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

Detailed Report

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Submitted to:
George Loisos
The Pacific Gas and Electric Company
on behalf of the
California Board for Energy Efficiency Third Party Program

Submitted by:

HESCHONG MAHONE GROUP
11626 Fair Oaks Blvd. #302
Fair Oaks, CA 95628

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1. EXECUTIVE SUMMARY

This study looks at the effect of daylighting on human performance. It includes a focus on skylighting as a way to isolate daylight as an illumination source, and separate illumination effects from other qualities associated with daylighting from windows. 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 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. 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 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 with the least.

The three districts have different curricula and teaching styles, different school building designs and very different climates. And yet the results of the studies show consistently positive and highly significant effects. This consistency persuasively argues 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 supports the thesis that these performance benefits from daylighting can be translated to other building types and human activities.

2. INTRODUCTION

Is there an effect of daylighting on human performance?

The purpose of this study was to look for a clear relationship between human performance in buildings and the presence of daylight. This daylight could come from windows or skylights. We postulated that, by including buildings with skylights in the study, we could isolate the effect of pure daylight from all of the other ways that windows might influence human behavior.

Skylights provide a relatively simple illumination function, whereas windows may have a far more complex effect on people. Windows typically offer a view, which may provide relaxation, inspiration or distraction. They are often operable, which may add ventilation, air quality, and thermal comfort issues. Daylight illumination levels from windows are highly variable within a space, and may include aspects of unacceptable contrast and glare. User control of blinds or curtains also adds another variable that may be hard to define. Windows are connected with personal status, and may have psychological implications beyond their mere physical attributes. Skylights, especially diffusing skylights designed to provide uniform illumination, would not seem to be as imbued with cultural meaning and don't tend to have as much variability in their function.

This report describes a study of how well elementary school students perform on standardized tests in relationship to the characteristics of their physical environment—specifically, how much daylighting is likely to exist in their classrooms. A companion study looks at the relationship between skylighting and retail sales. Both use a statistically rigorous methodology to isolate other potential influences, and report on the magnitude of an observed effect and its statistical certainty.

We chose to study elementary schools since children at that age spend most of their school time in one physical environment—their assigned classroom. Whereas students in middle schools and high schools tend to move from classroom to classroom throughout the day, in elementary schools children are usually assigned to one teacher in whose classroom they spend the majority of the school year. We reasoned that if the physical environment affects learning, it should be easier to identify any effects at the elementary level where we could characterize a given student's environment with some certainty.

Since this is an interdisciplinary study, there are readers of many disciplines who have interest in its findings. We have attempted to satisfy the concerns of a wide range of readers, and so have perhaps included more detail than any one of these readers may find useful. We have also prepared a shorter, "condensed," version of this report, which is available. In the discussion of the results at the end of the report, we also hypothesize why such an effect might occur. It is beyond the scope of this study to determine a causal mechanism, but we suggest pathways that might be considered in further research.

2.1 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. Facility managers often contended that windows and skylights were a maintenance and security risk. Educational theorists argued that a more flexible arrangement of classrooms, with open walls between them, would encourage team teaching and creative learning. Others worried that windows might just be a distraction for students. And specifically in California, 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.

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

In a compilation of studies on windowless classrooms 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.[1]"

Collins also quotes from a 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 use 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."*

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 patterns of daylight levels, hormone levels, and student behavior, and concluded that windowless classrooms should be avoided[2].

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

[2] 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 Section 5.1.4.

Recent, more informal studies in the United States suggesting a relationship between daylighting and enhanced student performance have generated considerable excitement among daylighting advocates.[1] 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] 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 in North Carolina. The analysis, however, based on a small sample, cannot provide any certainty that this was not a random effect.

3. METHODOLOGY

Our study methodology compared the performance of people in similar buildings with a range of daylighting conditions. To do this, we sought organizations that had pre-existing productivity measurements that could be compared between buildings with and without skylights, or with a scalable range in daylight conditions. We began by casting a wide net looking for the ideal organizations that could provide us with data sets amenable to our analysis.

3.1 Data Set Criteria

Our criteria for selection included organizations which:

- Operated at least 60 sites, about ½ with and ½ without skylighting, or which had a scalable range of daylighting conditions
- Where all building sites had nearly identical operations, and similar climate conditions
- Where human performance measures, that could be identified by building site, were consistently tracked in an electronic database
- And, of course, where the organization was interested in participating in the study.

The human performance data could then be statistically analyzed to see if there was a significant correlation between the presence of daylighting and improved performance. We would attempt to control for as many other variables as possible using multivariate regression analysis. We realized that our ability to control for other influences on human performance or for random error would be limited by:

- The size of the data set
- The availability of information about other influences
- The time period of the performance measurements

Thus, our goal was to find data sets as large as possible that measured human performance over a long time period, and that allowed us the opportunity to control for other potential influences on performance.

3.2 Selection of Sites

We began our search for data sets by identifying target-building types, and then conducted an extensive phone search to identify organizations that might meet the criteria above. We focused on:

- Chain store retailers
- Manufacturers with multiple locations, or the potential for “before and after” measurements
- Distributors with multiple locations
- Elementary school districts
- Office buildings with identical operations at multiple sites

After identifying potential sites all over the country, we began a multi-level screening process. We interviewed potential candidates and attempted to negotiate cooperation agreements with the best candidates. For the commercial sites, confidentiality and interference in operations were significant concerns. A promising manufacturer with excellent data on employee productivity was eliminated as a study participant when the upper management ruled the study to be an unnecessary distraction to production.

After over 125 interviews with candidate organizations, we settled on four participants who best met our criteria:

- A chain store retailer
- Three elementary school districts

This report details the analysis and findings from the school district data. A companion report details the work with the retail data.

3.3 The School Data Sets

We chose to work with elementary school districts, and not high schools or other age groups, for a number of compelling reasons:

1. Elementary school children tend to spend the majority of their school time in one classroom with one teacher.
2. Elementary students tend to follow a highly standardized curriculum, so that individual student achievement tests can be compared across schools, and even across districts.
3. Elementary schools tend to have fairly uniform classroom design, with a standard size and shape.

The three school districts selected were

- Capistrano Unified School District in Southern California
- Poudre School District in Fort Collins, Colorado
- Seattle City Public Schools in Washington State

Each district has some schools with skylights and/or roof monitors, as well as schools without. The size of the districts ranged from 23 to 61 elementary schools.

We believed that the geographic diversity of the three districts would allow us to test for the effects of daylight across differences in climate, curriculum, administration, school design, and student testing protocols. By working with three districts, we also increased our chances of finding at least one data set that was sufficiently robust for detailed analysis.

The school districts agreed to provide us with one or two years of student scores on both math and reading standardized tests for all their children in grades 2 through 5. In addition, they provided associated demographic data that they collected about the students. To ensure confidentiality, all information that could potentially be used to identify an individual was removed from the data sets.

To confirm the impact of daylighting in these schools, we planned to check for consistency of results by running the analysis for a total of twelve cases:

- The three school districts
- The two tests (math and reading)
- Two alternate sets of daylight variables ("daylighting," and "skylights plus windows").

We reasoned that if we could find a consistent pattern among the results of these twelve distinct models, then we would have more robust findings.

Two sets of data were assembled for each school district. The first database contains the student records that we received from the district itself. The second database for each district contains the school/classroom characterizations of window lighting, skylighting, and daylighting.

3.3.1 Student Data

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

Types of Standardized Tests

We used two types of standardized student tests in our analysis. Seattle provided us with the Iowa Test of Basic Skills (ITBS), Form M, a national test. The raw test scores were formatted using a Natural Curve Equivalent (NCE) scale derived from national norms, which identifies equal increments in response, such that results at different ends of the scale can be correctly compared on an arithmetic scale. Thus, with an NCE scale, an improvement of 5 points has the same meaning whether it's at the high or low end of the scale. This allowed us to make meaningful judgments about how much of an effect a variable might have across the spectrum of possible scores.

Capistrano and Fort Collins provided us with "level tests" developed by the Northwest Evaluation Association (NWEA), specifically tailored to the districts' curricula. Since these tests do not have nationalized norms, they use the Rausch Unit (RIT) scale to create an equal interval scale that is similar to a NCE, but not calibrated to national norms. The RIT scale is calibrated across all (grade) levels of the tests, so that a growth of ten units is equivalent at any point in the scale or level.

The Capistrano tests were administered to all elementary school children in both the fall and spring of each year. This gave us the important opportunity to compare individual student progress within one school year. The Fort Collins tests were also administered in both spring and fall, but were optional for many students in the fall. As a result, it was not possible to compare student performance consistently between the two time periods across the whole data set.

Figure 1 below summarizes the source of the standardized tests used in our analysis, and the test format.

	ITBS (NCE scale)	NWEA Level Tests (RIT scale)	Absolute Scores Spring '98	Change in Scores Spr '98-Fall '97
Capistrano		X		X
Seattle	X		X	
Fort Collins		X	X	

Figure 1: Test Types for Three Districts

Demographic Information

Each district provided extensive information about the demographic characteristics of the students in the data sets so that we could control for these well-known influences on student performance. We attempted to assemble data sets which had demographic descriptors that were as similar as possible.

Student identification was masked by a false student record number for all data sets. In addition, some districts decided to provide some demographic data at a classroom level to further mask individual student records. Thus in Capistrano, we were provided with the percentage of students per classroom with free or reduced lunch, rather than a code per each student record. Similarly, in Seattle, information about participation in the gifted program was provided at a classroom, rather than a student level.

We have re-named the demographic variables in this report to make them generic, and avoid unnecessary focus on issues outside the scope of this study.

For example, we report on Ethnic 1, 2 and 3, rather than the ethnic indicators we were provided with. Similarly, in our reporting, we have scrambled the identification numbers for school sites, and any other identifying information.

3.3.2 Classroom Characteristics Data

A second data set, describing the physical characteristics for each classroom in the three districts, was created. When possible, we began by examining existing databases about the schools. This information was then verified and augmented by reviewing architectural plans and aerial photographs for all of the schools. Principals and maintenance personnel were also interviewed to confirm details about the windows and skylights. In addition, we conducted on-site surveys of most of the "types" of schools to confirm the information: we took photographs and daylight measurements, observed operations and interviewed a few teachers.

Size and Types of Classrooms

From the existing data sets, and especially from the architectural plans, we could usually identify;

- The original construction date of the school
- The size of the school (in square feet)
- The size of the classroom (in square feet)
- The type of the classroom—open, cluster or pod, portable, traditional
- The presence, size and geometry of windows and skylights.

Daylight, Window and Skylight Codes

Our initial intent was to isolate the effect of daylight through the study of skylighting. However, in this schools study we were unable to do so because of the prevalence of windows. The effect of skylights was inevitably mixed with the effect of windows. To resolve this, we collected data on both windows and skylights so that we could analyze them either separately or as a combined effect.

Whenever possible, the information collected included the dimensions of glazing, the transmissivity of the glazing, any fixed shading or obstructions, and the expected distribution of the light given the geometry of the glazing. It did not include window orientation, operable shading, or movable obstructions for windows. The effort was directed at creating a rough prediction of potential daylight illumination levels and distribution, but not of glare and other lighting quality parameters.

Ideally, a daylight variable would be based on observations of daylight illumination conditions throughout the school year. Many things change during the school year relative to daylighting. Curtains open and close. Pictures get posted on windows, then taken down. Trees loose their leaves, then leaf out again. Sun angles change, reflecting off of sidewalks, or not. Weather conditions change. Unable to account for all these temporal variations, we tried to create a relatively stable metric that described the "opportunity" for daylight over the course of the school year. Given the limited information we were working from, and especially the vast number of classrooms that we had to categorize (over 2000 in the three districts), we did not try to achieve any higher level of accuracy than a 0 to 5 scale.

We relied on the experience of the three daylighting experts involved in this study to apply the following qualitative guide to each classroom:

5 Best daylighting. Classroom is adequately lit with daylighting for most of the school year. Adequate daylight available throughout classroom.

4 Good daylighting. Classroom has major daylight component, and could occasionally be operated without any electric lights. Noticeable gradient in illumination levels.

3 Average condition. Classroom has acceptable daylight levels directly next to windows or under skylights. Strong illumination gradient. Some electric lights could occasionally be turned off.

2 Poor daylighting. Illumination is always inadequate without electric lights. Glare a likely problem.

1 Minimal daylighting. Small, token windows or toplighting.

0 Classroom has no windows or toplighting.

The window and skylight codes were assigned independent of each other, ranking the various options available in the districts, from none to best. The daylight codes, on the other hand, were assigned considering the combined effect of windows and skylights together. For example, if a skylight (code 2) in the back of a room balanced the light from windows on one wall (3), then the classroom was given a daylight code (4): higher than either the window or skylight codes for that room. Alternatively, if a room already had full daylighting from aggressive skylighting (5), then the presence of some windows (3) would not raise the daylight code (5).

In practice, the codes were assigned slightly differently for the different districts, based on the types of conditions encountered, and on our level of information. The following two charts summarize how the codes were applied in each district.

The average daylight footcandle (fc) expectations listed below were used as a rough guide for the rater. They were not verified with on-site measurements since we could not visit enough classrooms under similar daylighting conditions.

Window Ranking Scale

Quality description / CODE	Daylight distribution / likely fc room avg	SEATTLE	CAPISTRANO	FT COLLINS
Best **5**	even 50+fc	Window wall on two sides of room, high ceilings Clear glass, no sun penetration	Same as Seattle 150+ sf windows	Did not occur
Good **4**	acceptable 30+fc	Shallow classroom with window wall on one side #5 with medium tint and/or obstructions	Same as Seattle 100+ sf windows	Did not occur
Adequate **3**	dark areas 15+fc	Deep classroom with window wall on short side #4 with medium tint and/or obstructions #5 with dark tint and/or major obstructions	Same as Seattle 60+ sf windows	8-13% WFR clear glass
Poor **2**	glare from windows 5-10 fc	Windows on one side, 20% - 50% of wall length. #3 with tint and/or obstructions	Windows 30 sf- 50 sf, no tint Windows 40 sf - 60 sf medium tint Windows 60 sf - 80 sf dark tint	3-4% WFR medium tint
Minimal **1**	very local 1-5 fc	Windows < 20% of wall length Heavily obstructed windows	Windows 40 sf or less, medium or dark tint Example: most portables	1-2% WFR medium tint
None **0**	none 0 fc	No windows	No windows	No windows
District specific notes:		Window percentages are of wall length, not area	960-1050 sf typcial classrooms	WFR = Average classroom window to floor area ratio

Figure 2: Window Codes as Applied

Skylight Ranking Scale				
Quality description CODE	Daylight distribution likely fc room avg	SEATTLE	CAPISTRANO	FT COLLINS
Best 5	even 50+fc	Very large skylight > 20% of floor area Fixed louvers	Central skylight, 6' x 6' pyramid diffuser Operable louvers	South facing monitor, diffusing glass Operable shades
Good 4	acceptable 30+fc	Large skylight area >12% of floor area Black out blinds	Clear 6' x 6' skylight, corner of room Same as #5, deeper well	Did not occur
Adequate 3	dark areas 15+fc	Medium skylight area 4-10% of floor area Black out blinds	Central skylight, flat diffuser 6' x 6', low transmission Operable louvers	Did not occur
Poor 2	local 5-10 fc	Small skylight area 2-4% of floor area Interior room with small clerestory area	Medium tint 2' x 8' monitor, at back wall	Did not occur
Minimal 1	very local 1-5 fc	Interior room with minimal access to clerestory	Did not occur	Spill from monitor in adjacent hallway
None 0	none 0 fc	No toplighting	No toplighting	No toplighting

Figure 3: Skylight Codes as Applied

On-Site Observations

Site visits were performed twice for each school district. The first round of site visits confirmed the presence of skylights and scoped out the range of conditions that should be accounted for in our classroom data sets. As part of this exercise, we took sample light level readings in Capistrano and Seattle to help us categorize the types of toplighting and the range of window conditions. Sample illumination readings for each district are included in the appendix.

A second round of site visits took place after the preliminary analysis and before the final analysis, to confirm the categories used in the data sets, to verify conditions, and to investigate operating conditions at the schools. All in all, the greatest attention was paid to verifying information from the Capistrano schools, which became our primary analysis site. With over 60 schools in the Seattle district, we focused our attention on those schools with toplighting or exceptional conditions. The least attention was paid to Fort Collins schools, which had the most uniform conditions, and also turned out to be our weakest data set.

Between both rounds, we visited sites representing over 90% of the Capistrano schools, 25% of the Seattle schools, and 30% of the Fort Collins schools.

3.3.3 Data Assembly

Microsoft Access was used to join all the student record data sets and the building characteristic data. Data spanning the 96/97 and 97/98 school years were received from all districts. In the case of Capistrano, the data arrived in 16 separate tables. The districts provided similar, but not identical information.

All information that might have allowed identification of an individual was stripped from the data set. Any identification numbers for students or school sites contained in this report have been transformed, and are not actual values.

