we report on the specific model results for each district.

The study used a powerful statistical analysis technique, called multivariate linear regression analysis, to control for other influences on student performance. These mathematical models allow us to isolate the effect of one variable, while controlling for the influence of all the others. The models also tell us the statistical probability that we have a "true" effect, and the power of each variable in predicting results.

With the Capistrano data, we created a model based on the change in test scores between the fall of 1997 and spring of 1998. Thus, this analysis looks at the <u>rate</u> of learning during the school year that the students occupied a given physical environment. It also uses each student as his or her own control. As a result, all of the demographic variables drop out, and we are left with a simple model containing only those few variables that are seen to directly influence student improvement.

For the other two districts we had to use only the final spring test scores, rather than the difference between a fall and spring test. The models for these two districts report on a snapshot of student performance at one point in time. There is an assumption that the most recent classroom experience will influence how students perform on tests. However, the absolute level of student performance is a function of many influences, including where each student started at the beginning of the year and all the advantages or disadvantages that the students brought with them into the classroom. Thus, in these models, the demographic and socio-economic variables become important predictors of absolute student performance, and add many more control variables to our final equation.

The Capistrano District provided by far the most complete and complex data set that we analyzed. We had the most information about its diversity in student population, administrative structure, and physical conditions. In the Capistrano analysis we were also able to account for the influence of the individual school, and to test for the influence of the individual classroom environment. Thus, we have the highest confidence in the results from the Capistrano study. The Seattle and Fort Collins studies are very suggestive of a daylighting effect on performance, but are not as exhaustive in their analysis or conclusive in their findings. It is the consistency of the positive findings from all three districts that makes a strong case that we have, indeed, found a valid effect.

2.1   Capistrano Characteristics

The Capistrano Unified School District, in Orange County, CA, serves a population of more that 40,000 students in 44 schools from kindergarten through high school. It covers an area of more than 195 square miles and includes 10 small cities in an area of southern California that extends 25 miles inland from the Pacific coast. We were provided with data on the district's 27 elementary schools, of which nine included skylights in their classrooms.

The district tends to have a wealthy population, although there are pockets of lower income and immigrant families. The older neighborhoods nearest the coast tend to have the highest average household income. However, new developments farther inland are also very upscale. The district population is 75% white, 17% Hispanic, 5% Asian, 2% African American and 1% other minorities.

2.1.1   School Characteristics

The physical plant of the Capistrano Unified School district is similar in many ways to other California school districts. They have a set of schools which date from the 1950s through the 1990's, with substantially more built in later years. The schools are all single story, and almost all classrooms have a door directly to the outdoors. The district has a number of schools which represent plan types popular in each decade:

- **Finger schools** from the 50's and 60's with ample daylighting from windows on two sides of the classrooms, grassy planted areas in between the wings, and careful attention to orientation and sun angles.

- **Wing schools**, from the late 60's and early 70's with wings of back-to-back classrooms each with a single window wall, usually with very low transmission ("black") glass. Plans generally show little attention to orientation and sun angles.

- **Open plan schools** from the 70s, with few, if any, windows into the classroom "pods." Classroom areas were designed to flow into one another, often with a shared central resource area. Partitions have since been added to all of the original open plan schools so that there is some visual privacy, but rarely acoustic privacy, between classrooms. Due to recent class size reduction mandates in California, these open plan schools have often been subdivided into even smaller classroom areas than originally anticipated, creating a maze-like atmosphere.

- **Modular plan schools** from the 80s, typically in wings, but often with clustered classrooms divided by movable partitions and shared work rooms. Built with pre-fabricated elements.

- **Most recent schools** in the 90's have a variety of plan types, some wing schools, some with interior hallways and common workrooms.

- **Portable** or "re-locatable" classrooms. California schools have been required to install portable classrooms to address the needs of a rapidly changing

population. These classrooms are similar to mobile homes: they are factory built, shipped to the site, and installed above grade. These portables exist at every school site in the district, and constituted 40% of all classrooms in our data set. Because every school site had at least a handful of portables, and because of their uniformity across schools, the portables served as a standardized element in our analysis.

Figure 1: Classrooms with Maximum (left) and Minimum (right) Daylighting in Capistrano

Figure 2: Type A Skylight (left) and Type B Skylight (right)

As described above, the district has a wide range of window conditions, depending on the plan type. In addition to these common school plan types, Capistrano had a rather unique feature, in that many of the later school plans included skylights in the classrooms. In the late 70's, after having built a number of open plan schools with no windows at all, the school board became concerned that natural daylight was essential for a healthy and positive classroom setting, and so directed all architects hired to design new campuses to provide natural lighting in the classrooms, including both windows and skylights. As a result, the district now has nine elementary campuses that include skylights in the classrooms.

There are five types of skylights that have been employed in nine of the schools. Two have a diffusing lens that spreads the daylight evenly throughout the classroom (such as Type A skylight in figure 2 above), while three allow patches of sunlight to enter the classroom (type B, above). Two of the skylight types are

manually controlled, allowing the teacher to dim the daylight, while one type has dimming louvers controlled by an electric switch on the wall. The skylights were identified by type in this study, rather than by the amount of daylight they were expected to allow in.

We also collected and analyzed information about the presence of air conditioning and operable windows in the classroom. We would have liked to include information about the different types of electrical lighting used in the schools, but this information was not available. Capistrano schools use fluorescent lighting throughout the district, and lighting systems are generally designed to provide an average of 50 footcandles of light on classroom work surfaces. However, there have been so many remodels and retrofits of the electric lighting system in recent years that the actual equipment type is highly variable.

2.1.2 Capistrano Results

Figure 3 summarizes the increases in test scores for the daylighting-related variables for the four Capistrano regression models. As part of the analysis we calculated the statistical certainty that these effects were a "true" effect which could be replicated in other analyses of the data. This is expressed as a percent certainty. The chart shows the value of each variable's effect, its statistical certainty, and the relative effect of each variable compared to the average progress of all students in the Capistrano District.