The information that we eventually had available to consider for each district is detailed below:

Physical Conditions:	Capo	Seattle	Ft Collins
Daylight Code: 0-5,	X	X	X
Window Code: 0-5	X	X	X
Skylight Code: 0-5	X	X	X
and/or Skylight Types: (A, AA, B, C, D)	X	X	
Air Conditioning: yes/no,	X		
AC types: original, retrofit, wall mount, none	X		
Operable Windows: yes/no	X		
Classroom type: traditional, portable, semi-open, modular	X	X	X
School Operation:			
School Site ID:	X	X	X
Language Program: yes/no	X		
Year Round Schedule: yes/no	X		
Students per School: count	X	X	X
Students per Classroom: count	X	X	
Age of School: yrs since original construction	X	X	X
Student Characteristics:			
Grade level	X	X	X
Classroom assignment	X	X	
Ethnicity	X	X	X
Special Education program	X	X	X
Non-English speaking		X	X
GATE identified: Student level	X		
Gifted classroom: 70%+ gifted		X	
Lunch Program: student level		X	X
Lunch Program: % in classroom	X		
Living w/ mother, father, other?		X	X
Gender	X	X	X
Absences Unverified: count per student	X		
Absences Unexcused: count per student	X		
Number of Tardies: count per student	X		

Figure 4: List of Descriptive Data Fields for Each District

3.3.4 Data Cleaning

A substantial effort was expended in cleaning the data sets and matching the student records to classroom locations. We received data from every student in the district, but were only interested in those students taking standardized tests while participating in a standardized curriculum, while spending a majority of their time in one “homeroom.” Thus, we set criteria to include only second through fifth grade students being taught under the “normal” district conditions. We made these judgements based on conversations with the personnel from each district involved in testing and curriculum.

Criteria that we used for elimination from the data set were:

- Grade assignment K-1 or 6+
- Missing test scores
- Missing classroom identification (except in Fort Collins)
- Special education code
- Non-English speaking
- Attendance at a specialized academy (non-standard curriculum)
- Participant in home schooling program
- Codes outside of proper range or format

We choose to include the gifted and talented (GATE) identified students in Capistrano and Seattle because they were taught in the regular curriculum, often with before or after school enrichment programs. They spend most of their time in the same classroom with the regular students, and they are following the same curriculum path. (We were not given a GATE identifier for Fort Collins.) Special education identified students, on the other hand, have a wide variety of codes—visually handicapped, physically handicapped, learning disabled, behavior problems—with all kinds of pull-out programs, special tutors, and different curriculum tracks. Sometimes, they spend only one to two hours in their assigned “mainstream” homeroom. Also, the special codes and classifications used by the three school districts varied considerably. Rather than trying to sort out codes between districts, and trying to figure out which students spent a majority of their time in the classroom on the main curriculum, and which were in pull-out programs, we decided to just eliminate all special education codes across the board.

In addition, we encountered a considerable challenge matching students to classrooms. The Capistrano data set linked students to teachers, but not to classrooms. Thus, we had to create a map from teacher to classroom location for each school. This was possible for a majority of the 97-98 data, but much more difficult for the 96-97 data, as many records were lost. Ultimately, we dropped the hope of using the 96-97 data because too many schools no longer had records.

Comparing Across Years

We were provided with test scores for spring and fall for both the 97-98 and 96-97 school years. We hoped this would give us the opportunity to compare the progress of students from fall to spring and/or from year to year. The year to year comparison was discarded, however, as we found it impossible to map sufficient numbers of children from their teacher to their physical classroom location for the earlier period.

A year to year comparison presented two other challenges. First of all, 25% of the population was automatically lost when comparing between the years, since only 3 of the 4 grades could be compared between years. Secondly, and most important, we realized that there were significant differences in overall performance between the grade level tests. The grade level of students was consistently one of the most important explanatory variables in our regression models. Thus, comparing performance of an individual between successive grades was probably not valid.

The final analysis therefore uses only data from the 97-98 school year.

3.3.5 Size of Final Data Sets

The size of the final data sets was a function of how many student records could be matched to a specific classroom, had no missing fields for other descriptive information, and met all other criteria for inclusion. The largest group of records was removed from the final data sets simply because they were outside of the grade 2-5 range (some of the original data sets included children from K-8). Thus, in general the number of students was immediately reduced by 4/6ths or 4/7ths, or four grade levels out of six or seven. A few entire schools were removed because they were closed for all or part of the 97-98 year, or because they operated special academies outside of the normal curriculum.

	Original			Final		
	Records	Schools	Classrooms	Records	Schools	Classrooms
Capistrano	13,913	27	752	8,166	24	389
Seattle	16,384	61	1093	7,491	57	537
Fort Collins	8,408	23	NA	5,687	21	NA*

Figure 5: Size of Final Data Sets

*Fort Collins schools typically have about 18-24 classrooms per school, but the data was analyzed on a school level basis.

3.4 Regression Analysis

The data was entered into the statistical analysis software program, SPSS, to run multivariate linear regression models. The regression model calculates a "B" coefficient and a standard error for each variable included in the model. The standard error for each independent variable is used to calculate a number of statistical tests to predict the certainty of the observed effect.

The B-coefficient is the magnitude of the effect on the dependent variable of a one-unit change in the respective independent variable. If the variable is yes/no, then the B-coefficient is the full extent of the effect. For example, an assignment of a student to a language program is a yes/no variable. Thus a B-coefficient of +2.19 for a language program variable is interpreted to mean that, on average, students in the language program receive +2.19 higher points (± the standard error) on the standardized test which is being considered as the dependent variable.

If the variable has a range of units, such as the 0-5 window variable, then the B-coefficient is the effect of a one unit change in the 0-5 scale. For the full range of the potential effect, for example from no windows in classrooms (window code = 0) to maximum windows (window code = 5), one would multiply the B-coefficient times the range of the scale; in this example, by a factor of five.

The most important difference in the regression models for the three districts is the dependent variable. The Capistrano model used the change in math and reading student level-test scores from fall 1997 to spring 1998 as the dependent variables. The Seattle and Fort Collins models used only the actual value of the spring 1998 tests.

A number of preliminary runs were conducted to understand the behavior and influence of the variables. Four models were run simultaneously for each set of primary daylighting variables considered:

1. **Reading Daylight**: dependent variable = reading scores, run with the daylight variable
2. **Reading Skylight**: dependent variable = reading scores, run with the window and skylight variables
3. **Math Daylight**: dependent variable = math scores, run with the daylight variable
4. **Math Skylight**: dependent variable = math scores, run with the window and skylight variables

It was assumed that in a robust model, all of the significant variables would perform similarly in all four models. Thus, if a variable, whether a primary daylighting variable or one of the many control variables listed earlier, showed up positive in one of the models and negative in another, we looked further for problems in the data and/or co-linearity with other variables.

3.4.1 Refinement of Models

After all the variables of interest for a particular run were entered into the model, the residuals were calculated for each student record. The residual for a record is the actual value of the dependent variable for that record, minus the value predicted by the regression equation. The student records with the greatest absolute value for their residuals were considered to be the outliers. Once an outlier was identified, an indicator for the student record was entered into the model in order to control for the influence of the outlier on the model. A judgement was made by the analyst on the number of outliers to be entered into the model, according to the distribution of the residuals for each model.

The full regression equation was then run again in SPSS, this time including the newly identified outlier indicator variables. The same process was performed to identify any additional outliers that may have become more influential due to the addition of the first set of outliers. After several such runs of the full model, with new outliers being added during each run, a model was settled on that identified all the extreme cases.

The next step in the process was to use the backward elimination method to select the subset of independent variables that were most significant in the models. The backward elimination method removes the least significant predictor at each step. A non-daylighting variable was dropped if its statistical significance was less than 0.10 (90% certainty of an effect). A daylighting variable had to achieve a higher significance of 0.05 for inclusion in the model (95% statistical certainty). We used a lower standard of significance for the non-daylighting variables as a conservative method to include all potential influences which might reduce the impact of the daylighting variables.

Once the most significant subset of variables was identified, those variables were entered into the regression. The residuals were inspected again to ensure that there were no additional outliers in the model. If outliers were identified, then the model was run again with the corresponding indicator variable included. This iterative process was used to develop each preliminary model and the final model described in this report.

As the last step in the analysis, a step-wise regression was performed to determine the explanatory power of each variable included in the final models. The step-wise regression calculated the R^2 for each additional variable added to the model, in order of influence. This is termed the “explanatory power” of each independent variable, as it is a function of both the magnitude and the certainty of the observed effect. The R^2 for each variable reflects its ability to effectively explain the variation of the data found in the data set. The most powerful explanatory variables enter the step-size regression first, and the least powerful, but still significant, enter last. (See the Appendix for charts which show the order of entry, and the change in R-squared, for all variables included in the final models.)

4. 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 discuss the analysis process, and any peculiarities for the analysis of that district. Finally, we report on the specific model results for each district.

The greatest attention is given to the Capistrano analysis, since it is the most detailed model and, we believe, has the most interesting findings. With the Capistrano data we were successful in creating a model based on the change in test scores between the fall of 1997 and spring of 1998. Thus, this model, which we refer to as the "delta" model, reflects the change that occurred in students' understanding of the class material during the school year that they 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 the rate of student improvement.

For the other two districts we had to use the actual test scores from one time period rather than the change in score between two time periods. These models, which we refer to as the "static" models, 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 administered in the spring at the end of the school year. However, the absolute level of student performance is a function of many influences, including where each student started at the beginning of the year. Thus, in these static models, the demographic and socio-economic variables become important predictors of absolute student performance, and add many more variables to the final equation[1].

4.1 Capistrano Characteristics

The Capistrano School Unified District provided us with data on 27 elementary schools, of which nine included skylights in their classrooms. The Capistrano District was by far the most complex data set that we analyzed. We had the most information about its diversity in student population, administrative structure, and

[1] Including a previous year's test score could also help to control for initial differences at the start of the year. While this method could help control for initial differences, but could also create serious co-linearity problems in the model, making it more difficult to interpret. We were limited by incomplete data for previous years, and so choose not to explore this approach.

physical conditions. It presented both the greatest challenges and the greatest opportunities for study.

4.1.1 Demographic Characteristics

The Capistrano Unified School District 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 Orange County in California. It runs inland 25 miles from the Pacific coast.

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.

4.1.2 District Curriculum

The district maintains great uniformity in its basic elementary curriculum and testing procedures (one of our basic selection criteria). However, they do allow each school to operate special magnet programs or establish special “flavors” for their schools. Children are allowed to attend any school in the district, but their parents must provide transportation. Many special programs attract children to schools outside of their neighborhood. The variety of elementary programs include:

- Three year-round schools (with varying schedules)
- Three bi-lingual immersion programs (two Spanish, one Japanese)
- Environmental education
- Arts centered education
- Gifted and Talented cluster classrooms
- Extensive parent participation

The district has a gifted and talented program (GATE) which operates within each school. GATE identified children are clustered into classrooms so that there are no fewer than eight GATE children in one classroom, to ensure that they have a functional peer group. Each school is responsible for creating its own GATE program, but most include enrichment activities before or after school for the GATE children.

The district also operates many special education programs. Most special education students are mainstreamed into regular classrooms, with additional support provided outside of the classroom. Some children, especially those with extreme physical disabilities, attend a school with special facilities for their treatment. Non-disabled children also attend classes at these schools.

4.1.3 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 1950's through the 1990's, with substantially more built in later years. (Schools built before the 1950's have generally been converted to other uses due to lack of earthquake safety.) The schools are all single story, and almost all classrooms have a door directly to the outdoors. The district has a number of "pairs" and "families" of school types that were built by the same architect from similar plans. (See Appendix for photographs of schools and classrooms.) 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 window 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. They are typically 24' x 40' with a door and 3' x 6' window at one narrow end, and a smaller window and HVAC unit at the other narrow end. Perhaps 10% of the portables are 30' x 30' versions, but with similar window areas. There are a handful of 18' or 12' x 40' classrooms. 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 something of a “placebo” in our analysis.

The size of classrooms and schools was not considered in the Capistrano analysis since in California the size of an elementary classroom is highly standardized at 960-1000 SF. There has been a recent phenomenon of creating smaller classrooms for grades 1-3 due to requirements for class size reduction. Formulas, based on average daily student attendance, have been used to determine the maximum square footage allotment for classrooms in school districts that compete for state funding. As a result, the square footage of schools is a direct function of the number of students attending. Thus, the only size variable we considered at Capistrano was the number of students per classroom and the number of students per school.

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.

Daylight Code	Number of Students	Window Code	Number of Students	Skylight Type	Number of Students
0	942	0	942	A SKYLIT	492
1	1435	1	5317	AA SKYLIT	279
2	3849	2	932	B SKYLIT	350
3	953	3	420	C SKYLIT	336
3.5	139	3.5	139	D SKYLIT	106
4	390	4	184	No Skylight	6705
4.5	120	4.5	120		
5	440	5	214		
Grand Total	8268	Grand Total	8268	Grand Total	8268

Figure 6: Daylight Codes for Capistrano District

Figure 6 shows the distribution of final daylight codes assigned for the Capistrano district, including the readjustments described on page 32. The very large number for Window Code 1 is largely due to all the portables in the district, which constitute about 40% of the classrooms in our data set. The large number of Skylight Code 0 describes the relative rarity of skylights.

Skylight Types

There are five types of skylights that have been employed under various plans:

Skylight Type A has an acrylic bubble skylight on the roof and an inverted prismatic pyramid diffuser set in a splayed ceiling well in the center of the classroom. It also includes a manually operated internal louver to control illumination levels. This 6'x6' skylight design provides high levels of diffuse illumination (50 to 250 footcandles measured on a sunny day) distributed to the entire floor area of the classroom, but little to the walls. This skylight type was initially assigned a code of 3, 4 or 5 depending on variations in skylight transmittance and well depth that affected the levels of illuminance achieved in the classrooms. (The final analysis uses just the Skylight type, not the code number.)

Skylight Type AA is similar to Type A, but uses a flat diffuser (made of “twinwall”) set in the plane of the ceiling. There were fewer of this type of skylight, and they only occurred in older modular classrooms. They were initially assigned a code of 3.

Skylight Type B is a clear 6'x6' skylight with no louver controls. It is set at one corner of the classroom, generally over the teacher’s desk. It frequently allows sun to splash directly on the classroom walls or floor. Horizontal illumination on a sunny day ranged from 15 to 100 footcandles. Vertical daylight illumination on the classroom walls was typically higher (15 fc vs. 5 fc) than in the types A and AA. They were initially assigned a code of 4.

Skylight Type C is a clear 6'x6' skylight with louver controls. It is set in the center of the classroom, with a deep well. On a sunny day, sunlight splashes directly on the classroom floor if the louvers are not closed. Observation revealed that many of these skylights seem to have their louvers closed, presumably to reduce direct sun onto students. They were initially assigned a code of 3.

Skylight Type D is an angled, tinted clerestory, with a horizontal opening of about 2' x 6', that lights part of a wall in some formerly open classrooms. Observation revealed that areas lit by these clerestories have often been reduced to storage areas on the periphery of open classrooms. They were initially assigned a code of 2.

Skylight Louvers

Three of the skylight types have operable louvers that are manually controlled, allowing the teacher to dim the daylight. In two of the skylight types, A and AA with diffusing lenses, the louvers are controlled with a turning rod device. Over 85% of those skylights were observed to have their louvers open. On a clear summer day the skylights provided 250 fc in the center of the classroom. When closed, they provided 10-15 fc. (See sample illumination readings in Appendix) In one classroom we visited, where the louvers were closed, the teacher, new to the classroom for a summer school session, said that she didn't know how to operate them. One of her second grade students promptly popped up and offered to show her how to operate the skylight. We concluded that the student body provides an important continuity of knowledge about the operation of special features in schools.

A third skylight type, C, with a clear plastic dome, also had louvers, but controlled by an electric switch on the wall. We were told that these louvers were originally controlled by photosensors, but that they didn't work right (no further information) and so the photosensors were disabled. We did not visit any of these schools in session, and so could not interview any teachers about their actual operation. However, many were observed to be fully closed. Given that the clear skylight cast a 6' x 6' patch of full sunlight into the center of the room, it seemed logical to assume that teachers would keep them closed on any sunny day, and might get into the habit of keeping them closed much of the time.

Window Coverings

Very few classrooms had any form of daylight modulation or control for windows. Two portables had vertical blinds that were purchased by the local PTA, reportedly more to provide security for computers than light control. Perhaps 10% of the traditional classrooms still had working black-out curtains. The few teachers who used them regularly said their primary motivation was to hide computer equipment, which otherwise might be easily visible to thieves.

Teachers in classrooms with extensive window areas (codes 3-5) were observed to frequently mount artwork on the glass, so that 20%-50% of the glass area might be obstructed by paper. This seemed to occur regardless of the tint of the glass, suggesting that it was driven more by a need for additional display space than a desire to cut down the amount of light entering the room. Classrooms with small window areas (codes 1-2) were rarely observed to have artwork taped to the windows. Occasionally announcements were taped up in windows next to entry doors. Thus, it appeared that large window areas were more likely to have their daylight contributions significantly reduced by obstructions than were small window areas.

A few classrooms were observed to have furniture obstructing their windows. This was more common in portables, where lack of storage space motivated the use of tall cabinets for storage.

Air Conditioning

Most schools in Capistrano are air conditioned. Air conditioning has been a standard feature there since the 1970s. Also, many earlier schools, but not all, have been retrofitted with air conditioning. All portables have air conditioning. Since classrooms with skylighting all have air conditioning, but not all air conditioned rooms have skylights, we decided to see if air conditioning influenced the effects of skylights. Maintenance personnel searched their records and identified which schools and which classrooms had original packaged roof top air conditioning, retrofitted air-conditioning, or none. Portable classrooms were assumed to have small, wall mounted units. The type of air conditioning unit was added to the database.

Almost all classrooms in the Capistrano district have their own thermostats, and the teachers can generally decide on the operation of the systems. The maintenance personnel cautioned us that some air conditioning units were functioning poorly, or were recently repaired or replaced. However, detail about actual operation of the systems was beyond the scope of our investigations. Thus, our database reflects the presence of a system, not its condition or operation.

Operable Windows

Skylit classrooms, being air conditioned as part of the original design, also have no operable windows. We hypothesized that the lack of natural ventilation might influence results, so we also collected information about which classrooms had operable windows. Older schools and newer schools tended to have operable windows. All portables have operable windows. The presence of operable windows was added as a yes/no variable. Even though we could identify which classrooms had operable windows, we could not identify if and when those windows were opened. Many might be rusted or painted shut, or rarely used. Thus, this variable is treated as an indicator of the potential for natural ventilation.

Teachers in the older, non-air conditioned schools with ample daylight were observed to make use of their operable windows on a pleasant spring day. One teacher was extremely appreciative of the cross ventilation provided by her classroom design.

All teachers interviewed in portables reported making use of their operable windows. They considered the cross ventilation provided by windows on both narrow ends of the classroom to be an essential feature of the portables. “It can get really stuffy in here, and with colds and body odor, I try to keep as much fresh air in here as I can.”

Open Doors

In addition, from our on-site visits we observed that many teachers leave their doors open during class. This was especially true of teachers in portables. At various schools, 60-80% of the portable classrooms were observed to have their doors open, compared to perhaps 10% of the traditional classrooms. This was observed consistently in summer, fall and winter. This strategy for portables was effective because there was an operable window at the opposite end of the classroom that would allow cross ventilation, whereas most traditional classrooms do not offer through ventilation. Teachers interviewed in portables all reported that they opened the doors for ventilation, because the portable classrooms tended to get stuffy. “I open my door in the morning and leave it open all day, all year round, except for a few days if it’s really windy or cold outside, or if the playground is especially noisy.”

A door opened for ventilation also greatly increases the daylight entering the classroom. Light reflects off of the entry porch and floor and penetrates deeply into the space. For this reason, after the site visits, we up-graded the daylight rating of the portable classrooms from a 1 to a 2.

Electric Lighting

We were unable to collect sufficient information about the electric lighting conditions in the classrooms to include it in the data set. We did take illumination readings and found highly consistent levels for the electric lighting. Regardless of the vintage of the equipment it would seem that all classrooms in the district were designed to provide an average of 50 footcandles of electric lighting illumination. Within a given classroom, electric lighting levels might vary between a low of 30 to a high of 80 footcandles directly under a fixture. Most of the classrooms had some form of bi-level switching which allowed the teacher to use only one half or one third of the lights. It is not known if, or how often, such a feature was used. (In most classrooms observed in session, all of the lights were on. Those observed with electric lights off, or partially off, were usually in the midst of some special activity, such as recess, art class, or video presentation.)

In Capistrano, fluorescent lighting is universal in the classrooms. There are a variety of luminaire types, including pendant wrap around, recessed prismatic, recessed parabolic louvers, and suspended indirect. Most of the luminaires use energy efficient magnetic ballasts and T-12 lamps, but there are a considerable number of schools with T-8s and electronic ballasts which were either original in new schools, or retrofitted into older schools. While the traditional classrooms within a given school had fairly consistent lighting equipment, the portables in each school were highly variable. There was no way to verify which schools, or which classrooms, currently had which type of lighting other than by on-site inspection of every classroom, which was beyond our resources for this project.

4.2 Capistrano Analysis

We first analyzed the Capistrano data set by looking at absolute scores for one test period, spring 1998. These initial models considered all of the demographic information and the three daylighting variables ([daylight 0-5] or [windows 0-5 plus skylight 0-5]). The resulting equations were very complex, incorporating up to 25 variables, including all of the demographic information. From the point of view of the daylighting variables, these static models tended to be unstable. In general, the skylighting variable tended to show up negative or not significant, the window variable tended to show up positive or not significant, and the daylight variable did all three.

Our hypothesis was that there were one or more unknown variables strongly correlated with skylighting and windows that were confounding the results. We hypothesized that the skylight variable might be affected by the presence of air conditioning or lack of natural ventilation, since all skylit classrooms had fixed windows and air conditioning. So we collected data about the presence of operable windows, and the status of air conditioning for each classroom, and added these variables to the model.

Skylight Variables

Since the skylighting variable (0-5) seemed to be highly unstable, we also ran models looking at skylighting in different ways:

- Skylighting: yes-no
- Each skylighting code, 0-5, run separately as its own variable
- "Types" of skylights, based on their configuration rather than expected illumination levels. (described in Section 4.1.3 above)

The third approach, skylight "types," proved to be the most fruitful, producing the most consistent and significant results. It consistently distinguished between the effects of the 5 types of skylights found in the schools. All skylight types are represented at two or three schools, and all schools with skylights also have classrooms with no skylights.

From this analysis we concluded that the patterns of distribution and control of light from a skylight are more significant than the absolute illumination levels.

School Level Effects

We also hypothesized that there might be school level effects that were interacting with the presence of windows and skylights. So we added a school level variable. We were able to isolate school effects in Capistrano because each school site had more than one type of daylighting condition. Each school had at least the original traditional classrooms plus a collection of portable classrooms. [1] Some schools had three or four types, with original classrooms, additions of various vintages, plus the portables.

Approximately one half to one third 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 addition of a school level variable increased the precision of the model and increased our confidence that we had accounted for any effects which might be attributable to a special program, an extra highly motivated staff, an active PTA or exceptional parent participation at one school site.

[1] There is an exception, one school which consists completely of portable classrooms.

Static vs. Delta Models

Next we tested an improvement, or delta model, using the difference in scores between the fall and spring tests, rather than the absolute scores (static model). The delta model was very stable and simple. All demographic variables dropped out as insignificant. The air conditioning variable dropped out. A few of the classroom type variables remained significant in some of the models. We were left with significant positive effects in all four models for daylight, windows, and one or two of the five skylight types, and a negative effect for one skylight type.

We concluded that the delta model was the strongest approach since it isolated the effect of learning in a single physical environment during the school year, and allowed each student to serve as his/her own control.

Second Round of Site Visits

Once the model seemed very stable and robust, we conducted a second round of site visits to verify conditions at nine schools that we had not visited previously. We found a few surprises that caused us to re-adjust some of the daylight and window codes:

- Some schools, and classrooms were found to have lower transmission glass than previously reported. The daylighting codes for these classrooms were correspondingly reduced.
- Portable classrooms were found to have their doors open a great deal of the time, bringing in substantial daylight. The daylighting code for all portable classrooms was increased from 1 to 2.
- One school was found to have rebuilt some classrooms since the original plan. The window and daylight codes were adjusted to fit the actual condition.

Air Conditioning, Operable Windows and Classroom Types

After making the corrections to the data set described above, the daylighting variables decreased slightly in magnitude but remained significant. However, the pattern of significance for the classroom types, air conditioning, and operable windows once again became unstable. We studied the co-linearity among these variables and found them highly inter-related. The Pearson correlation coefficient is shown in Figure 7. For example, many of the rooms without operable windows were found to be semi-open/open rooms. The correlation between these variables created some overlapping influence and caused some of the variables to be significant in some models and insignificant in others.

While we were sure that the daylighting variables were significant, we were not sure which other physical characteristics of the classrooms should be included in the final models.

		Permanent Portable	Semi-Open/ Open Room	Air Conditioning	Operable Windows
Pearson Correlation	Semi-Open/Open Room	-.155			
	Air Conditioning	.106	.136		
	Operable Windows	.041	-.555	-.245	
	Skylight Type AA	.537	-.084	.057	.150

All correlations are significant at the 0.01 level (2-tailed).

Figure 7: Co-linear Variables

We decided that, in order to achieve greater clarity in the models, some of these variables should be eliminated in favor of others. After examination, the most satisfactory set of equations were found to include the operable window variable but not the other variables. The other choices of variables were rejected because they were not found to give consistent results across the four basic models.

The equations that included the room types were also very inconsistent. When portables, modular classrooms, and semi-open/open rooms were included in the models, instead of air conditioning and operable windows, many different results arose. The three variables surfaced with different magnitudes and signs in the four models depending on which of the three were included, indicating that there was a strong co-linearity between the variables.

These models did show that portable classrooms generally had a positive influence on change in student scores. No conclusion could be drawn about the modular classrooms since they flipped signs in the models. The semi-open/open rooms also changed signs in the models, thereby making it difficult to draw conclusions about this type of room. Indeed, there was a strong negative correlation between semi-open rooms and operable windows. Due to this correlation, the apparently positive effect of operable windows on student performance could be due to some unknown negative characteristic of semi-open rooms.

There is also a positive correlation between Skylight Type AA and the modular classroom type. Due to this correlation, it is possible that the apparent positive effect of Skylight Type AA on performance might be due to some other unknown positive characteristic of the modular classroom room type.

Air conditioning consistently showed a negative effect, but did not show up as significant in all of the models. When both operable windows and air conditioning were included in the equation, the operable windows variable was significant in three of the four models, seemingly taking over the significance of air conditioning. Once the room types were eliminated, we found that air conditioning was statistically significant in only one of the models.

A final statistical test indicated that the eliminated variables did not have a significant impact as a group on the model. The window, skylight, and daylight variables remained steady in magnitude and significance, indicating that our estimate of the effect of these variables was generally not affected by the correlation between the other variables. It was decided to also exclude the air conditioning variable based on this process.

4.3 Capistrano Results

Figure 8 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 8: Summary Daylight Findings for Capistrano

The Capistrano Core Level Tests are reported on a special scale system called Raush Unit or “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[1]. For the charts in this report we have translated all the test results into a consistent scale of 1-99 in order to facilitate comparison between the districts[2]..

[1] Please note that in all cases 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.

[2] This was done by dividing the B-coefficient by the range of scores unique to each data set, then multiplying by 98, the number of intervals in a scale of 1-99. See the Appendix for tables with the conversion factors used for each district.

We also report the test results as a percentage effect to show the relative magnitude of the findings[1].

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 (normalized)[2] 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

[1] For Capistrano and Seattle the following formula was used to calculate the percentage effect:
Percentage effect = (raw B-coefficient * variable range) / raw district mean .
For Fort Collins, where the scores ranged from 153 to 280, we created a normalized mean, based on a scale of 1-99. Thus, for Fort Collins:
Percentage effect = (normalized B-coefficient * variable range) / normalized district mean.

[2] Raw RIT values are 1.7 and 2.6 respectively. See appendix for charts of raw values, and conversion factors to normalized values.

up to one month of instructional time in the reading and math curriculum that could be used for other areas of learning.

Important Formatting Notes

In the body of this report, we report the effect of the daylighting variables by the "maximum effect" observed, from the lowest to highest daylighting condition at each district. Thus, if the window variable had a range of 0-5, then the B-coefficient is multiplied by five to obtain the "maximum potential effect". In cases where the variable had a smaller range, then we used that smaller range as a multiplier. For example in Seattle, where the window code only ranged from 1-4.5, then the multiplier is 3.5, not 5. Thus, the "maximum potential effect" should be interpreted as the range of effect seen between the classrooms in each district with the least and the most windows or skylights or daylighting. Because each district did not have the same range of daylighting codes the results are not strictly equivalent. We chose to take this more conservative approach to avoid any potential for over reporting the effects.

It is very important to keep in mind that the Capistrano models use the relative *change* in test scores over a school year as their measure, not absolute levels of testing. Thus, a negative B-coefficient for Capistrano means comparatively less progress than the norm, not negative progress.

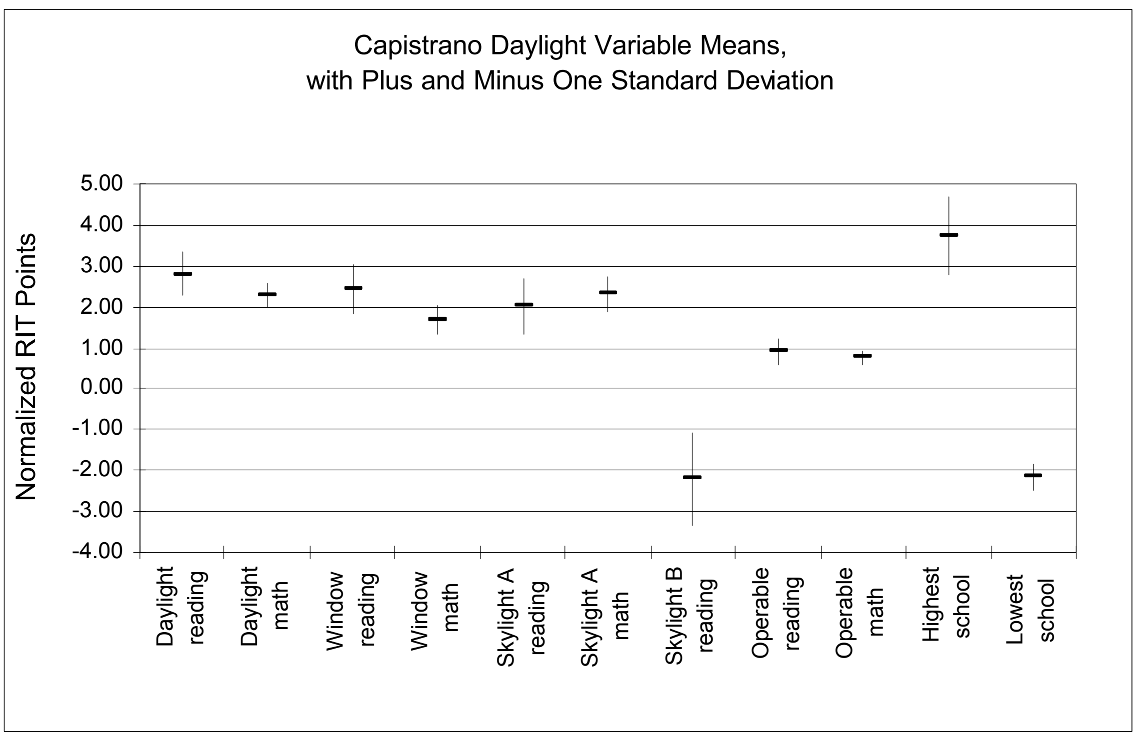

Figure 9: Capistrano Daylight Variables with Standard Deviations

Figure 9 plots the Capistrano results for the daylighting variables, this time showing the range of the standard deviations for each variable. The more precise the variable, the smaller the spread for the standard deviation. Thus the math-model variables for daylight and operable windows are seen to have relatively small standard deviations, while the Skylight B reading variable has a much larger spread, indicating that it is less precise. For comparison, the highest and lowest performing schools in the data set have been included. See the following Section 4.3.2 for a discussion of high and low schools, and other variables in the model.

Further Detail in Appendix

Full detail of the model equations are included in the Appendix. The Descriptive Statistics charts in the Appendix list the mean, minimum, maximum, and standard deviation for each variable entered into the model. These are followed by the results of the regression equation for each of the four models. These charts list the raw B-coefficient for each variable found significant in the model, along with its standard error, the student t-test, and its significance. A Beta coefficient is also reported, which measures the relative power and precision of each variable. The R^2 for each model is also reported in the caption for each chart. A second set of charts show the order of entry for each variable and the change in R-squared as that variable was added to the model. At the beginning of each district's charts is a conversion chart which lists the district mean used to calculate the percentages, and any scalar used to normalize the values reported in the text.

4.3.2 Discussion of The Regression Variables

The results for all major variables of the Capistrano regression equations are presented below in Figure 10. The Daylight, Window and Skylight variables each were run in only two of the four models, thus by definition, they have a maximum of two bars. The same set of control variables was considered in all models, and thus when a control variable was significant in all four models it has four bars in the graph. We attempt to interpret the pattern and magnitude of these findings below.