Capistrano	Analysis Results			Percentage Effect	
NEA Core Level Tests Range: -29 to +79	Difference in Average Test Improvement (normalized RIT points)		Statistical Certainty	Difference as a % of District Average Improvement	
Change, Fall to Spring	Reading	Math	Reading	Math	Reading	Math
Model 1						
Daylight, Min. to Max.	2.8	2.3	99.9	99.9	26%	20%
Operable Windows	0.8	-	99.8	n/s	7%	-
Model 2						
Windows, Min. to Max.	2.4	1.7	99.9	99.9	23%	15%
Skylight A	2.0	2.3	99.7	99.9	19%	20%
Skylight B	-2.2	-	94.9	n/s	-21%	-
Operable Windows	0.9	0.8	99.6	99.9	8%	7%

Figure 3: Summary Daylight Findings for Capistrano

The Capistrano Core Level Tests are reported on a special scale system called "RIT." The average student in our data set progressed in reading scores by 8.8 RIT points and in math scores by 12.5 points from fall to spring[5]. For the charts in this report we have translated all the test results into a consistent scale of 1-99 in

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[5] These values are averages for our specific data set, not the district, because our data set was a sub-set of all students in the district. For the percentage effects discussed here, the raw RIT score (not the normalized score shown in the chart) was divided by this average from our data set.

order to facilitate comparison between the districts. We also report the test results as a percentage effect to show the relative magnitude of the findings.

Daylighting was found to have a considerable effect in the Capistrano schools. For example, all other things being equal, students in classrooms with Skylight Type A were found to progress an additional 2 points in reading and 2.3 points in math[6] than those in classrooms without skylights. This translates into a 19% faster learning rate for reading and a 20% faster learning rate for math on average for the children in those classrooms.

Summary results in the Capistrano Unified School District:

◆ The classrooms with the most amount of daylighting are seen to be associated with a 20% to 26% faster learning rate, as evidenced by increased student test scores over one school year, compared to classrooms with the least amount of daylighting.

◆ The classrooms with the most window area are seen to be associated with 15% to 23% faster rate of improvement over a one year period when compared to classrooms with the least amount of windows.

◆ The classrooms with the Skylight Type A are seen to be associated with a 19% to 20% faster improvement when compared to classrooms with no skylights.

◆ The classrooms with the Skylight Type B are seen to be associated with a 21% decrease for reading tests, and no significant results for math tests, when compared to classrooms with no skylights.

◆ Classrooms with operable windows are seen to be associated with 7% to 8% faster improvement in three out of four cases, when compared to classrooms with fixed windows.

Another way to look at these results is that the average child in the Capistrano district is making about 1 point of progress per month on the reading test and 1.5 points of progress per month on the math test over the course of the approximately eight months between the fall and the spring tests. Students in the most daylit classrooms are progressing more quickly, gaining one to two points more over the course of the school year than students advancing at the average rate. Thus, by advancing more quickly, students in daylit classrooms could save up to one month of instruction time in the reading and math curriculum that could be used for other areas of learning.

2.1.3 Other Capistrano Variables

The results for all major variables of the Capistrano models are presented below in Figure 4. For this chart the values of the analysis results (called the B-coefficient) have been normalized to a scale of 1-99 so that they can be

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[6] These are the normalized RIT values. Raw RIT values are 1.7 and 2.6 respectively. Thus, a 1.7 difference in reading scores, divided by the 8.8 district average, equals a 19% effect.

compared with the other two school districts. The same set of control variables was considered in all regression models, and thus when a control variable was significant in all four Capistrano models, it has four bars in the graph. The Daylight, Window and Skylight variables each were run in only two of the four models, and thus, they have a maximum of two bars. We discuss the patterns and magnitudes of these findings below.
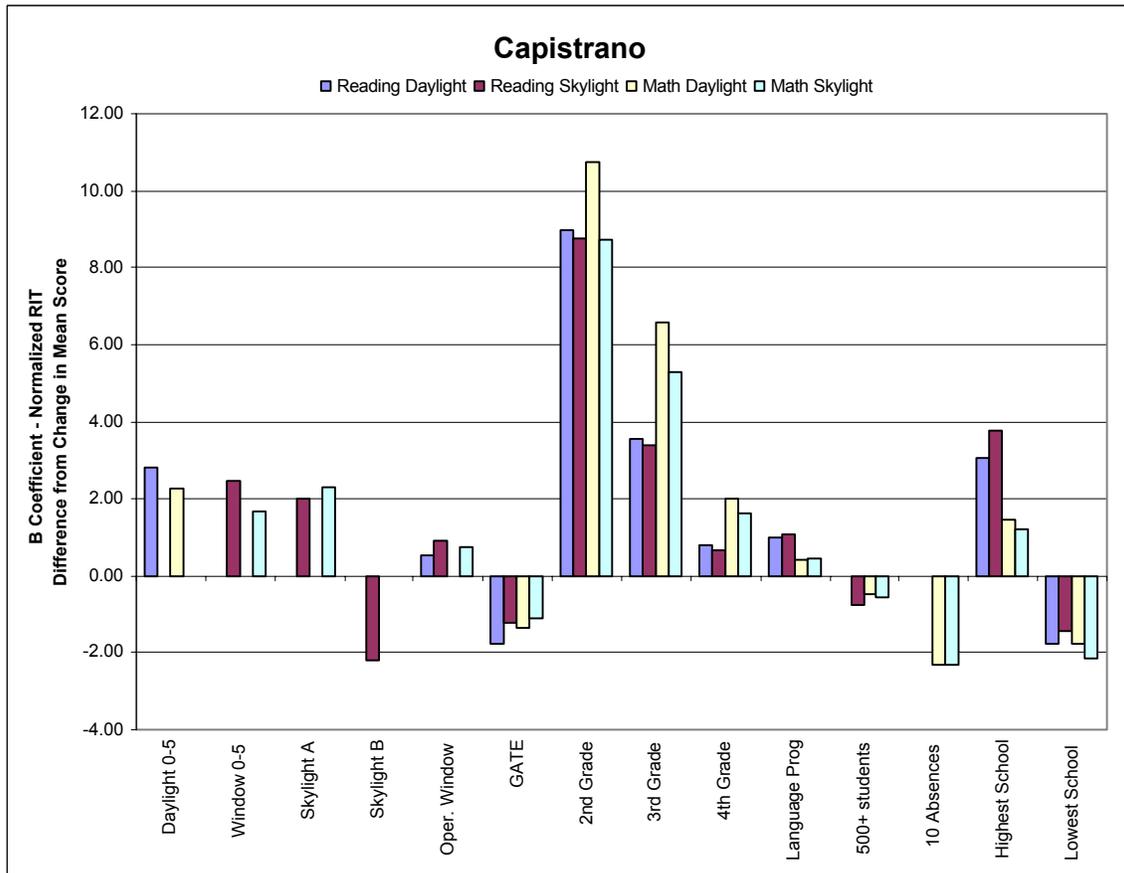
Figure 4: Capistrano Relative Importance of Variables, Normalized RIT Points, Difference From Change in Mean Score