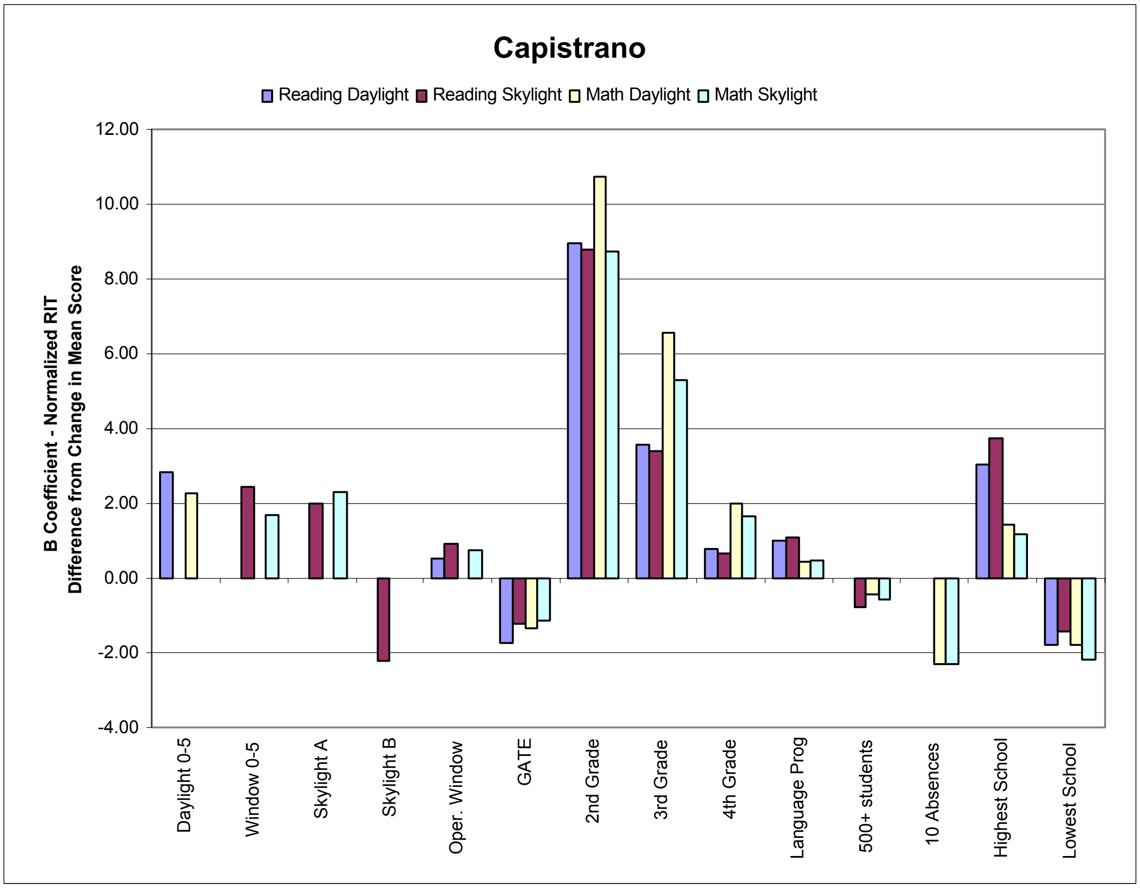

Figure 10: Capistrano, Percentage Point Difference from Change in Mean Score

Daylight, Skylights, and Windows: The daylight, window and skylight type A variables are all positive and strongly 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 to be 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. They generally have rather small populations, making them less likely to show up as significant in a model. Furthermore, each had some lighting qualities that would seem to make them less of a positive attribute to a classroom. Skylight Type AA is similar to Skylight Type A, except with a flat diffuser at the ceiling plane, rather than an inverted pyramidal diffuser recessed into a coffered ceiling. Illumination levels from Skylight Type AA are slightly lower and less uniform around the classroom. It shows a positive, but not significant, effect in one model. Skylight Type C is a clear skylight, like Type B, but located in the center of the classroom. Thus, on sunny days, sunlight will land directly on student desks, unless the louvers are closed. We observed most of them to be closed on the day we visited. It would seem likely that teachers would keep the louvers closed to avoid problems caused by direct sunlight. And if the louvers are closed much of the time, the skylight would have little effect on the learning environment. Skylight Type D is a very modest monitor type light, which provides a splash of filtered daylight over sinks in some open classroom schools.

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 that is consistently performing well provides high illumination levels, which are 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, if small, 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. In general, in this district, air conditioning seemed to be associated with a negative effect. (see discussion in Section 4.2.) About half of the air conditioned classrooms also had operable windows.

There are many possible interpretations of these findings, including the effects of other co-linear 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 NWEA level tests, where younger grades typically make greater progress[1].

[1] More information about expectations for RIT level tests can be found at http://www.nwea.org/altexpgr.htm.

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 (Gifted and Talented) 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 in the RIT scaled tests, children at higher levels make less progress per year than those at lower levels, these results are consistent with expectations.

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: The positive or negative effects of the school site could be due to any one 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 any number of 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 potential effects.

It is very noteworthy that, in our analysis, 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 every 500 student increase in population, performance decreases by less than one percentage point. Since the mean school population in Capistrano (for grades 2-5) is about 900 students with a standard deviation of $\pm$ 200, this is not likely to be a major effect.

The observations about the variables included in the final models are summarized below in Figure 11.

Significant Variables:	Comment
Daylight Codes	Positive effects
Grade Level	Strongest effects
GATE Program	Negative effect
School Site	Significant for 30%-45% of schools
Operable Windows	Positive in 3 of 4 models
Language Program, (bilingual immersion)	Positive, stronger for reading than math
Absences	Negative effect for math only
School Population	Slight negative effect for larger schools

Insignificant Variables:	Comment
Ethnicity	Not a factor
Socio-Econ Status	Not a factor
Age of School	Not a factor
Year Round Program	Not a factor
Tardies	Not factor
Vintage of School	Not a factor
Gender	Slightly significant in only one math model
Type of Classroom	Inconsistent findings, co-linearity with air conditioning and operable windows
Air Conditioning	Negative trend, co-linearity with operable windows
Students per class	Probably absorbed by grade level variable

Figure 11: Significant and Insignificant Variables in Capistrano

4.3.3 Stepwise Regression

The R^2 for the final Capistrano models ranged from 0.25 to 0.26. This could be interpreted to mean that about 25% of the variation in the data sets can be explained by the models. For some types of regression analysis, such as those explaining the behavior of the physical world, this might be considered to be very low. However, for regression models which deal with the behavior of individuals, which are highly variable, this is considered to be a very creditable result, and is consistent with other analyses performed with this type of data.

Figure 12 below summarizes the findings of the step regression performed to determine the relative explanatory power of each variable in the model. Variables are listed in order of entry into the model. The earlier the entry, the more powerful the variable is in predicting how a student will perform.

This chart excludes the outliers, since they are not of particular interest in interpreting results. For full detail on the step regression results, please see the Appendix.

MODEL				
Order of Entry	**Reading Daylight**	**Reading Skylight**	**Math Daylight**	**Math Skylight**
1	Second Grade	Second Grade	Second Grade	Second Grade
2	Third Grade	Third Grade	Third Grade	Third Grade
3	School 61	School 61	Fourth Grade	Fourth Grade
4	GATE	GATE	GATE	GATE
5	School 64	School 64	**Daylight**	School 72
6	**Daylight**	**Window**	School 72	**Window**
7	School 72	Language Prog	School 59	School 50
8	School 85	School 81	Absence Unverified	School 59
9	Fourth Grade	School 82	School 62	**Skylight Type A**
10	Language Prog	Fourth Grade	School 77	School Population
11	School 82	**Skylight Type B**	School 82	Absence Unverified
12	School 73	School Population	Schol 61	School 74
13	School 67	School 66	School Population	**Oper. Window**
14	School 62	School 67	Language Prog	School 62
15	**Oper. Window**	School 77	School 67	School 82
16	School 81	School 62	School 71	School 85
17	School 77	School 73	Absence Unexcused	Absence Unexcused
18		**Skylight Type AA**	**Oper. Window**	School 70
19		Female		Language Prog
20		School 60		
21		**Oper. Window**		
22		**Skylight Type A**		
23		School 72		
24		School 85		
Outliers:	6	6	6	6

Figure 12: Order of Entry for Capistrano Variables

This analysis shows that the daylight and window variables are particularly strong explanatory variables of how much a student will progress within a given year. They enter as the fifth or sixth variable into the models, exceeded in strength only by what grade the student is in or if they are in a GATE program.

Depending on the model, eight to twelve schools of the district's 27 show a significant impact on a student's progress, but this generally is less of an influence than the daylight and window conditions. The skylight and operable window variables have more variance as to when they enter the models, some in the middle and some nearer the end. Often they are seen to have more explanatory power than if the child is in a language program, the size of the school, or how many absences the child has during the year.

It makes sense that the window and daylight codes would have the strongest explanatory power of all the variables of interest, since every classroom has a code for these variables, whereas there is a much smaller population of classrooms with skylights or operable windows.

The delta R^2 for the daylighting variables varies from 0.0026 to 0.0002. This means that they are contributing about 1% to 0.1% of the explanatory power (R^2 = .25) of the model. Again, while this may seem very small, it is still comparable to the explanatory power of other commonly accepted variables included in the equations, such as the number of absences, gender, the size of the school, or participation in a special program.

4.3.4 Interactions Among Other Independent Variables

Using the daylighting - math model, we looked at interactions between daylighting and the other explanatory variables, namely school size, unverified absenteeism, unexcused absenteeism, the gate program, the language program, and the three grade level indicator variables. We first looked at scatterplots of the residuals versus each of these variables. The residual plots did not reveal any indication of interaction. As a check we created the interaction variables and measured their significance as a group. The p-value was .099 indication that there was only a weak effect at best. When we looked closer we found that there was no significant interaction with the grade variables, but there was a weak interaction between daylighting and school size (p-value = .046), and daylighting and unexcused absenteeism (p-value = .062). The estimated effect was positive for all students in the sample, but varied from .0 to 1 for most students, with the distribution centered at 0.5. The results indicate that the effect of daylighting on math performance tends to be higher in larger schools and for students with higher unexcused absenteeism.

In this exercise, we did not find any interactions that suggested that the model might be compromised by interaction effects.

4.3.5 Classroom Level Analysis

After reviewing analysis with the above regressions, using the student records as the dependent variable, there still remained a concern that the analysis might be reflecting a classroom level phenomenon. This student level analysis assumes that both teachers and students are assigned randomly to classrooms, and that there is no bias such that “better” teachers or “better” students are preferentially assigned to daylit classrooms. To test this hypothesis we conducted a classroom level analysis to see if the significance and magnitude of the daylighting variables would remain the same, or would decrease in certainty and size.

We created a new analysis database at the class level by calculating the average of the dependent and explanatory variables of each model within each classroom. For example, the number of absences was calculated as the classroom average value of the absences of each student. In the case of an indicator variable, it becomes equal to the fraction of students in the classroom. For example, since Gate_N was an indicator variable in the original model, its new value is the fraction of the students in the classroom that are in the GATE program. The same is true for the gender and the grade indicators. In the case of any class-level variable, such as the skylighting indicators, we simply used the value for the class.

We excluded the students that had earlier been identified as outliers in the student level analysis. Dropping a student from the database is essentially equivalent to including an indicator variable for the student-level analysis. We also calculated the number of students in each class and the residual standard deviation of the original student-level models.

We used weighted least squares to fit the models. We used a maximum likelihood estimation methodology to identify the most appropriate model for the residual variance of the classroom-level models. We postulated a variance-component model for the student-level model. Specifically we assumed that the random component of the test performance of each student is the sum of a classroom-specific effect that is common to all students in a given classroom, and a student-specific effect.

In the case of the math model, the classroom component of the variance was about 20% of the total variance, while the student component of the variance was about 80%. In the case of the reading model, we found no classroom component of variance. We may postulate that the classroom effects are associated with differences between teachers. In this case, these results suggest that Capistrano teachers are quite uniform in their ability to teach reading, but vary in their ability to teach math. Alternatively, classroom effects may be a function of grouping students into classrooms by abilities. It may be that the district is more likely to assign students to a given classroom based on their math ability, but not likely to track children into classrooms based on their reading ability.

The following table compares the results of the classroom level analysis with the original student level analysis. The table shows the regression output for the Skylight Type A explanatory variable for the math and reading models.

Math	B	Std Err	t	Sig
Student Level	2.556	0.469	5.449	0.000
Class Level	2.451	0.830	2.953	0.003
Reading	B	Std Err	t	Sig
Student Level	1.668	0.560	2.979	0.003
Class Level	1.932	0.728	2.655	0.008

Figure 13: Classroom Level Analysis Results for the Skylight Variable

The following points are important to observe:

- The coefficient remained stable. The math coefficient dropped slightly but the reading coefficient rose a fair amount. Neither change was statistically significant.
- The standard errors increased as we expected.
- The t-statistics fell and the significance levels became somewhat poorer. But both variables are still highly significant.

As might be expected, the R-square statistic was much higher at the class level. The math model explained 67% of the variance at the class level. The reading model explained 47% of the variance at the class level. This illustrates the fact that the R-square statistic is strongly affected by the level of aggregation.

We did not repeat the analysis of the daylight models but we would expect the results to be similar. Please see the Appendix for the full text of the Capistrano classroom level analysis.

4.4 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 be much smaller than Capistrano, averaging (grades 2-5) 200 students in our data set.

Seattle provided us with student test score records for all elementary students attending 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 spring of 1998. These scores were analyzed using the Normal Curve Equivalent (NCE) format (see section 3.3.1). The analysis for Seattle uses the actual test scores for this one point in time, not the change in test scores between time periods.

In addition to the test scores, the data set included codes for the student's classroom location, grade, ethnicity, sex, and socio-economic status. As mentioned earlier, all information was stripped from the data set that might have allowed identification of an individual. Similar to Capistrano, a similar data cleaning effort matched the classroom codes used in the test score data set to classroom codes from other sources of information. About 90% of students could be matched to classroom locations.

4.4.1 Seattle Buildings

The elementary schools in Seattle had a large range of conditions. Mostly older, the schools range in age from 8 to 90 years old. Most are multiple story buildings with interior hallways and both indoor and covered facilities for student use, such as gymnasiums, covered play areas, libraries, cafeterias and auditoriums. Many 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 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. Many schools had skylights that lit the hallways and recreation areas. These skylights outside of classrooms were not included in our analysis.

Originally we believed that nine schools had some form of toplighting in some of their classrooms. However, we were only able to verify toplighting in four schools. The most prevalent types of toplighting were sawtooth monitors, some facing east, some facing north. One school with open-type classrooms has clerestory windows that allow daylight deep into the building. A handful of classrooms have three small skylights, and another group have large central skylights with louvers covering most of the ceiling. Please see the Appendix for photographs of selected classroom conditions.

We examined historical records, a maintenance database, aerial photographs, and architectural plans of each school, to create a classroom database that added the following information, linked to the homeroom location of each student:

- Square footage of classroom
- Square footage of school
- Traditional, open (pods) or portable classroom
- Age of school (original construction date)
- Daylighting code
- Window code
- Skylight code

As with Capistrano, on-site investigations were conducted twice. We visited a number of schools initially to scope out the range of daylighting conditions, in order to develop the daylighting codes as they were applied to this district. After the data set was developed and the draft analysis completed, we visited nine additional schools to confirm exceptional conditions. Given that Seattle is such a large district, with 60 schools, we were only able to conduct on-site visits to about 25% of the schools.

During a site visit to a skylit school, it became clear that there was a high population of gifted students in this school in a special “accelerated” program. We realized that we didn’t have a gifted indicator for the Seattle data. The district was unable to provide it by student, so they created a “gifted room” identifier, that located classrooms across the district with more than 70% gifted children where an accelerated curriculum was pursued. Adding this variable to the analysis reduced the resulting coefficient for skylights, and daylight.

Daylight Code	Number Of Students	Window Code	Number Of Students	Skylight Code	Number Of Students
1.00	369	1.00	419	.00	7089
1.50	70	1.50	70	1.50	8
2.00	599	2.00	599	2.00	20
2.50	285	2.50	235	2.50	50
3.00	4334	3.00	4674	3.00	278
3.50	146	3.50	146	3.50	145
4.00	1272	4.00	1363		
4.50	84	4.50	84		
5.00	431				
Grand Total	7590	Grand Total	7590	Grand Total	7590

Figure 14: Daylight Codes, Seattle Public Schools

The chart in Figure 14 shows the distribution of daylight codes in our data set for the Seattle district. The vast majority of classrooms had a window code of 3 (average) and no skylights.

Other Conditions

The Seattle district has very few portable classrooms. There was also little variation of daylighting conditions within a school site. Thus we did not have the same opportunity to add a site variable to the analysis as we did in Capistrano.

We were told that no schools in Seattle had air conditioning, and that most have operable windows. Most of the schools have fluorescent lights. A recent project has been retrofitting T-8 lamps and electronic ballasts in some schools, but most schools during the time period of this study had older systems, mostly T-12 lamps and magnetic ballasts. A number of schools had an incandescent lighting system. We were unable to add information about the lighting system to the analysis.

4.4.2 Seattle Results

The Seattle analysis 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 four models.

Figure 15 summarizes the effects for the daylighting-related variables of the four Seattle models. The chart first shows the B-coefficient for the reading and math scores on the NCE scale of 1-99. All these variables were found to have 99.9%

certainty. The percent effect of these scores relative to the district average score (reading: 57, math: 59[1]) is reported in the right column. The full results of the Seattle analysis are included in the Appendix at the end of this report.

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 15: Summary Daylight Findings for Seattle

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 with the least window area or daylighting. A 6% to 7% effect is observed for skylit classrooms.

The Regression Equations

The results for all the major variables of the Seattle regression equations are presented below in Figure 16. There are many more variables than for Capistrano, since this is a static model. Demographic variables become important in predicting a student's actual score, rather than improvement, as in Capistrano. We attempt to interpret these findings below.

The magnitude of the **daylighting variables** is considerably larger in Seattle than Capistrano (6-9 points vs. 2-3 points for windows and daylighting). There are a number of possible explanations. It may partially be a function of a less detailed model, which can account for fewer other influences, such as the role of each school site. It may reflect a bias of students with higher initial test scores attending schools with more daylight. Or it may reflect a cumulative effect of daylighting over a longer time period.