Each value predicts how far a given student is likely to diverge from the norm if the variable applies. It is very important to keep in mind that the Capistrano models use the rate of <u>change</u> in test scores over a school year as their measure, not the absolute levels of testing. Thus, a negative value for a variable means that those students made slightly less progress than the norm, but they still made progress.

Daylight, Skylights, and Windows: The daylight, window and skylight type A variables are all positive and highly significant.

Skylight Type A had the most even light distribution of the five skylight types, fully diffused without any potential for direct sunlight to enter the room. It also allowed

the teacher to control the amount of daylight with the use of manually controlled louvers.

The observation that both the daylight variable and the Skylight Type A variable have slightly larger effects than the window variables argues for the theory that the presence of daylight in and of itself, and not view or other aspects of windows, are responsible for the positive effects.

The results for the other skylight types were less compelling. The negative effect for Skylight Type B that is observed in one model might reasonably be interpreted as a function of the glare caused by sunlight splashing on the classroom walls. Skylight Type B is a clear acrylic skylight located in the corner of the classroom, often over the teacher's desk. It is not provided with any controls to modulate the light. Thus, on sunny days, sunlight makes its way directly onto the walls or the teacher's desk. This finding suggests that control of light and/or diffusion of direct sunlight are important features to include in a classroom skylight system.

The other three skylight types, AA, C and D, had no significant coefficients. These skylights do not diffuse the light as evenly as skylight A, and in fact these skylights were often closed by the teachers. Thus, from these findings, it would seem that the mere presence of a "patch of daylight" or "connection to the outdoors" through toplighting is not sufficient to provide positive effects. The one skylight (type A) that performs well provides high levels of illumination, evenly distributed in the classroom. It does not allow any direct sunlight into the classroom, and also allows the teacher to easily modulate the light levels.

Operable windows were also found to have a significant positive coefficient for three out of four of the models. We posit that allowing the teacher the option of using natural ventilation when desired is a positive feature for classrooms. About half of the classrooms with operable windows in this district also had air conditioning. However, in some of our preliminary analysis air conditioning in this district seemed to be associated with a negative effect. There are many possible interpretations of these findings, including interactions with other variables, the mild climate in Capistrano, malfunctioning air conditioning units, or air quality issues. We would suggest that this finding deserves further study.

Grade Level: The grade level of the student tended to be the most powerful predictor of progress made between the fall and the spring tests. This is consistent with the RIT scales of the Capistrano core level tests, where younger grades typically make greater progress.

In addition, California has recently mandated class size reduction for kindergarten through third grades so that students in the lower grades can receive more attention from their teachers. The maximum student/teacher ratio in those grades is 20:1, whereas in the higher grades in our data set, fourth and fifth, the ratio is commonly 30:1.

Gifted and Talented (GATE) and Bilingual Programs: Participation in a GATE program shows a negative effect, meaning that GATE identified children made

slightly less progress in a year than non-GATE children. The best explanation of this would seem to be that GATE children already score very high on the tests. Since they are already at the top of the group, it is more likely, given all the variation in the system, that their scores will rise less quickly than others. This is also consistent with the observation that, in the RIT scaled tests, children testing at higher levels make less relative progress per year than those at lower levels.

The positive effect of the bilingual program might be attributable to two further explanations, other than the obvious conclusion that the program is helping children progress more rapidly. Since the bilingual program children tend to have slightly lower actual scores than the norm, they would tend to progress faster than the norm. Alternatively, since the bilingual programs are magnet programs, they may attract more dedicated families, creating a self-selection bias for this population.

School Site: Approximately 1/3 to ½ of the schools showed up in the models as having a significant influence on how much a student learned over the course of the school year. The positive or negative effect of the school site could be due to any of a number of mechanisms. The site might have a special program, a more motivated staff, more active parents, a better neighborhood, a better location, or other influences that make one school "better" than another. It is one of the strengths of the Capistrano analysis that we were able to include individual school sites as variables in the models to account for these effects.

It is very noteworthy that the effect of moving from a classroom with the least to the most daylighting is of the same order of magnitude as the effect that would be seen by moving from an average school in the district to one of the highest, or lowest, performing schools in the district.

Unverified absences had a slight negative impact on math improvement, but not on reading improvement. Ten unverified absences have the same order of magnitude effect (negative) as learning in a skylit or daylit room (positive).

Size of school: The size of the school was found to have a small but significant negative effect. For the very largest school in the district, average student performance decreases by less than one percentage point. For the smallest, performance increases by about one half a percentage point.

2.1.4 Validity of the Model

The Capistrano analysis was put through two additional statistical tests to determine the validity of the results. One test looked at the "explanatory power" of the daylight variables relative to the other variables included in the model. The daylight and window variables were relatively powerful when compared to the other variables, while the skylight and operable window variables tended to have lower explanatory power. However, in general, all the daylighting variables offered as good, if not a better explanation for how far a student would progress, as the variables for which school they attended, whether they were in a special language program, or how many absences they each had.