[1] Again, these values are the district average for the data set used in this study, which is a subset of the whole district.

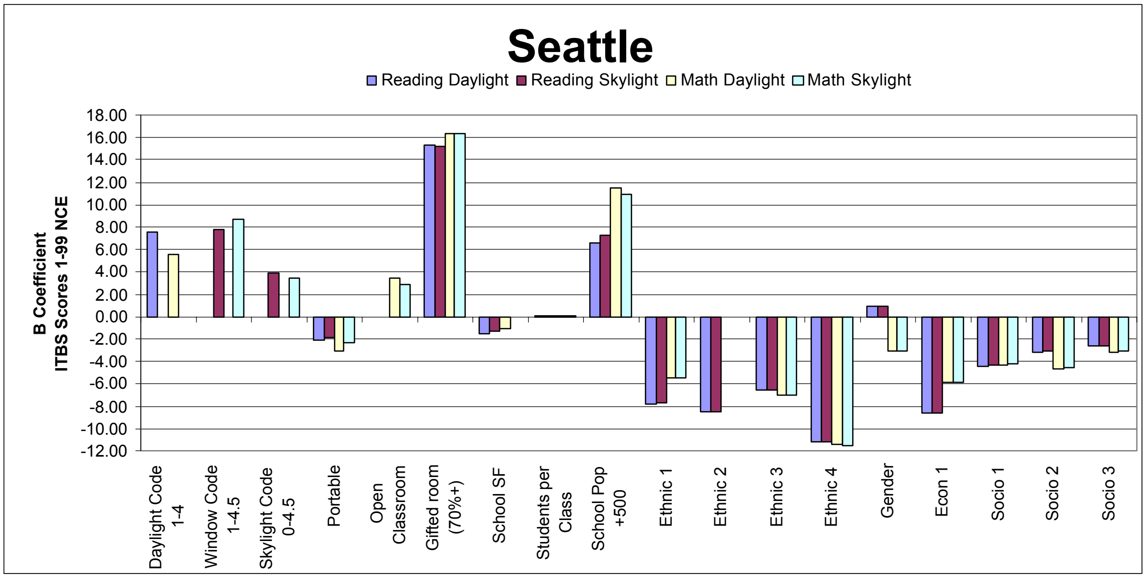

Figure 16: Seattle, Percent Point Difference in Mean Score

It should be remembered that these models looked at actual test scores, not the change between two periods. Thus, they reflect levels of achievement attained over a student's career to date, rather than improvement over one year. It is possible then, assuming that most students stay at one school site, that the effects of daylighting might be cumulative over a student's career, and thus larger than for a single school term.

In the Seattle analysis, we tried some models that distinguished between the skylight types. We wanted to see if the type or orientation of the skylight made a significant difference in performance. In general the skylight codes showed positive results of similar magnitude. There were no significant differences between toplighting systems that faced north, versus those that could let the sun in (facing east or south). However, the significance of each variable was often reduced, since we were dealing with smaller populations. We concluded that in this district it was more meaningful to leave the skylight variable on the 0-5 scale.

The **gifted room** variable has the greatest magnitude of effect. As would be expected, students in a gifted program are seen to be scoring 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 very small size of the Seattle schools (mean is 200 students in grades 2-5), this may indicate that these schools are below an optimum size. Or it may be that larger schools in Seattle have some other advantage, such as better facilities.

The **demographic variables**—ethnicity, economic and social status—are seen to have a strong influence. However, it is interesting that mostly their magnitude is equal to, or less than, the daylighting variables.

Other variables, portable classrooms, open classroom, school square feet, students per class, have occasional and modest impacts.

The R^2 for the Seattle models at $R^2 = 0.26$ to 0.30, are just slightly higher than for Capistrano.

Stepwise Regression

Order of Entry	**Reading Daylight**	**Reading Skylight**	**Math Daylight**	**Math Skylight**
1	econ 1	econ 1	Ethnic 4	Ethnic 4
2	Gifted room (70%+)	Gifted room (70%+)	Gifted room (70%+)	Gifted room (70%+)
3	Ethnic 4	Ethnic 4	econ 1	econ 1
4	Ethnic 2	Ethnic 2	Grade 2	Grade 2
5	Grade 2	Grade 2	Gender	Gender
6	Ethnic 1	Ethnic 1	Grade 3	Grade 3
7	Grade 3	Grade 3	Ethnic 1	Ethnic 1
8	Ethnic 3	Ethnic 3	School Pop	School Pop
9	School Pop	**Window**	Ethnic 3	Ethnic 3
10	**Daylight**	Students per Class	Socio 3	Socio 3
11	Students per Class	School Pop	Socio 2	Socio 2
12	Socio 3	Socio 3	Socio 1	Socio 1
13	Socio 1	**Skylight**	Vintage	**Skylight**
14	Square Feet	Socio 1	Open rm	**Window**
15	Socio 2	Socio 2	**Daylight**	Open rm
16	Gender	Square Feet	Portable	Students per Class
17	Portable	Gender	Students per Class	Portable
18	Grade 4	Grade 4	Square Feet	
19		Portable		
# Outliers	5	6	3	5

Figure 17: Order of Entry for Seattle Variables

When we look at the step regression to see the order of entry for the variables, the daylighting variables fall in the middle range for the reading models, and the lower end of the range for the math models. The delta R^2 for the daylighting variables are similar to Capistrano, at 0.003 to 0.001. While these values are small, Figure 17 shows that the daylighting variables do have more explanatory power than variables that might commonly be considered important indicators of a student's achievement, such as social status (single family households) or the number of students in a classroom.

4.5 The Fort Collins District

The Poudre School District in Fort Collins, Colorado is a rapidly growing school district about an hour 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. These schools have relatively modest windows. But other, older schools, have larger window areas. The range of daylighting conditions seemed to present a good opportunity for our study.

4.5.1 Fort Collins Data

The Fort Collins district provided us with data sets of student test scores for math and reading “level” tests for spring of 1998 and 1997 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. They use an RIT scale that allows comparison of scores across all levels. The data sets also included demographic information, similar to Seattle and Capistrano, including grade level, ethnicity, gender, socio-economic status, and special education codes.

From examination of district records we added information to the database about the age and the size of the school. We examined architectural plans for each school to determine classroom type (open vs. traditional classrooms), and develop the daylight, window and skylight codes. We also created density variables similar to Seattle, using students per school, and number of classrooms per school, neither of which proved to be a significant variable in the final models.

Similar to Seattle, students identified with special education and bilingual codes and special academies were removed from the data set. The final 1998 data set included about 5700 students grades 2 through 5. The 1997 data was much less complete, so we did not use it in our analysis.

Economic Status

The economic status variables that were available for this study (free and reduced lunch) do provide a useful indicator for the low end of the economic scale, but they do not provide an indicator for the high end of the economic scale.

As an initial screening measure, we reviewed school locations relative to the economic class of neighborhoods with district personnel, and concluded that there was probably enough socio-economic variation within both the skylit and the non-skylit schools to avoid a strong confounding effect of economic class by school. Although the skylit schools did constitute all of the newer schools in the district, there was a wide range of ages of schools in the district (44 years), so it was felt that an age variable would have enough variation to effectively capture any vintage effects independent of the skylights. For example, if older schools were associated with both higher economic status and larger window areas, then that effect should be reflected in the coefficient for the age of the school.

School Level Analysis

Unfortunately, due to the structure of the data sets given to us by Fort Collins, we were not able to identify students by their classroom location. The finest grain information we could obtain was the grade level of student per school location. As a result we had to analyze the Fort Collins student performance data by school location, rather than by classroom location. This was a serious drawback, and reduced the precision of our analysis for Fort Collins. This limitation was partly ameliorated by the observation that daylighting conditions throughout a given school site are quite similar. Fort Collins schools did not have portable classrooms, or classroom wings of different vintages, and window types and sizes do not tend to vary much within a school plan. However, given the school-level of the analysis, it is not possible for us to distinguish between potential school level effects and daylighting conditions within a school for the Fort Collins analysis.

4.5.2 Fort Collins Buildings

The district has recently built seven schools using the same basic plan with large overhead monitors in the classrooms, and modest vision windows in each classroom. Older schools tend to have larger windows. The oldest schools in the district have been retired to other uses.

We again categorized the window and skylight conditions by review of architectural plans. We applied the same criteria for assigning codes that had been used in Capistrano and Seattle. The final coding in Fort Collins was much simpler and more general, because it was, by necessity, at the school level, rather than by classroom. There was considerable, but not absolute, uniformity between daylighting conditions for each classroom within a school. We certainly could not account for orientation or obstructions specific to a classroom. To create a window code for each school, we averaged the window to floor area ratio for the classrooms in each school. These averages fell into three distinct groupings, that were assigned the following codes:

Window code 1	1-2%% window to floor ratio
Window code 2	3-4%% window to floor ratio
Window code 3	8-13%% window to floor ratio

South-Facing Monitors

In the skylit schools, the monitors run the length of each classroom, and have angled, un-shaded glass facing due south. They have semi-diffusing glass, either sand blasted or “solar glass,” to diffuse the direct sunlight. On-site observations determined that fuzzy images can be seen through the monitors, indicating that the glass is only partially diffusing. Illumination measurements were made at some schools, indicating that the south facing clerestories provide very high levels of illumination in the middle and back of the classrooms (100-150 fc), but the south end of the classrooms tends to be darker (40-60 fc). This represents roughly a 10% daylight factor. In one classroom during a sunny period, 450 fc were measured in a corner of the room. (See Appendix for sample illumination readings and photographs of classrooms.)

The monitors are also provided with opaque insulating shades that are designed to operate on an automatic schedule, closing every night and opening every morning. The teacher has an override, which allows the room to be darkened at will. The principals of a few schools were interviewed to explain the typical operation of the shades. They believed that the shades were primarily closed only in the early fall and late spring to avoid overheating, and during video presentations. However, on-site observation of five schools on a partly cloudy day in February found 60% of the shades closed during the school day.

We hypothesized that the very bright light from the monitors was disturbing to the teachers, who tended to close the shades. An interview with the architect confirmed that teachers at one time had complained about how bright the monitors were. The response had been to design monitors with a slightly less transmissive glass (-05%) and to move the teaching wall for some of the teachers to the east or west wall of the classroom. Currently a majority (±60%) of the teaching walls are perpendicular to the monitors.

In the final models, the monitors were treated as a yes/no variable. Rooms with a monitor were assigned a daylight code of 5, based on our expectations of high illumination levels. In retrospect, given that the monitors seemed to be closed much of the time, this may have been an overestimate.

Daylight Code	Number of Students	Window Code	Number of Students	Skylight Code	Number of Students
1	2092	1	2092	0	4027
2	1106	2	3652	1	2239
3	829	3	522		
5	2239				
Grand Total	6266	Grand Total	6266	Grand Total	6266

Figure 18: Daylight Codes for Fort Collins

Other Characteristics

None of the schools in Fort Collins have air conditioning. The skylit schools do have a thermostat activated venting system that exhausts hot air from the top of the monitors. Information about air conditioning and natural ventilation was not included in our analysis for this district.

All of the schools visited in Fort Collins have fluorescent lighting, but we could not confirm that fluorescent lighting was universal in all schools. The skylit schools have pendant mounted direct/indirect fixtures which appear to have T-8 lamps. Information about electric lighting was not included in our analysis for this district.

4.5.3 Fort Collins Results

The Fort Collins analysis found a similar pattern of positive, significant results for the daylighting variables. These results are normalized to a 1-99 scale, just as with the other districts. Data used to normalize the results and calculate the percentage effects are included in the Appendix.

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 19: Summary Daylighting Findings for Fort Collins

The Fort Collins results in Figure 19 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. Therefore, there is the greatest likelihood that there are other variables which we have not accounted for that are influencing 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 a minimum to maximum window condition 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 may also be 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.

The Regression Equations

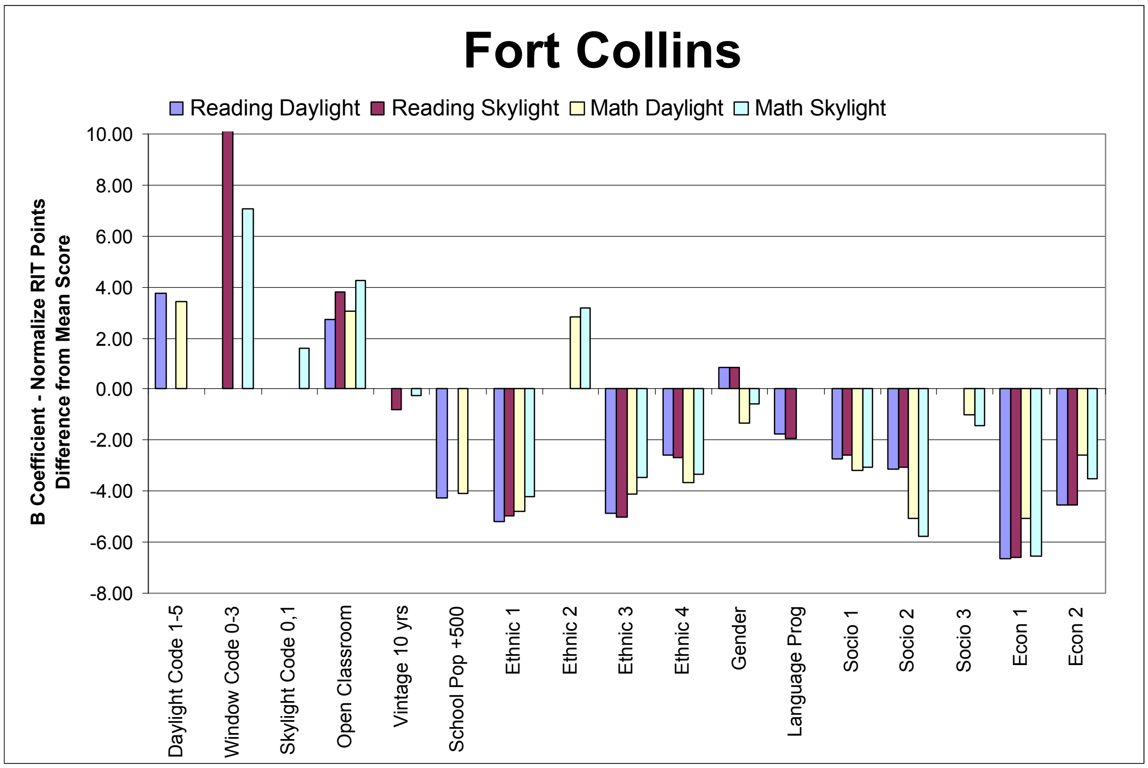

Figure 20: Fort Collins Percentage Point Difference in Mean Score

The B-coefficients for the variables in Fort Collins regression equations in Figure 20 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. With a different mix of immigrant populations between the two cities, the shifts in the ethnicity variables seem reasonable. The positive daylight variables have a similar magnitude to the negative demographic variables. Thus, one's assignment to a daylit classroom would seem to be as significant as one's ethnicity in determining performance on the standardized tests.

In general, due the limitations of the Fort Collins data, we did not explore the impact of other variables for this data set. Because of the uniformity of the schools, and our inability to distinguish between the daylighting conditions in various classrooms, it is much more likely that there are specific school effects which are confounded with the daylighting conditions particular to a given school.

The R^2 for the Fort Collins models is considerably higher than the Capistrano or Seattle models (0.37 to 0.44). The delta R^2's for the daylighting variables also have a similar range, 0.001 to 0.004.

The order of entry for the daylighting variables is similar to Seattle, in the middle to low range, with less influence on the math models than the reading models. In general, we would expect the Fort Collins daylighting variables to have less effect, since defined on a school wide level, rather than a classroom level, they had less accuracy than the other districts.

Variable	MODEL:			
Order of Entry	**Reading Daylight**	**Reading Skylight**	**Math Daylight**	**Math Skylight**
1	GRADE3	GRADE3	GRADE3	GRADE3
2	GRADE4	GRADE4	GRADE4	GRADE4
3	Economic 1	Economic 1	Economic 1	Economic 1
4	Ethnic 1	Ethnic 1	GRADE5	GRADE5
5	GRADE5	GRADE5	Ethnic 1	Ethnic 1
6	School Pop	Economic 2	Economic 2	Economic 2
7	Economic 2	VINTAGE	Gender	Gender
8	**Daylight**	Ethnic 3	Ethnic 2	Ethnic 2
9	OpenClass	Socio 1	Socio 2	VINTAGE
10	Ethnic 3	LANGPROG	Socio 1	Socio 2
11	LANGPROG	Gender	Ethnic 3	Socio 1
12	Socio 1	**Window**	Ethnic 4	Socio 3
13	Gender	OpenClass	Socio 3	Ethnic 4
14	Socio 2	Socio 2	**Daylight**	Ethnic 3
15	Ethnic 4	Ethnic 4	OpenClass	OpenClass
16			School Pop	**Window**
17				**Skylight Code 0,1**
18				School Pop
Outliers:	8	8	9	4

Figure 21: Order of Entry for Fort Collins Variables

5. DISCUSSION AND CONCLUSIONS

We began this study uncertain that we would be able to find any significant effects of daylighting using a regression analysis methodology on large student performance data sets. We pursued the study of three school districts in the hope that at least one district would be amenable to this analysis technique. As a result of our work, uncertainty has transformed to certainty, and many new areas of investigation are suggested.