The second statistical test ran the same data through a new model that looked at the average performance of each classroom group, rather than of individual students. The daylighting variables all remained highly significant in this test. This test implied that the influence of being in a given classroom group, whether because of the teacher or the class dynamics, was less significant than the variations between individual students. This may be because the Capistrano District does not group students into classrooms by abilities, or because the Capistrano teachers are all reasonably similar in their ability to teach the math and reading curriculum. However this statistical test did allay concerns that we had picked up a "teacher effect" instead of a "daylighting effect" in our analysis.

2.2   The Other Districts

We performed a similar analysis for two other school districts, one in Seattle and another in Fort Collins. Due to limitations in the data, the analysis for these two districts was less detailed than for Capistrano.

The studies in Seattle and Fort Collins used the absolute value of the students' final scores on math and reading tests at the end of the school year, rather than the amount of change from the beginning of the year. As a result, more variables show up as significant in the models. For example, students' ethnic background and socio-economic status become important predictors of their actual test scores, whereas in Capistrano these variables were not significant predictors of how far a student would progress in one year.

We have less confidence in the results of these models, since the analysis was less detailed. There is more probability that there are other factors that we were not able to account for that could invalidate the results. However, we find it very suggestive that in two very different districts, in different states, we found very similar results to the Capistrano analysis. In both of these districts we also found large, positive, and highly significant effects for daylighting.

2.2.1 The Seattle District

Seattle Public School District is a primarily urban school district in the city of Seattle, Washington. Its neighborhoods tend to be in the older, more densely settled areas of the city. It has also expanded by incorporating neighboring suburban districts. Elementary schools in Seattle tend to have far fewer students than Capistrano, and a great deal more floor space per student.

Seattle provided us with student test score records for all elementary students at over 60 school locations. The test scores used in the analysis are from the Iowa Test of Basic Skills (ITBS), Form M, for grades 2 to 5, for math and reading, administered in the spring of 1998. In addition to the test scores, the data set included codes for the students' classroom location, grade, ethnicity, gender, socio-economic status and participation in special programs.

The elementary schools in Seattle have a large range of physical conditions. Mostly older, the schools range in age from 20 to 90 years old. Most are multiple story

buildings with interior hallways, and extensive indoor and covered facilities for student use, such as gymnasiums, covered play areas, libraries, cafeterias and auditoria. Many schools have had multiple additions over the years, but, in general, daylighting conditions within a given school were fairly similar across all classrooms.

Most Seattle elementary schools have substantial windows with clear glass, although some have lightly tinted glass and a few have minimal or no windows. There are a few "open" schools from the 1970s with "pod" classrooms that share a common space in the center. These open classroom schools typically have few, if any, windows. Some schools are clearly designed for full daylighting, with high ceilings (11') and window walls on two sides of the classroom.

Daylight was also provided from clerestory windows high up in the walls, sawtoothed monitors or skylights in four of the schools. One school with open-type classrooms has high clerestory windows that allow daylight deep into the building. One group of classrooms has three small skylights along the inner wall, and another group has large central skylights with diffusing louvers that cover most of the ceiling.

Figure 5: Older Seattle School With Windows Code 4, Exterior (left), Interior (right)

Figure 6: Seattle Classrooms With Clerestory Windows (left) and Central Skylight and Diffusing Louvers (right)

2.2.2 The Fort Collins District

The Poudre School District in Fort Collins, Colorado is a rapidly growing school district about two hours north of Denver, situated in the college town for Colorado State University. The district has many new facilities, some of which include aggressively daylit classrooms which are lit from rooftop windows, called sawtooth monitors. The sawtooth monitors in Fort Collins face south, and although they diffuse the sunlight somewhat, they are very bright. Teachers have the option of pulling an insulating shade across the skylight to darken the room. On one partly sunny winter day, we observed that 60% of classrooms had their shades closed.

These skylit schools have modestly sized windows. Other older schools with the sawtooth monitors have somewhat larger window areas. However, none of the Fort Collins schools have classrooms with the very large windows designed for complete daylighting, as we found in the Capistrano or Seattle districts.

The Fort Collins district provided us with data sets of student test scores for math and reading "level" tests for spring of 1998 for 23 schools. These level tests for math and reading, developed by Northwest Educational Association, are similar to the tests used in the Capistrano analysis. The data sets also included demographic information, similar to Seattle and Capistrano, including grade level, ethnicity, gender, socio-economic status, and special program codes.

Based on an examination of district records, we added information to the database about the age and the size of the schools. We examined architectural plans for each school to determine classroom type (open vs. traditional classrooms), and develop the daylight, window and skylight codes.

Due to the structure of the data sets given to us by Fort Collins, we were not able to identify students by their specific classroom location, but only by their grade level within a school. As a result the final analysis in Fort Collins was much simpler and more general than the other two districts. Luckily, most schools in Fort Collins had fairly uniform daylighting conditions for all their classrooms. Thus an overall school daylighting code was a reasonable approximation of individual classroom conditions.

Figure 7: New Fort Collins School with Monitor Skylights

Figure 8: Interior of Fort Collins school with South Facing Monitor Skylight

We were told that none of the schools in Fort Collins have air conditioning. Thus, information about air conditioning and natural ventilation was not included in our analysis for this district.

All of the schools visited in Fort Collins had fluorescent lighting, but we could not confirm that fluorescent lighting was universal in all schools. Information about electric lighting was not included in our analysis for this district.

All of the schools visited in Fort Collins had fluorescent lighting, but we could not confirm that fluorescent lighting was universal in all schools. Information about electric lighting was not included in our analysis for this district.

2.2.3 Seattle and Fort Collins Findings

Both the Seattle and the Fort Collins analyses found a similar pattern of positive, significant results for the daylighting variables. These results were not only significant, but remarkably consistent in magnitude across all models.

It should be remembered that these results are from different tests with different scales. The Seattle tests used a scale called normal curve equivalent which ranges from 1-99. The Fort Collins tests used the same RIT scale as Capistrano. We have put all the test results in our graphs on the same 1-99 scale in order to make the results between districts as comparable as possible. However, we are still trying to compare apples and oranges, so we must generalize and talk about fruit instead. The percentage effect is perhaps the best way to compare across districts.