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

- We found a uniformly positive and highly significant correlation between the presence of daylighting and student performance in all three districts.
- We found that daylighting, provided from skylights, distinct from all the other attributes associated with windows, has a positive effect.
- 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 uncertainties that remain. This kind of observational study cannot determine a causal relationship. We have merely shown an association between the presence of daylight and higher student performance, not shown that daylighting causes students to learn more. Daylighting seems to be a good predictor of student performance, but there are other possible associations that might be involved in this correlation. The most obvious one is that there is some bias of “better” teachers being assigned to classrooms with more daylight.

Other lesser findings can also be derived from this study, discussed below, and in the body of this report. We consider whether the magnitude of findings between the districts is significant, and why they may exist. We also consider whether there are lessons to be learned about the importance of windows per se versus daylight illumination, and what our findings suggest about the design of daylighting systems to achieve the best human performance. These discussions are purely speculative, based on our interpretation of the findings from the data in combination with our observations as architects visiting the school sites.

Finally, we consider possible physiological mechanisms whereby daylighting might cause higher performance. We relate some of these hypotheses to work that has been done by others. Again, at this point, all of these potential causal mechanisms are purely speculative, and will require more focused research to resolve.

5.1.1 A Possible Teacher Effect

The most outstanding question remaining from this study is whether there is a correlation between “better” teachers and classrooms with more daylight. We use the term “better” teacher as a catch-all for whatever qualities in a teacher might result in the higher student test scores observed in the analysis. This might be a function of teachers with more seniority or training or experience being assigned to classrooms with more daylight. It might be a function of teachers in daylit classrooms being more motivated or alert or responsive to students.

We attempted to address this issue in two ways in the study. First we informally interviewed teachers, principals and administrators in the district to see if we could identify any bias in how teachers were assigned to classrooms. This is a touchy subject, and teacher privileges are not freely discussed. We could not, however, detect an obvious systematic bias. We were told of senior teachers who preferred the portables, of schools organized around themes, classes grouped by grade level, and (in Capistrano) the constant reshuffling of classroom assignments due to population growth and class size reduction.

Teachers did strongly and consistently express a preference for classrooms with operable windows. Increasing ventilation seems to be very high on their priority list for classroom characteristics. There was also some implication that a view was desirable, so it is possible that more senior teachers might be more likely to end up with classrooms with a view. A view might correlate with larger windows, but would not correlate with skylights. In one seasoned administrator’s perspective, daylighting would have to correlate with five or six other factors that teachers strongly prefer in classrooms—such as carpets, sinks, storage space, new furnishings—in order for daylighting to have a bias in teacher selection of classrooms.

The second way that we attempted to address this issue was by performing the classroom-level analysis for Capistrano discussed earlier. The results of that investigation showed that a classroom level analysis, such as would be influenced by differences among teachers, was not particularly more accurate than a student level analysis.

Neither of these investigations, however, is conclusive. There are other possible approaches that might help to answer this question with further investigation.

1.) We could try to correlate data describing teacher experience, such as years of service and highest degree, with classroom location to see if there was a correlation between daylighting and experience. This would be most useful in a district like Capistrano where teachers could be assigned to different daylight conditions within a school. In districts like Seattle, or Fort Collins, with little variation in daylighting conditions within the school, such a correlation might just indicate a school preference.

2.) We could try to survey a sample of teachers to see what their perceptions are about classroom assignments, and their preferences for various classroom attributes. We could then correlate preference for daylighting with teacher characteristics, such as experience, and simultaneously find out the relative importance of daylighting in teacher preferences compared to other classroom attributes.

If teachers are indeed sorting themselves out so that those in daylit classrooms are getting better results—because they have more tenure, are better trained, more motivation, better stamina, whatever—then we may have described a “teacher bias” effect for daylight, rather than a “student performance” effect of daylight. There would seem to be two possibilities in this scenario. One, that daylight is inspiring better performance in teachers, or two, that the better teachers all manage to end up in the more daylit classroom. It would be nice to know which, but either way, as school administrator, it might be advantageous to have more daylit classrooms, if only as a competitive position against other districts competing for the best teachers.

5.1.2 Comparisons Between Districts

The results of the analysis of the three districts are remarkably consistent: all positive, in the range of a 2-9 percentage points effect, and all with 99% certainty of a valid effect. This is a remarkable finding.

Figure 22 on the following page presents the summary findings for the daylighting variables for all three districts. The reasons for differences between districts are interesting to consider, although they cannot be known based on the results of our study. The magnitude of the Capistrano test score effects (left column) are the smallest of the three districts, but this is to be expected for a number of reasons:

- **Operable Windows**: The Capistrano model isolates the positive effect of operable windows, which may be included in the Seattle and Fort Collins results for the window variable. We did not collect information about operable windows in Seattle or Fort Collins.
- **School Site Effects**: The Capistrano model controls for more variables, especially the individual school sites, which is likely to reduce the observed effect for all other variables, including the daylighting variables. Thus, with the inclusion of the school site variable in Capistrano, we would expect the B-coefficient of the daylighting variables to be reduced.
- **Cumulative Effects:** The delta scores for Capistrano report on the improvement over one school year, whereas the other two districts report on actual test scores at a given point in time, which presumably include the effect of the initial starting point at the beginning of the year. Thus, the Capistrano results can be interpreted as a yearly improvement effect, while the other two districts may be reflecting more of a cumulative effect of having been at a well

daylit school over a number of years, averaged over the range of grades 2-5. It should also be remembered that the daylighting conditions within a given school in Seattle and Fort Collins are relatively homogeneous, which would reinforce any possible cumulative effect, whereas the daylighting conditions within a given school in Capistrano can be quite dissimilar (from portables to traditional classrooms), which would tend to reduce any cumulative effect. Further study is clearly needed to test this hypothesis.

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%

Capistrano Delta Normalized Results

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%

Seattle Normalized Results

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%

Poudre Normalized Results

Figure 22: Comparison of Three Districts

5.1.3 Other Possible Discrepancies

The other districts may also have higher (or lower) results for other reasons having to do with the information in our data sets:

- **Unknown Co-linearity**: The Seattle, and especially the Fort Collins, data sets are not as thoroughly reviewed and refined as the Capistrano data, and thus might include errors or co-linearity with unknown variables, which could either raise or lower the results. We uncovered one such correlation in Seattle with the gifted students program. There may be others that we were unable to observe.
- **Compressed Daylight and Window Scales**: The Seattle and the Fort Collins results are derived from compressed scales. For example, in Fort Collins no windows were graded above a scale of 3. In Seattle, the highest window code was 4.5. Simple extrapolation suggests if the two districts had some classrooms with larger window area, which could have been assigned a code of 5, that the maximum window effect for those districts might have been even larger. We were not able to conduct any tests to see how sensitive the analysis is to the range of daylight codes.
- **Sub-Optimum Daylight Design**: The Fort Collins skylight variable is for a skylight condition that lighting experts generally consider to be less than optimum. Poor lighting quality would presumably lower the positive effect associated with skylighting. Furthermore, a large percentage of the skylights may have their shades closed during class time, which would also greatly reduce any potential effect.
- **Neighborhood Effects**: Large windows may be associated with more prestigious neighborhoods. Older schools tend to have bigger windows, and if these older schools tend to occur in older, established, leafy neighborhoods, larger windows may also have an association with higher income households. Any such correlation in Capistrano would be captured in the school site variables, since the influence of a particular neighborhood would be seen at the school level. However, we could not control for such influences in Seattle and Fort Collins. We did control for age of the school, so if this older school/larger windows/better neighborhood hypothesis is true, part of the effect should be absorbed in the age of school variable. We also controlled for free and reduced lunch, which can be used to characterize the low end of the economic scale, but there were not similar variables to capture any effects due to students at the high end of the economic scale.

  At the beginning of the analysis, we did a reality check in each district to make sure that the skylit schools did not have an exclusive relationship to high-income neighborhoods, but we did not perform a similar check for the range of window size. Currently, if “better” schools—due to a more motivated staff, more involved or highly educated parents, or whatever—are associated with more daylighting in Seattle or Fort Collins, our model cannot distinguish between any daylighting effect and any "better" school or neighborhood effect.

- **Inaccurate Daylight and Window Codes**: In Capistrano the skylights were carefully studied. We tested the sensitivity of the skylight codes and determined the most accurate characterization of the toplighting for that district. We may not have achieved as much accuracy in the daylight codes and window codes, especially for Seattle and Fort Collins, since those districts were not as extensively visited as Capistrano. In Fort Collins it was observed on one day that the skylights were closed in 60% of the classrooms. If this is typical, then the daylighting codes for that district would be overestimating the amount of daylight typically occurring in the classrooms, and would likely result in a finding of a reduced effect. In Seattle, there were also black out curtains observed in many skylights, but most were observed to be open. If the additive effect of windows and skylights differs from what we expect, then the results for the combined daylight code would also shift.

5.1.4 Lessons about Daylight

In Capistrano the daylighting effect is seen to be slightly larger than the window effect. This is interesting, because in Capistrano the daylight scale was adjusted to more closely reflect the daylight levels observed on site, and the window scale was adjusted to more closely reflect the size of the window independent of the amount of daylight entering. Thus, this one finding strongly suggests that there is a daylight effect, and that the potential amount of daylight in a classroom is an important consideration.

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.

The results of the analysis are also suggestive of 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[1].

[1] 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.

Design Issues

It is clear from our analysis some of the skylighting systems considered in this study perform well and some do not. Our analysis showed more consistency when considering skylight systems by design type, rather than by the 0-5 illumination scale assigned by the daylighting experts. In other words, the way that the system was designed to affect light quality in the room seemed to be more significant than how we ranked the systems for the quantity of illumination expected.

The systems that performed well (Skylight Types A and AA in Capistrano, sawtooth monitors, clerestories and skylights in Seattle) generally had the following characteristics:

- They provided wide, diffuse distribution of daylight, by using diffusing lenses and/or diffusing louvers and wells.
- They prevented direct penetration of sunlight into the classrooms
- They allowed the teacher direct control of the amount of daylight illumination through the use of louvers or blinds

The skylight systems that did not perform as well, or that even had negative effects, (Skylight Type B and C in Capistrano, sawtooth monitors in Fort Collins) had some of the following characteristics:

- They allowed direct sunlight into the classrooms,
  (or partially diffuse sunlight, as in Fort Collins)
- They relied on automatic controls, which were not performing as originally intended
- They created small areas of very high daylight illumination, which contrasted with other areas in the classroom with relatively little daylight

In our observations of schools for this study it was clear that successful daylighting from windows prevented the penetration of direct sunlight into classrooms. In general, the architects of the schools we visited seemed likely to make sure that windows were deeply shaded, and/or to include provisions for modulation of the daylight entering the rooms through the windows. Security concerns seemed to be the main reason teachers were motivated to use blinds or curtains that would make the windows opaque. However, some well-designed daylit classrooms also offered the capability to incrementally adjust the amount of light through the use of operable blinds.

5.1.5 Hypotheses for Causal Mechanisms for A Daylighting Effect

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, such as carefully focused laboratory studies or intervention studies in the field, are required to identify what mechanisms may be involved for daylighting to cause such an effect. Now that it has been shown that there is a likely correlation, such studies should be conducted.

Daylight is quite a complex phenomenon and there are many pathways whereby it might have an effect on human beings. Certainly, more than one pathway may be operating simultaneously. We also do not know if it has a uniform effect on people, or affects some more than others. Below, we discuss a number of possible explanations. At this point, they are at the level of hypotheses, extrapolated from other research, or our own informal investigations. .

Improved Visibility due to Higher Illumination Levels

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. Daylighting is highly variable, and so these illumination levels change by the time of the day, and by season, and thus, it is not possible to be precise about how much additional illumination is provided. The base illumination is obviously the electric lighting system. Maximum illumination is probably achieved on sunny days, depending on the type of skylight and for which season the design is optimized. Figure 23 below summarizes the maximum and minimum illumination levels that we observed in the classrooms. From these observations it is clear that illumination levels three to ten times higher than electric lighting are at least occasionally observed in these classrooms. Daylighting levels from windows are probably much less, but when added to the existing base of electric illumination, will still result in significantly higher illumination levels.

District:	Min. Observed Electric Illumination Levels	Max. Observed Skylight Illumination Levels
Capistrano	30 footcandles	400 footcandles[A]
Seattle	30 footcandles	85 footcandles[B]
Fort Collins	30 footcandles	450 footcandles[A]

Figure 23: Max. and Min. Classroom Illumination Levels

[A] Sunny Day, point location [B] High Overcast

Higher illumination levels have repeatedly been shown to increase the visibility of tasks and the speed and accuracy of people performing those tasks[1].

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

Improved Visibility due to Improved Light Quality

It has been hypothesized that daylight has better "light quality" that is more appropriate for human visual tasks, and thereby increases 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 spectral distribution
- 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 spectral distribution relates to the wavelengths of radiation included in the light source. Daylight has a continuous spectrum, whereas most electric sources are strong in some areas of the spectrum and weak in others. The spectrum of daylight does change dramatically throughout the day, as the sun moves through the sky. However, as a continuous spectrum, daylight renders all colors well, and in tones that we tend to consider most "natural." Better spectral distribution may improve the visibility of the learning environment by making colors more vivid.

Absence of flicker relates to the oscillations in light levels that occur in electric lighting due to the light source's response to alternating current. People have complained that flicker is responsible for a multitude of problems, including headaches, eye strain, and attention deficit problems.

Daylight has no oscillations. 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[1]. It may be that the reduction of flicker due to the presence of daylighting has a similar effect. Daylighting would tend to diminish the effects of flicker from magnetic ballasts by providing a steady base level of illumination.

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 differential illumination on three-dimensional objects with 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 that the shadows and highlights make objects more attractive and easier to understand three dimensionally. A similar effect may make objects more memorable for students in the learning environment.

A brief story: in one informal experiment we conducted, a teacher in a room with no windows, and with highly diffuse fluorescent fixtures, complained that the lighting in her room was much too dim. Illumination readings showed the classroom averaged about 50 footcandles, similar to all others in the district. When we opened the door, allowing some daylight into the room, she exclaimed: “See! That’s so much better!” Illumination readings barely showed an increase in illumination levels, with at best an additional 5 footcandles at horizontal surfaces near the door and less on vertical surfaces around the room. These levels of change are generally considered imperceptible. However, every object in the room now did have highlights and sparkle. Corners and edges of objects became more defined. It seems possible that she had interpreted “flat” light to mean “dim” light.

Improved Health

Daylight might improve performance through better long term health. A number of researchers have attempted to demonstrate these connections. For the Capistrano data set we considered attempting to see if there was a correlation between absences and daylighting. However, the number of students with repeated absences is a greatly reduced number than the overall population. This small population decreases the chances of finding significant effects, so we did not pursue this tact.

[1] 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.

While exposure to daylight is widely believed to promote health, the actual biological pathways are less certain. Exposure to daylight is well 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 seem to be key to helping regulate our circadian rhythms[1]. 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[2]. 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.

Daylight Deprivation

The higher 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.

The Seattle and Fort Collins schools are very different from the Capistrano schools in one very important way: they tend to have double-loaded interior hallways, and ample indoor facilities, such as libraries, gymnasiums, and cafeterias, 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, and trip to the bathroom, library or administration. The climate in Capistrano, of course, is also more amenable to outdoor play. It rarely rains, never snows, and is sunny and warm most of the year. Thus, Capistrano children are inevitably exposed to the daylight outdoors much more frequently than Seattle or Fort Collins children.

One would expect the Capistrano children to be less sensitive to subtle changes in daylight exposure in the classroom since they had such a large exposure during the rest of the day, outside of the classroom. In Seattle, for example, with shorter days during the winter, and persistent cloudy weather, children may have less exposure outside of the classroom, and therefore, incremental changes within the classroom may have more influence. If exposure to daylight improves long term health, then it would follow that the children in Seattle and Fort Collins

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[1] 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.

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

would be more sensitive differences in classroom exposure, and might show a greater range of effects.

Improved Mood

Most people will tell you that they like daylight because it is more "natural[1]." 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 that 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 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."

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 and capable of absorbing new information. If this is true, then merely providing more illumination, above the threshold level for melatonin suppression, 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, have fewer complications, and clearer memories of their treatment when they are treated in rooms with a daylight and/or a view[2]. The positive treatment results are generally interpreted to be a result of the added stimulus from the variability of daylight or a

[1] 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.

[2] 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

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.

Improved Behavior

A number of teachers and parents have suggested that daylight improves behavior, both by increasing focus and sociability. Stories have surfaced of children with attention deficit disorder (ADD) who can perform better under daylight than fluorescent light. We know of no conclusive research in this area, however, a study observing the behavior of school children in daylit classrooms in Sweden is suggestive.