Seattle	Analysis Results				Percentage Effect	
ITBS Iowa Test of Basic Skills NCE Scale 1-99	Difference in Average Test Scores (NCE percentage points)		Statistical Certainty		Difference as a % of District Average Score	
Spring Scores	Reading	Math	Reading	Math	Reading	Math
Model 1						
Daylight, Min. to Max.	7.5	5.6	99.9%	99.9%	13%	9%
Model 2						
Windows, Min. to Max.	7.7	8.7	99.9%	99.9%	13%	15%
Skylights, Min. to Max.	3.9	3.4	99.9%	99.8%	7%	6%

Figure 9: Summary Daylight Findings for Seattle

Figure 9 summarizes the percentage effects for the daylighting related variables of the four Seattle models. All these variables were found to have 99% certainty. All other things being equal, students in classrooms with the largest window area, or the most daylight, were found to be testing 9% to 15% higher than those students in classrooms with the least window area or daylighting. A 6% to 7% effect is observed for skylit classrooms.

We do not report on a rate of improvement here because the Seattle models looked at the level of test scores at the end of the year, not the change between fall and spring, as in Capistrano. While the percentage effect is smaller, the magnitude of the difference in test scores is considerably larger in Seattle than Capistrano. This may be partially a function of a less detailed model. It may also reflect a cumulative effect of daylighting over a longer time period. For instance, if daylighting has a positive effect on learning, and if students stay at a well daylit school over the course of a few years, then the effects of daylighting might be cumulative over a student's career, and thus larger than for a single school term.

Fort Collins	Analysis Results				Percentage Effect	
NEA Core Level Tests Normalized Scale 1-99	Difference in Average Test Scores (normalized RIT points)		Statistical Certainty		Difference as a % of District Average Score	
Spring Scores	Reading	Math	Reading	Math	Reading	Math
Model 1						
Daylight, Min. to Max.	3.8	3.4	99.9%	99.9%	7%	7%
Model 2						
Windows, Min. to Max.	10.2	7.0	99.9%	99.9%	18%	14%
Skylight Monitor	-	1.6	n/s	99.7%	-	3%

Figure 10: Summary Daylight Findings for Fort Collins

The Fort Collins results in Figure 10 show a 7% improvement in test scores in those classrooms with the most daylighting, and a 14% to 18% improvement for those students in the classrooms with the largest window areas. There is a 3% effect for math scores in the classrooms with the roof top monitors and no significant effect on reading scores.

The Fort Collins results may be influenced by a number of factors which are distinctive about this district. First of all, we had the least amount of information about the characteristics of the students and schools in the Fort Collins district. Of the three districts studied there is the greatest likelihood that there may be other unknown variables that influenced the findings.

Secondly, the district has only a modest range of window conditions. There were no classrooms in Fort Collins without any windows, and no classrooms with really large window areas, or what we considered "full" daylighting. Because of this limited range of window conditions in our model, the effect of going from minimum to maximum window area may be unreported.

Finally, the skylighting variable is considerably weaker in these models than in Seattle, having only a small positive magnitude for math, and no significance for reading. We believe that the weak positive effect of the skylight variable may be a function of poor lighting quality from the south facing monitors, and the observation that many teachers seem to keep the shades down to solve this lighting quality problem. One would expect that skylights that are closed off much of the time would not have much of an effect.

The results for the daylighting variable are probably also depressed for the same reason, since the daylighting code was a function of the skylighting code. We assigned the classrooms with skylights the highest daylight code for our analysis, on the expectation that they would have the highest daylight illumination levels. We didn't know the extent of the glare problems or the operation of the shades until after the analysis was completed. Ideally, a daylight variable would be based on observations of daylight illumination conditions throughout the school year. Such observations, however, were beyond the resources of this study.

2.2.4 Other Variables

The results for all the major variables of the Seattle regression models are presented below in Figure 11. There are many more variables than for Capistrano, as discussed above, since demographic variables remain important in predicting a student's actual test level, rather than their yearly progress, as in Capistrano. We attempt to interpret these findings below.
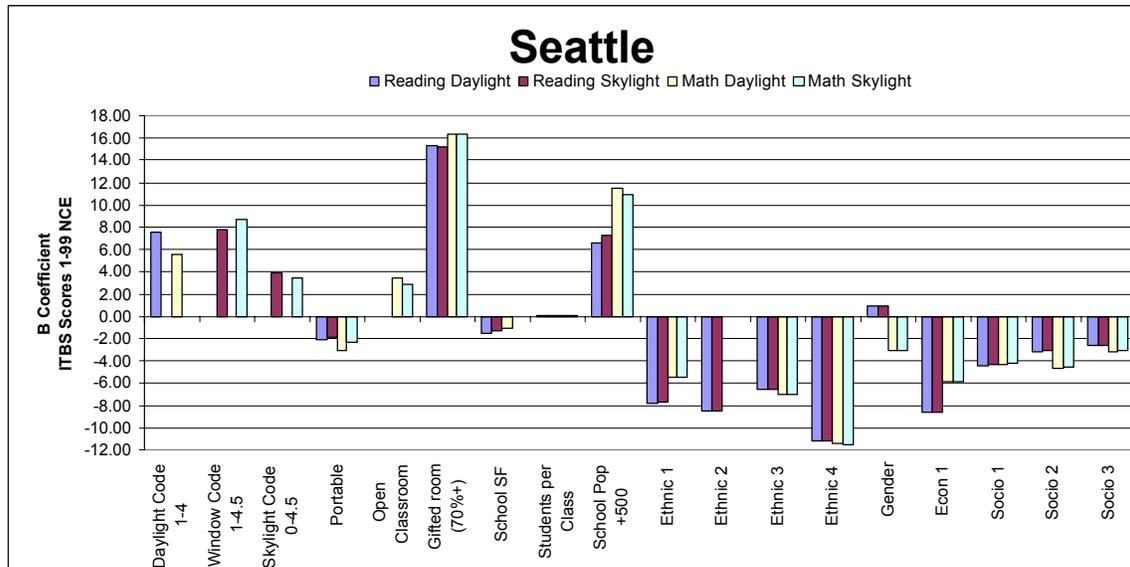
Figure 11: Seattle Relative Importance of Variables, Difference in Mean Score

The **gifted room** variable has the greatest magnitude of effect. As would be expected, students in a classroom with many gifted children (70%+) are likely to score about 15 points higher than the mean.

The **school population** variable shows a strong positive effect, so that the larger the school, the better students perform. This might seem to be contradictory to findings from other studies. However, given the small size of some Seattle schools, this may indicate that these schools are below an optimum size. Or it may be that larger schools in Seattle have some other advantages, such as better facilities.

The **demographic variables**—ethnicity, economic and social status—are seen to have a strong influence. It is interesting to note, however, that the magnitude of these variables is mostly equal to, or less than, the daylighting variables. In later tests on the explanatory power of these variables it was found that the amount of daylight in a classroom was sometimes a more potent predictor for how well a student would perform than their gender, whether they were living in a single parent household, or how many students there were in their classroom.

Other variables, such as the type of classrooms (portable or open), school area in square feet, and students per class, are seen to have occasional and modest impacts on student performance.
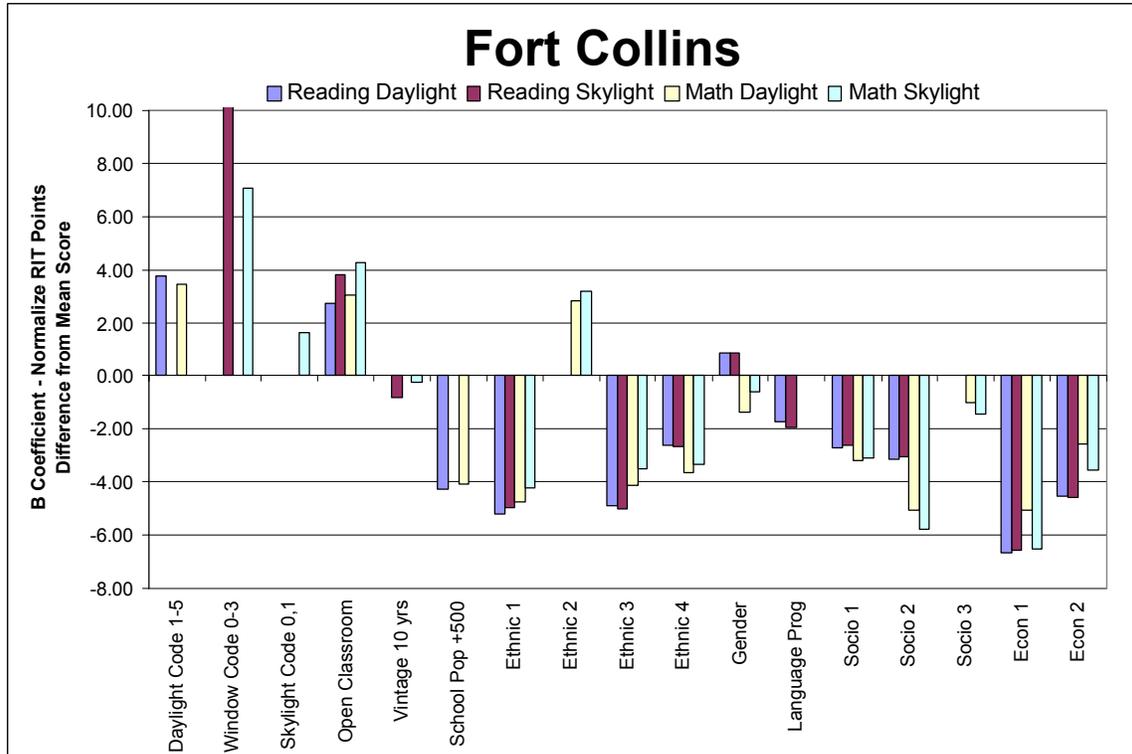
Figure 12: Fort Collins Relative Importance of Variables, Difference in Mean Score

The results of the Fort Collins regression equations in Figure 12 show a very similar pattern to Seattle. Indeed, the very similarity of the results for the diverse variables across districts argues for the validity of the models. It seems reasonable that there would be a change in the impacts of the ethnicity variables between the cities because of the different mix of immigrant populations in each. The daylight variables have about as large a positive effect upon the students as the other variables have a negative effect. Thus, one's assignment to a daylit classroom seems to be as significant as ethnic or social factors in determining performance on the standardized tests.

3. DISCUSSION AND CONCLUSIONS

The results of the analyses of the three districts are remarkably consistent: all show positive daylight effects with highly significant results. The actual magnitude of the effects is less important than the observation that a consistent effect can be found in three very different school districts.

We began this study uncertain that we would be able to find any significant effects of daylighting using the statistical analysis methodology. We pursued the study of three school districts in the hope that at least one district would be amenable to this analysis technique.

From this study, we have made a number of important findings:

- ◆ We found a uniformly positive and statistically significant correlation between the presence of daylighting and better student test scores in all three districts.

- ◆ We found that the positive effect of daylighting was distinct from all the other attributes of windows.

- ◆ We found that this methodology of using large, pre-existing data sets can be a successful and powerful tool for investigating the effects of the physical environment on human performance.

There are many other lesser findings that can also be derived from this study. We refer the reader to the more detailed report for full discussion. This type of statistical study has many limitations. It cannot prove the "cause" for an effect. It merely shows the magnitude of an effect and the certainty of an association between variables. However, questions about a mechanism that might "cause" such an effect quickly arise in most readers minds. Here, in conclusion, we offer a few observations about the most successful daylighting designs, and some educated guesses about how such a "daylighting effect" might function.

3.1   Lessons about Daylight

We cannot easily compare between the districts because the data sets are so different. However there are some lessons within each district that may have broader validity.