Kuller and Lindsten 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 the student's behavior, especially ranked for sociability and concentration. Children in classrooms with daylight 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. It is the mismatch of moods within a classroom that they find problematic, rather than a particular individual's behavior. 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 co-operate, and also eventually have an impact on annual body growth and sick leave.[1]"

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

6. APPENDICES

6.1 Statistical Charts

6.2 Report on Classroom-level Analysis for Capistrano

6.3 Sample Illumination Readings

6.4 Classroom Plans and Sections

6.5 Photographs of Schools and Classrooms

6.1 Statistical Charts

Capistrano School District Tabular Results

Capistrano Conversion Factors
Count of Students by Daylight Codes
Reading Descriptive Statistics
Math Descriptive Statistics
Readying Daylight Model
Reading Skylight Model
Math Daylight Model
Math Skylight Model
Readying Daylight Model Order
Reading Skylight Model Order
Math Daylight Model Order
Math Skylight Model Order

Seattle School District Tabular Results

Seattle Conversion Factors
Count of Students by Daylight Codes
Reading Descriptive Statistics
Math Descriptive Statistics
Readying Daylight Model
Reading Skylight Model
Math Daylight Model
Math Skylight Model
Readying Daylight Model Order
Reading Skylight Model Order
Math Daylight Model Order
Math Skylight Model Order

Fort Collins School District Tabular Results

Fort Collins Conversion Factors
Count of Students by Daylight Codes
Reading Descriptive Statistics
Math Descriptive Statistics
Readying Daylight Model
Reading Skylight Model
Math Daylight Model
Math Skylight Model
Readying Daylight Model Order
Reading Skylight Model Order
Math Daylight Model Order
Math Skylight Model Order

6.1.1 Capistrano School District Tabular Results

Capistrano Conversions	Reading	Math
Low score	-22	-29
High score	59	79
Range	81	108
Scalar 1-99 scale	1.21	0.91
District mean	8.83	12.51
Daylight Code Ranges	B-coefficient multiplier	
Daylight 0-5	5	5
Window 0-5	5	5
Skylight A	1	1
Skylight AA	1	1
Skylight B	1	1

Table 1: Capistrano Conversion Factors

Window Code	Number of Students	Daylight Code	Number of Students	Skylight Type	Number of Students
0	942	0	942	A SKYLIT	492
1	5317	1	1435	AA SKYLIT	279
2	932	2	3849	B SKYLIT	350
3	420	3	953	C SKYLIT	336
3.5	139	3.5	139	D SKYLIT	106
4	184	4	390	No Skylight	6705
4.5	120	4.5	120		
5	214	5	440		
Grand Total	8268	Grand Total	8268	Grand Total	8268

Table 2: Count of Students by Daylight Code, Capistrano

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Daylight Code	8268	.000	5.000	2.029	1.241
Window Code	8268	.000	5.000	1.364	1.093
Skylight Type A	8268	.000	1.000	.060	.237
Skylight Type AA	8268	.000	1.000	.034	.181
Skylight Type D	8268	.000	1.000	.013	.113
Skylight Type B	8268	.000	1.000	.042	.201
Skylight Type C	8268	.000	1.000	.041	.197
Operable Windows	8268	.000	1.000	.607	.488
School pop-per 500	8268	.808	3.036	1.759	.403
Vintage	8268	2.000	64.000	17.666	13.295
Absences Unexcused-per 10	8268	.000	6.000	.532	.536
Absences Unverified-per 10	8268	.000	1.200	.011	.062
Econ 3	8268	.000	1.000	.147	.203
Ethnic 1	8268	.000	1.000	.147	.354
Ethnic 2	8268	.000	1.000	.050	.218
Ethnic 3	8268	.000	1.000	.003	.050
Ethnic 4	8268	.000	1.000	.015	.121
Ethnic 5	8268	.000	1.000	.013	.111
Ethnic 6	8268	.000	1.000	.002	.040
Gender	8268	.000	1.000	.508	.500
GATE prog	8268	.000	1.000	.135	.342
Grade 2	8268	.000	1.000	.268	.443
Grade 3	8268	.000	1.000	.245	.430
Grade 4	8268	.000	1.000	.250	.433
Lang prog	8268	.000	1.000	.172	.377
Students per Class	8268	5.000	44.000	23.896	5.886
Tardies	8268	.000	105.000	4.742	8.541
Year Round	8268	.000	1.000	.120	.325
Sch 59	8268	.000	1.000	.032	.176
Sch 60	8268	.000	1.000	.041	.198
Sch 61	8268	.000	1.000	.067	.251
Sch 62	8268	.000	1.000	.044	.204
Sch 64	8268	.000	1.000	.020	.142
Sch 65	8268	.000	1.000	.031	.173
Sch 66	8268	.000	1.000	.032	.176
Sch 67	8268	.000	1.000	.053	.224
Sch 69	8268	.000	1.000	.064	.245
Sch 70	8268	.000	1.000	.035	.185
Sch 71	8268	.000	1.000	.034	.180
Sch 72	8268	.000	1.000	.066	.248
Sch 74	8268	.000	1.000	.043	.202
Sch 76	8268	.000	1.000	.046	.210
Sch 77	8268	.000	1.000	.050	.218
Sch 78	8268	.000	1.000	.043	.203
Sch 79	8268	.000	1.000	.041	.198
Sch 81	8268	.000	1.000	.056	.229
Sch 82	8268	.000	1.000	.043	.203
Sch 84	8268	.000	1.000	.029	.169
Sch 85	8268	.000	1.000	.062	.241
Sch 173	8268	.000	1.000	.031	.172
Sch 273	8268	.000	1.000	.024	.152
Reading Delta (sp98-fa97)	8166	-22.000	59.000	8.829	9.102
Valid N (listwise)	8166				

Table 3: Capistrano Reading Descriptive Statistics

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Daylight Code	8268	.000	5.000	2.029	1.241
Window Code	8268	.000	5.000	1.364	1.093
Skylight Type A	8268	.000	1.000	.060	.237
Skylight Type AA	8268	.000	1.000	.034	.181
Skylight Type D	8268	.000	1.000	.013	.113
Skylight Type B	8268	.000	1.000	.042	.201
Skylight Type C	8268	.000	1.000	.041	.197
Operable Windows	8268	.000	1.000	.607	.488
School Pop-per 500	8268	.808	3.036	1.759	.403
Vintage	8268	2.000	64.000	17.666	13.295
Absences Unexcused-per 10	8268	.000	6.000	.532	.536
Absences Unverified-per 10	8268	.000	1.200	.011	.062
Econ 3	8268	.000	1.000	.147	.203
Ethnic 1	8268	.000	1.000	.147	.354
Ethnic 2	8268	.000	1.000	.050	.218
Ethnic 3	8268	.000	1.000	.003	.050
Ethnic 4	8268	.000	1.000	.015	.121
Ethnic 5	8268	.000	1.000	.013	.111
Ethnic 6	8268	.000	1.000	.002	.040
GATE Prog	8268	.000	1.000	.135	.342
Gender	8268	.000	1.000	.509	.500
Grade 2	8268	.000	1.000	.268	.443
Grade 3	8268	.000	1.000	.245	.430
Grade 4	8268	.000	1.000	.250	.433
Lang Prog	8268	.000	1.000	.172	.377
Students per Class	8268	5.000	44.000	23.896	5.886
Tardies	8268	.000	105.000	4.740	8.540
Year Round	8268	.000	1.000	.120	.325
Sch 59	8268	.000	1.000	.032	.176
Sch 60	8268	.000	1.000	.041	.198
Sch 61	8268	.000	1.000	.067	.251
Sch 62	8268	.000	1.000	.043	.204
Sch 64	8268	.000	1.000	.020	.142
Sch 65	8268	.000	1.000	.031	.173
Sch 66	8268	.000	1.000	.032	.176
Sch 67	8268	.000	1.000	.053	.224
Sch 69	8268	.000	1.000	.064	.245
Sch70	8268	.000	1.000	.035	.185
Sch 71	8268	.000	1.000	.034	.180
Sch 72	8268	.000	1.000	.066	.248
Sch 74	8268	.000	1.000	.043	.202
Sch 76	8268	.000	1.000	.046	.210
Sch 77	8268	.000	1.000	.050	.218
Sch 78	8268	.000	1.000	.043	.203
Sch 79	8268	.000	1.000	.041	.198
Sch 81	8268	.000	1.000	.056	.229
Sch 82	8268	.000	1.000	.043	.203
Sch 84	8268	.000	1.000	.029	.169
Sch 85	8268	.000	1.000	.062	.241
Sch 173	8268	.000	1.000	.031	.172
Sch 273	8268	.000	1.000	.024	.152
Math Delta (sp98-fall97)	8150	-29.000	79.000	12.507	7.906
Valid N (listwise)	8150				

Table 4: Capistrano Math Descriptive Statistics

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	3.025	.298		10.153	.000
	Daylight Code	.464	.085	.063	5.473	.000
	Operable Windows	.643	.212	.035	3.041	.002
	GATE prog	-1.452	.257	-.055	-5.628	.000
	Grade 2	10.860	.251	.524	43.324	.000
	Grade 3	4.298	.254	.204	16.890	.000
	Grade 4	.937	.252	.045	3.727	.000
	Lang prog	.838	.239	.035	3.521	.000
	Sch 61	2.195	.370	.061	5.922	.000
	Sch 62	1.584	.477	.035	3.319	.001
	Sch 64	2.517	.638	.039	3.940	.000
	Sch 67	1.359	.416	.033	3.265	.001
	Sch 72	-1.460	.376	-.040	-3.882	.000
	Sch 77	.863	.428	.020	2.011	.044
	Sch 81	.990	.431	.025	2.295	.022
	Sch 82	1.668	.449	.037	3.714	.000
	Sch 85	-1.255	.388	-.033	-3.237	.001
	Sch 173	1.527	.516	.029	2.962	.003
	O17	41.349	7.922	.050	5.220	.000
	O28	-37.469	7.926	-.046	-4.727	.000
	O50	36.543	7.916	.044	4.617	.000
	O58	35.565	7.923	.043	4.489	.000
	O71	40.681	7.925	.049	5.133	.000
	O82	39.651	7.917	.048	5.009	.000

a. Dependent Variable: Reading Delta (sp98-fa97)

Table 5: Capistrano Reading Daylight Model R^2=0.246

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	4.561	.595		7.661	.000
	Window Code	.405	.099	.048	4.087	.000
	Skylight Type A	1.668	.560	.043	2.982	.003
	Skylight Type AA	.443	.513	.009	.861	.388
	Skylight Type B	-1.826	.934	-.040	-1.954	.051
	Operable Windows	.750	.263	.040	2.856	.004
	School pop-per 500	-.636	.292	-.028	-2.175	.030
	GATE prog	-1.489	.258	-.056	-5.757	.000
	Gender	-.292	.176	-.016	-1.663	.096
	Grade 2	10.630	.254	.512	41.781	.000
	Grade 3	4.097	.257	.194	15.968	.000
	Grade 4	.785	.254	.038	3.098	.002
	Lang prog	.896	.244	.037	3.680	.000
	Sch 60	-.911	.482	-.020	-1.891	.059
	Sch 61	2.497	.393	.069	6.342	.000
	Sch 62	1.670	.483	.037	3.456	.001
	Sch 64	2.649	.644	.041	4.105	.000
	Sch 66	1.109	.646	.021	1.714	.087
	Sch 67	1.389	.418	.034	3.319	.001
	Sch 72	-1.195	.453	-.033	-2.642	.008
	Sch 77	.865	.443	.020	1.950	.051
	Sch 81	3.103	.790	.078	3.923	.000
	Sch 82	1.969	.456	.044	4.321	.000
	Sch 85	-1.202	.490	-.032	-2.457	.014
	Sch 173	1.176	.554	.022	2.122	.034
	O17	41.764	7.920	.051	5.273	.000
	O28	-37.713	7.924	-.046	-4.759	.000
	O50	36.169	7.918	.044	4.568	.000
	O58	35.679	7.922	.043	4.504	.000
	O71	40.887	7.923	.050	5.161	.000
	O82	39.552	7.915	.048	4.997	.000

a. Dependent Variable: Reading Delta (sp98-fa97)

Table 6: Capistrano Reading Skylight Model R^2=0.248

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	8.022	.408		19.682	.000
	Daylight Code	.504	.067	.079	7.481	.000
	School Pop-per 500	-.508	.198	-.026	-2.567	.010
	Absences Unverified-per 10	-2.636	1.226	-.021	-2.150	.032
	Absences Unexcused-per 10	-.260	.143	-.018	-1.815	.070
	GATE Prog	-1.237	.223	-.054	-5.546	.000
	Grade 2	9.709	.215	.539	45.129	.000
	Grade 3	5.929	.219	.323	27.084	.000
	Grade 4	1.811	.216	.100	8.373	.000
	Lang Prog	.492	.205	.023	2.406	.016
	Sch 59	-1.090	.435	-.024	-2.505	.012
	Sch 61	.897	.313	.029	2.863	.004
	Sch 62	1.446	.395	.037	3.662	.000
	Sch 67	.837	.355	.024	2.359	.018
	Sch 71	.803	.429	.018	1.873	.061
	Sch 72	-1.614	.321	-.051	-5.026	.000
	Sch 77	1.166	.365	.031	3.197	.001
	Sch 82	1.197	.379	.031	3.159	.002
	O02	-34.466	6.830	-.048	-5.046	.000
	O18	35.115	6.838	.049	5.136	.000
	O32	62.456	6.835	.088	9.137	.000
	O33	34.059	6.838	.048	4.980	.000
	O45	-40.309	6.830	-.056	-5.902	.000
	O48	-46.423	6.831	-.065	-6.796	.000

a. Dependent Variable: Math Delta (sp98-fall97)

Table 7: Capistrano Math Daylight Model R^2=0.256

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	8.621	.429		20.111	.000
	Window Code	.372	.079	.051	4.684	.000
	Skylight Type A	2.556	.469	.077	5.449	.000
	Operable Windows	.835	.192	.051	4.338	.000
	School Pop-per 500	-.601	.210	-.030	-2.828	.005
	Absences Unverified-per 10	-2.534	1.234	-.020	-2.057	.040
	Absences Unexcused-per 10	-.292	.143	-.020	-2.032	.042
	GATE Prog	-1.235	.223	-.054	-5.533	.000
	Grade 2	9.611	.216	.533	44.482	.000
	Grade 3	5.837	.220	.318	26.557	.000
	Grade 4	1.804	.217	.099	8.290	.000
	Lang Prog	.513	.217	.025	2.385	.017
	Sch 59	-1.898	.439	-.043	-4.323	.000
	Sch 60	-2.347	.407	-.059	-5.765	.000
	Sch 62	1.312	.407	.033	3.214	.001
	Sch70	-1.265	.458	-.030	-2.773	.006
	Sch 72	-2.383	.372	-.075	-6.404	.000
	Sch 74	-.851	.388	-.022	-2.194	.028
	Sch 82	1.207	.387	.031	3.110	.002
	Sch 85	-1.089	.409	-.033	-2.665	.008
	O02	-33.927	6.832	-.048	-4.965	.000
	O18	35.609	6.824	.050	5.218	.000
	O32	61.504	6.833	.086	9.001	.000
	O33	34.274	6.833	.048	5.015	.000
	O45	-40.338	6.823	-.057	-5.912	.000
	O48	-45.852	6.833	-.064	-6.710	.000

a. Dependent Variable: Math Delta (sp98-fall97)

Table 8: Capistrano Math Skylight Model R^2=0.258

Variable	B	Order of Entry	Change in R^2
Grade 2	10.860	1	0.184
Grade 3	4.298	2	0.026
Sch 61	2.195	3	0.006
GATE prog	-1.452	4	0.004
71	40.680	5	0.003
17	41.348	6	0.002
82	39.650	7	0.002
Sch 64	2.517	8	0.002
28	-37.470	9	0.002
50	36.543	10	0.002
58	35.564	11	0.002
Daylight Code	0.464	12	0.001
Sch 72	-1.460	13	0.002
Sch 85	-1.254	14	0.002
Grade 4	0.937	15	0.001
Lang prog	0.838	16	0.001
Sch 82	1.668	17	0.001
Sch 173	1.528	18	0.000
Sch 67	1.359	19	0.000
Sch 62	1.584	20	0.000
Operable Windows	0.643	21	0.001
Sch 81	0.990	22	0.000
Sch 77	0.863	23	0.000
(Constant)	3.025		
		Model R^2	**0.246**

a. Dependent Variable: Reading Delta (sp98-fa97)

Table 9: Capistrano Reading Daylight Order

Variable	B	Order of Entry	Change in R^2
Grade 2	10.629	1	0.184
Grade 3	4.097	2	0.026
Sch 61	2.497	3	0.006
GATE prog	-1.489	4	0.004
71	40.886	5	0.003
17	41.763	6	0.002
82	39.551	7	0.002
Sch 64	2.649	8	0.002
28	-37.714	9	0.002
50	36.169	10	0.002
58	35.678	11	0.002
Window Code	0.405	12	0.002
Lang prog	0.896	13	0.001
Sch 81	3.103	14	0.001
Sch 82	1.969	15	0.001
Grade 4	0.785	16	0.001
Skylight Type B	-1.826	17	0.001
School pop-per 500	-0.637	18	0.001
Sch 66	1.109	19	0.001
Sch 67	1.389	20	0.001
SCH 68	0.865	21	0.001
Sch 62	1.670	22	0.001
Sch 173	1.176	23	0.000
Skylight Type AA	0.443	24	0.000
Gender	-0.292	25	0.000
Sch 60	-0.911	26	0.000
Operable Windows	0.750	27	0.000
Skylight Type A	1.668	28	0.000
Sch 72	-1.195	29	0.000
Sch 85	-1.202	30	0.001
(Constant)	4.561		
		Model R^2	**0.248**

a. Dependent Variable: Reading Delta (sp98-fa97)