In Capistrano the daylighting effect is seen to be slightly larger than the window effect. This one finding strongly suggests that there is indeed a specific daylight effect, as opposed to a window effect, and that the amount of daylight provided in a classroom is important.

The positive effect seen for skylights in all three districts also reinforces the thesis that daylighting in and of itself is important, in addition to whatever other attributes of windows may influence behavior, such as view, communication, ventilation, or status.

Capistrano has the largest number of skylit classrooms, and the greatest variety of skylight types. This greatly strengthened the analysis for the Capistrano district. Seattle had relatively few skylights, and Fort Collins had only one type, which made it more difficult in those districts to distinguish between the effects of the windows versus other sources of daylight.

The results of the analysis also suggest some lessons specific to the design of skylights and windows. We discuss these design issues here for the sake of school officials and designers who wish to consider including more daylighting in the design of schools[7]. It is clear from our analysis that some of the skylighting systems considered in this study perform well and some do not. In our observations of schools for this study it was clear that successful daylighting systems (Skylight Type A in Capistrano, sawtooth monitors, clerestories and skylights in Seattle) blocked the penetration of direct sunlight into classrooms and allowed the teacher to have control over the amount of daylight entering the class. The skylighting systems that did not perform as well (Skylight Type B in Capistrano, sawtooth monitors in Fort Collins) created patches of very bright light or allowed direct sunlight in. Also, these poorer performing skylights did not have a system to allow teachers to fully modulate the amount of daylight entering the classroom.

3.2   Possible Explanations

This study has established a positive correlation between higher test scores and the presence of daylight in classrooms. However, this type of study cannot prove that daylighting actually causes the students to learn more or perform better. Other types of studies are required to identify what it is about daylighting that might cause such an effect. Daylight is quite a complex phenomenon and there are many mechanisms that it might have an effect on human beings. We also do not know if it has a uniform effect on people, or influences some people more than others. Below, we discuss a number of possible explanations. At this point, they are at the level of informed guesses.

3.2.1 Improved Visibility Due to Higher Illumination Levels

Higher illumination levels have repeatedly been shown to increase the visibility of tasks, and the speed and accuracy of people performing those tasks[8].

It is clear, from our illumination measurements of the skylit classrooms in all three districts, that they tend to have significantly higher illumination levels than other classrooms. At peak conditions, average illumination levels in these skylit classrooms are two to three times higher than in classrooms with electric lighting.

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[7] Readers who are interested in design issues are urged to consult some of the many excellent texts on daylighting, including *Tips for Daylighting with Windows* downloadable from http://eande.lbl.gov/BTP/pub/designguide/ or the *Skylighting Guidelines*, downloadable from www.energydesignresources.com.

[8] See page 91, *Lighting Handbook*, 8th Edition, Illuminating Engineering Society of North America, 1993.

Daylighting levels from windows probably tend to be somewhat lower and more variable, but windows are still likely to contribute to significantly higher illumination levels than classrooms without windows.

3.2.2 Improved Visibility Due to Improved Light Quality

It has been hypothesized that, compared to electric lighting, daylight has better "light quality" that is more appropriate for human visual tasks, thereby increasing the visibility of the task, independent of the illumination levels. "Light quality" is a holistic term which typically includes a number of attributes of the lit environment that are generally considered to be favorable. These are often described to include:

◆ Better distribution of light

◆ Better color rendition

◆ Absence of flicker

◆ Sparkle or highlights on three-dimensional objects

We'll discuss each in turn.

Better distribution of light relates to how the light falls in a space, and which surfaces are well illuminated. In electric lighting design for the typical office (after which many classroom lighting systems are patterned) most of the light is directed downwards towards the desk top. Thus, horizontal surfaces are more brightly illuminated than vertical surfaces.

In contrast, daylight is a very diffuse source of light, and tends to more evenly illuminate surfaces in all directions—up, down and sideways. Daylight entering from a window also tends to most brightly illuminate vertical surfaces, such as walls and the sides of people's faces.

Since classroom tasks involve a great deal of looking at people, and learning from material displayed on the walls of the classroom, it may be that the stronger vertical component of daylight improves visibility in this way.

Better color rendition relates to the way colors tend to look more vivid under daylight. Daylight includes a continuous spectrum of light wavelengths, whereas most electric sources are strong in some areas of the spectrum and weak in others. Therefore, daylight renders all colors well, and in tones that we tend to consider most "natural." Better color rendition may improve the visibility of the learning environment by making colors more vivid and true.

Absence of flicker relates to the very rapid fluctuations in light levels that can occur in electric lighting due to the alternating electrical current. People have complained that flicker is responsible for a multitude of problems, including headaches, eye strain, and attention deficit problems.

Daylight does not flicker. In contrast, fluorescent lamps run on magnetic ballasts can have a noticeable flicker. Fluorescent lights run on electronic ballasts cycle hundreds of times faster, and so have dramatically reduced flicker problems.

Incandescent lamps generally are not perceived to have flicker problems. Studies have shown that people working under fluorescent lights with electronic ballasts have higher productivity than people working in similar conditions under lights with magnetic ballasts[9]. Thus, it may be that the reduction of flicker due to the presence of daylighting has a similar effect.

If we were able to distinguish daylight effects between classrooms with and without magnetic ballasts, we might be able to isolate this potential mechanism.

Sparkle or highlights on three-dimensional objects may be another aspect of lighting quality from daylight. Since a daylight source (window or skylight) is generally the brightest surface in the room, it tends to cause highlights and soft shadows. This might also be described as semi-directional lighting. Artists will tell you that they prefer daylight in their studios partly for the way the shadows and highlights make objects more attractive and easier to understand three-dimensionally. A similar effect may make objects more memorable and the setting more lively for students in the learning environment.

3.2.3 Improved Health

Daylight might improve performance through better long term health. A number of researchers have attempted to demonstrate these connections. While exposure to daylight is widely believed to promote health, the actual biological mechanisms are less certain. Exposure to daylight is known to increase the production of Vitamin D. The high illumination levels associated with daylight have also recently become recognized as a treatment for seasonal affective disorder (SAD). The timing of exposure to high illumination levels seems to be key to helping regulate our circadian rhythms[10]. Bright light suppresses the production of melatonin, a brain hormone, and increases alertness. Melatonin, which is secreted primarily at night, triggers a host of biochemical activities which may effect our immunological functions, including the production of estrogen. A recent article in *Science News* summarizes medical research on the relationship of exposure to light and cancers. A number of studies conducted in England and Sweden suggest that there may be a relationship between exposure to light and some types of estrogen-related cancers[11]. While these studies are somewhat controversial, what is certain is that there are complex biochemical pathways whereby exposure to light may influence our overall health.

3.2.4 Daylight Deprivation

The larger performance effect found for windows and daylight in Seattle and Fort Collins might be a function of greater sensitivity to indoor daylight exposure than exists in Capistrano students.

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[9] Veitch and Newsham, "Lighting Quality and Energy-Efficiency Effects on Task Performance, Mood, Health, Satisfaction and Comfort," IESNA Journal, Vol 27, Number 1, Winter 98.

[10] Boivin, D.B., Duffy, J.F., Kronauer, R.E., Czeisler, C.A., "Sensitivity of the Human Circadian Pacemaker to Moderately Bright Light", Journal of Biological Rhythms, Vol 9, Nos 3-4, 315-331, 1994.

[11] Rafoff, J "Does Light Have a Dark Side?" Science News, Volume 154, No 16, October 17, 1998.

The Seattle and Fort Collins schools are very different from the Capistrano schools in one very important way: they tend to have more indoor facilities, such that children can spend all day indoors. This is, of course, necessary in a rainy or cold climate. Capistrano schools, on the other hand, typically have no interior hallways, play spaces, or eating areas. Therefore the Capistrano school designs require a student to go outside five or six times a day, for every recess, lunchtime, trip to the bathroom, or visit to the library or administration offices. The climate in Capistrano is also more amenable to outdoor play. It rarely rains, never snows, and is sunny and warm most of the year. Furthermore, as the most southerly of the districts, the days are significantly longer during the winter. Thus, Capistrano children are inevitably exposed to the daylight outdoors much more frequently than Seattle or Fort Collins children.

If frequent exposure to daylight improves long term health, then it would follow that the children in Seattle and Fort Collins, who see less sun overall, might be more sensitive to daylight exposure in their classrooms, and would show a greater magnitude of positive effects from a daylit classroom.

3.2.5 Improved Mood

Most people will tell you that they like daylight because it is more "natural[12]." When asked to elaborate, they are likely to say, "it just makes me feel better," or happier, or more content. While the exact mechanism may be unclear, it is certain that they think daylight improves their mood.

Daylight may help the students directly by improving their mood, or indirectly, by improving the mood of the teachers. Most teachers we interviewed felt that windows and daylight improved the mood of their students, keeping them calm and improving their attention spans. Indeed, a number of teachers we interviewed in daylit classrooms specifically manipulated the lights to affect the children's mood. They frequently turned off all the electric lights during story time or art periods, to help the children calm down and expand their imaginations.

The teachers that we interviewed were absolutely sure that a view through a window lowered their personal stress level. One teacher in Capistrano summarized this experience well: "When I've had it with the kids and I can't answer another question, I just take a minute, look out the window at the view, and then I'm OK. I'm calm and ready to go back into the fray."

3.2.6 Higher Arousal Levels

It is know that high illumination levels cause higher arousal levels by suppressing the production of melatonin (see above). Thus, it is possible that the higher illumination levels in daylit classrooms simply help to keep children more alert

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[12] Heschong Mahone Group, "Skylighting Baseline Study," December 1998 for Pacific Gas and Electric, contract 460 000 8215. 67% of people interviewed sited "more natural light" as the primary advantage of skylighting.

and capable of absorbing new information. If this is true, then merely providing more illumination, from any source, should have positive consequences.

However, it would seem that the variability of daylight may also contribute to higher arousal levels. By creating an environment that is non-uniform in time, it may engender greater interest throughout the day. A number of classic studies have shown that patients in hospitals recover more quickly and have fewer complications when they are treated in rooms with daylight and/or a view[13]. The positive treatment results are generally interpreted to be a result of the added stimulus from the variability of daylight or a view. In one study patients with a view of trees did better than those with a view of a brick wall. In another study, patients with an obscured window that only allowed in diffused daylight did better than those with no window.

3.2.7 Improved Behavior

Some people believe that daylight improves behavior overall. The phrase "walk on the sunny side of the street" captures common wisdom that people tend to have a more positive outlook under sunny conditions.

Two researchers in Sweden conducted a study of 90 elementary school students and carefully tracked their behavior, health, and cortisol (a stress hormone) levels during a one year period in four classrooms. The four classrooms had different combinations of daylighting and fluorescent lighting conditions. They concluded that there were strong correlations between the amount of daylight and a student's behavior, especially when ranked for sociability and concentration. Children in classrooms with daylight or daylight-mimicking fluorescent lights tended to have typical seasonal and daily rhythms, while children in the classroom with only warm white fluorescent light showed aberrant patterns of both behavior and cortisol production. This study takes a holistic view of student performance, recognizing that there is a time for both arousal and calm, a time for cooperative social behavior and individual concentration. The authors concluded: "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 sick leave.[14]" A study such as this, however, may be limited by not accounting for daylight exposure outside of the classroom.

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[13] Wilson, L.M., "Intensive Care Delirium. The effect of outside deprivation in a windowless unit" Archives of Internal Medicine, (1972) 130 225-226. Also: Ulrich, R., "View Through Window May Influence Recovery from Surgery", Science, Vol. 224, 420-421, 1983, and Keep, P., James, J., Inman, M., "Windows in the Intensive Therapy Unit", Anathesia, Vol 35, 257-262, 1980

[14] Kuller, R and Lindsten, C "Health and Behavior of Children in Classrooms with and without Windows", Journal of Environmental Psychology, (1992) 12, 305-317.