Table 10: Capistrano Reading Skylight Order

Variable	B	**Order of Entry**	**Change in R^2**
Grade 2	9.741	1	0.149
Grade 3	5.929	2	0.064
32	62.456	3	0.007
Grade 4	1.811	4	0.006
48	-46.423	5	0.004
GATE prog	-1.237	6	0.003
45	-40.309	7	0.003
Daylight Code	0.504	8	0.003
Sch 72	-1.614	9	0.003
18	35.115	10	0.002
02	-34.466	11	0.002
33	34.059	12	0.002
Sch 59	-1.090	13	0.001
Absences Unverified-per 10	-2.636	14	0.001
Sch 62	1.446	15	0.001
Sch 77	1.166	16	0.001
Sch 82	1.197	17	0.001
Sch 61	0.897	18	0.000
School pop-per 500	-0.508	19	0.001
Lang prog	0.492	20	0.001
Sch 67	0.837	21	0.000
Sch 71	0.803	22	0.000
Absences Unexcused-per 10	-0.260	23	0.000
Operable Windows	0.249	24	0.000
(Constant)	8.022		
		Model R^2	**0.257**

a. Dependent Variable: MATHDELT

Table 11: Capistrano Math Daylight Order

Variable	B	Order of Entry	Change in R^2
Grade 2	9.611	1	0.149
Grade 3	5.837	2	0.064
32	61.504	3	0.007
Grade 4	1.804	4	0.006
48	-45.852	5	0.004
GATE prog	-1.235	6	0.003
45	-40.338	7	0.003
02	-33.927	8	0.002
18	35.609	9	0.002
Sch 72	-2.383	10	0.002
33	34.274	11	0.002
Window Code	0.372	12	0.001
Sch 60	-2.347	13	0.002
Sch 59	-1.898	14	0.001
Skylight Type A	2.556	15	0.001
School pop-per 500	-0.601	16	0.001
Absences Unverified-per 10	-2.534	17	0.001
Sch 74	-0.851	18	0.001
Operable Windows	0.835	19	0.001
Sch 62	1.312	20	0.001
Sch 82	1.207	21	0.001
Sch 85	-1.089	22	0.001
Absences Unexcused-per 10	-0.292	23	0.000
Sch 70	-1.265	24	0.000
Lang Prog	0.513	25	0.001
(Constant)	8.621		
		Model R^2	**0.258**

a. Dependent Variable: MATHDELT

Table 12: Capistrano Math Skylight Order

6.1.2 Seattle School District Tabular Results

Seattle Conversions	Reading	Math
Low score	1	1
High score	99	99
Range	98	98
Scalar to 1-99 scale	1	1
District Mean	57.35	58.82
Daylight Code Ranges	B-coefficient multiplier	
Daylight 1-5	4	4
Window 1-4.5	3.5	3.5
Skylight 0-4.5	4.5	4.5

Table 13: Seattle Conversion Factors

Window Code	Count Of Students	Daylight Code	Count Of Students	Skylight Code	Count Of Students
1.00	419	1.00	369	.00	7089
1.50	70	1.50	70	1.50	8
2.00	599	2.00	599	2.00	20
2.50	235	2.50	285	2.50	50
3.00	4674	3.00	4334	3.00	278
3.50	146	3.50	146	3.50	145
4.00	1363	4.00	1272	No Category	27
4.50	84	4.50	84		
No Category	27	5.00	431		
		No Category	27		
Grand Total	7617	Grand Total	7617	Grand Total	7617

Table 14: Count of Students by Daylight Code, Seattle

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Daylight Code	7590	1.000	5.000	3.053	.752
Window Code	7590	1.000	4.500	2.989	.734
Skylight Code	7590	.000	4.500	.212	.806
Class SF	7617	638.000	3616.000	1110.707	688.906
Open rm	7617	.000	1.000	.104	.306
Portable	7617	.000	1.000	.030	.171
School pop-per 500	7617	.088	.616	.381	.115
Vintage	7617	7.000	92.000	39.812	26.370
Econ 2	7617	.000	1.000	.405	.491
Ethnic 1	7617	.000	1.000	.066	.249
Ethnic 2	7617	.000	1.000	.214	.410
Ethnic 3	7617	.000	1.000	.021	.144
Ethnic 4	7617	.000	1.000	.227	.419
Gender	7614	.000	1.000	.512	.500
Gifted room (70%+)	7617	.000	1.000	.049	.216
Grade 2	7617	.000	1.000	.214	.410
Grade 3	7617	.000	1.000	.269	.444
Grade 4	7617	.000	1.000	.248	.432
Socio 1	7617	.000	1.000	.030	.172
Socio 2	7617	.000	1.000	.043	.202
Socio 3	7617	.000	1.000	.288	.453
Students per Class	7600	5.000	80.000	24.025	13.238
Reading NCE 98	7538	1.000	99.000	57.350	19.518
Valid N (listwise)	7491				

Table 15: Seattle Reading Descriptive Statistics

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Daylight Code	7590	1.000	5.000	3.053	.752
Window Code	7590	1.000	4.500	2.989	.734
Skylight Code	7590	.000	4.500	.212	.806
Class SF	7617	638.000	3616.000	1110.707	688.906
Open room	7617	.000	1.000	.104	.306
Portable	7617	.000	1.000	.030	.171
School pop-per 500	7617	.088	.616	.381	.115
Vintage	7617	7.000	92.000	39.812	26.370
Econ 2	7617	.000	1.000	.405	.491
Ethnic 1	7617	.000	1.000	.066	.249
Ethnic 2	7617	.000	1.000	.214	.410
Ethnic 3	7617	.000	1.000	.021	.144
Ethnic 4	7617	.000	1.000	.227	.419
Gender	7614	.000	1.000	.512	.500
Gifted room (70%+)	7617	.000	1.000	.049	.216
Grade 2	7617	.000	1.000	.214	.410
Grade 3	7617	.000	1.000	.269	.444
Grade 4	7617	.000	1.000	.248	.432
Socio 1	7617	.000	1.000	.030	.172
Socio 2	7617	.000	1.000	.043	.202
Socio 3	7617	.000	1.000	.288	.453
Students per Class	7600	5.000	80.000	24.025	13.238
Math NCE 98	7422	1.000	99.000	58.820	19.467
Valid N (listwise)	7379				

Table 16: Seattle Math Descriptive Statistics

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	54.667	1.726		31.672	.000
	Daylight Code	1.883	.342	.073	5.509	.000
	Class SF	-.002	.000	-.054	-3.427	.001
	Portable	-2.123	1.121	-.019	-1.893	.058
	School pop-per 500	6.662	1.762	.039	3.782	.000
	Econ 2	-8.675	.475	-.218	-18.253	.000
	Ethnic 1	-7.766	.797	-.099	-9.743	.000
	Ethnic 2	-8.461	.522	-.178	-16.214	.000
	Ethnic 3	-6.559	1.336	-.049	-4.908	.000
	Ethnic 4	-11.168	.557	-.238	-20.047	.000
	Gender	.912	.380	.023	2.398	.016
	Gifted room (70%+)	15.342	.894	.171	17.162	.000
	Grade 2	6.957	.596	.146	11.670	.000
	Grade 3	-2.074	.523	-.047	-3.966	.000
	Grade 4	.949	.529	.021	1.794	.073
	Socio 1	-4.481	1.131	-.039	-3.962	.000
	Socio 2	-3.182	1.011	-.033	-3.148	.002
	Socio 3	-2.618	.480	-.061	-5.449	.000
	Students per Class	.137	.025	.094	5.559	.000
	O07	-70.231	16.408	-.042	-4.280	.000
	O21	-65.215	16.413	-.039	-3.973	.000
	O26	-65.414	16.407	-.039	-3.987	.000
	O64	-67.927	16.409	-.040	-4.140	.000
	O73	-71.141	16.408	-.042	-4.336	.000

a. Dependent Variable: Reading NCE 98

Table 17: Seattle Reading Daylight Model R^2=0.297

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	52.910	1.828		28.938	.000
	Window Code	2.206	.374	.083	5.907	.000
	Skylight Code	.873	.239	.036	3.660	.000
	Class SF	-.001	.000	-.045	-2.731	.006
	Portable	-1.932	1.120	-.017	-1.724	.085
	School pop-per 500	7.268	1.766	.043	4.115	.000
	Econ 2	-8.657	.475	-.217	-18.242	.000
	Ethnic 2	-8.487	.521	-.179	-16.299	.000
	Ethnic 4	-11.167	.556	-.238	-20.090	.000
	Ethnic 1	-7.755	.796	-.099	-9.748	.000
	Ethnic 3	-6.570	1.334	-.049	-4.925	.000
	Gender	.919	.379	.024	2.422	.015
	Gifted room (70%+)	15.255	.899	.170	16.961	.000
	Grade 2	7.124	.597	.150	11.926	.000
	Grade 3	-1.991	.523	-.045	-3.809	.000
	Grade 4	.985	.528	.022	1.865	.062
	Socio 1	-4.358	1.129	-.038	-3.859	.000
	Socio 2	-3.051	1.009	-.031	-3.023	.003
	Socio 3	-2.543	.480	-.059	-5.303	.000
	Students per Class	.141	.024	.096	5.774	.000
	O07	-70.071	16.377	-.041	-4.279	.000
	O21	-65.146	16.382	-.039	-3.977	.000
	O26	-65.407	16.376	-.039	-3.994	.000
	O64	-67.774	16.377	-.040	-4.138	.000
	O73	-71.044	16.377	-.042	-4.338	.000
	O87	-63.627	16.380	-.038	-3.884	.000

a. Dependent Variable: Reading NCE 98

Table 18: Seattle Reading Skylight Model R^2=0.300

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	55.653	1.841		30.235	.000
	Daylight Code	1.391	.436	.054	3.190	.001
	Class SF	-.001	.001	-.037	-1.860	.063
	Open room	3.506	1.579	.056	2.220	.026
	Portable	-3.058	1.171	-.027	-2.611	.009
	School pop-per 500	11.522	2.065	.068	5.578	.000
	Vintage	.017	.010	.023	1.654	.098
	Econ 2	-5.790	.475	-.146	-12.193	.000
	Ethnic 1	-5.477	.803	-.070	-6.823	.000
	Ethnic 3	-6.978	1.381	-.051	-5.053	.000
	Ethnic 4	-11.452	.538	-.244	-21.272	.000
	Gender	-3.017	.392	-.077	-7.697	.000
	Gifted room (70%+)	16.394	.931	.185	17.614	.000
	Grade 2	6.104	.577	.129	10.571	.000
	Grade 3	-3.388	.477	-.077	-7.108	.000
	Socio 1	-4.339	1.167	-.038	-3.717	.000
	Socio 2	-4.691	1.057	-.048	-4.437	.000
	Socio 3	-3.107	.494	-.072	-6.291	.000
	Students per Class	.066	.033	.046	2.012	.044
	O06	54.400	16.802	.033	3.238	.001
	O23	58.049	16.824	.035	3.450	.001
	O43	-64.973	16.814	-.039	-3.864	.000

a. Dependent Variable: Math NCE 98

Table 19: Seattle Math Daylight Model R^2=0.258

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	51.877	1.751		29.620	.000
	Window Code	2.474	.376	.094	6.585	.000
	Skylight Code	.762	.245	.032	3.105	.002
	Open room	2.918	1.333	.046	2.188	.029
	Portable	-2.394	1.153	-.021	-2.076	.038
	School pop-per 500	10.869	1.904	.064	5.708	.000
	Econ 2	-5.793	.473	-.146	-12.242	.000
	Ethnic 1	-5.443	.801	-.070	-6.799	.000
	Ethnic 3	-6.991	1.378	-.051	-5.075	.000
	Ethnic 4	-11.526	.536	-.246	-21.489	.000
	Gender	-3.027	.391	-.078	-7.739	.000
	Gifted room (70%+)	16.384	.937	.185	17.484	.000
	Grade 2	6.305	.573	.133	11.012	.000
	Grade 3	-3.299	.475	-.075	-6.939	.000
	Socio 1	-4.223	1.165	-.037	-3.627	.000
	Socio 2	-4.562	1.054	-.046	-4.327	.000
	Socio 3	-3.062	.493	-.071	-6.212	.000
	Students per Class	.074	.032	.051	2.347	.019
	O06	54.540	16.762	.033	3.254	.001
	O23	56.990	16.802	.034	3.392	.001
	O32	55.008	16.761	.033	3.282	.001
	O43	-65.073	16.773	-.039	-3.880	.000
	O88	53.850	16.757	.032	3.214	.001

a. Dependent Variable: Math NCE 98

Table 20: Seattle Math Skylight Model R^2=0.262

VARIABLE:	B	Order of Entry	Change in R^2
Econ 2	-8.675	1	0.165
Gifted room (70%+)	15.342	2	0.035
Ethnic 4	-11.168	3	0.024
Ethnic 2	-8.461	4	0.021
Grade 2	6.957	5	0.017
Ethnic 1	-7.766	6	0.008
Grade 3	-2.074	7	0.004
Ethnic 3	-6.559	8	0.003
Students pop-per 500	6.662	9	0.002
Daylight Code	1.883	10	0.003
Students per Class	0.137	11	0.002
Socio 3	-2.618	12	0.002
73	-71.141	13	0.002
07	-70.231	14	0.002
64	-67.927	15	0.002
21	-65.215	16	0.002
26	-65.414	17	0.001
Socio 1	-4.481	18	0.001
Class SF	-0.002	19	0.001
Socio 2	-3.182	20	0.001
Gender	0.912	21	0.001
Portable	-2.123	22	0.000
Grade 4	0.949	23	0.000
(Constant)	54.667		
		Model R^2	**0.297**

a. Dependent Variable: Reading NCE 98

Table 21: Seattle Reading Daylight Order

VARIABLE	B	Order of Entry	Change in R^2
Econ 2	-8.657	1	0.165
Gifted room (70%+)	15.255	2	0.035
Ethnic 4	-11.167	3	0.024
Ethnic 2	-8.487	4	0.021
Grade 2	7.124	5	0.017
Ethnic 1	-7.755	6	0.008
Grade 3	-1.991	7	0.004
Ethnic 3	-6.570	8	0.003
Window Code	2.206	9	0.002
Students per Class	0.141	10	0.003
Students pop-per 500	7.268	11	0.002
Socio 3	-2.543	12	0.002
73	-71.044	13	0.002
07	-70.071	14	0.002
64	-67.774	15	0.002
21	-65.146	16	0.002
26	-65.407	17	0.002
87	-63.627	18	0.001
Skylight Code	0.873	19	0.001
Socio 1	-4.358	20	0.001
Socio 2	-3.051	21	0.001
Class SF	-0.001	22	0.001
Gender	0.919	23	0.001
Grade 4	0.985	24	0.000
Portable	-1.932	25	0.000
(Constant)	52.910		
		Model R^2	**0.300**

a. Dependent Variable: Reading NCE 98

Table 22: Seattle Reading Skylight Order

Variable	B	Order of Entry	Change in R^2
Ethnic 4	-11.452	1	0.117
Gifted room (70%+)	16.394	2	0.048
Econ 2	-5.790	3	0.037
Grade 2	6.104	4	0.020
Gender	-3.017	5	0.005
Grade 3	-3.388	6	0.005
Ethnic 1	-5.477	7	0.004
Students pop-per 500	11.522	8	0.004
Ethnic 3	-6.978	9	0.003
Socio 3	-3.107	10	0.002
Socio 2	-4.691	11	0.002
Socio 1	-4.339	12	0.001
43	-64.973	13	0.001
23	58.049	14	0.001
Vintage	0.017	15	0.001
Open room	3.506	16	0.001
Daylight Code	1.391	17	0.001
06	54.400	18	0.001
Portable	-3.058	19	0.001
Students per Class	0.066	20	0.000
Class SF	-0.001	21	0.000
(Constant)	55.653		
		Model R^2	**0.258**

a. Dependent Variable: Math NCE 98

Table 23: Seattle Math Daylight Order

Variable	B	Order of Entry	Change in R^2
Ethnic 4	-11.526	1	0.117
Gifted room (70%+)	16.384	2	0.048
Econ 2	-5.793	3	0.037
Grade 2	6.305	4	0.020
Gender	-3.027	5	0.005
Grade 3	-3.299	6	0.005
Ethnic 1	-5.443	7	0.004
Students pop-per 500	10.869	8	0.004
Ethnic 3	-6.991	9	0.003
Socio 3	-3.062	10	0.002
Socio 2	-4.562	11	0.002
Socio 1	-4.223	12	0.001
43	-65.073	13	0.001
23	56.990	14	0.001
32	55.008	15	0.001
88	53.850	16	0.001
06	54.540	17	0.001
Skylight Code	0.762	18	0.001
Window Code	2.474	19	0.001
Open room	2.918	20	0.004
Students per Class	0.074	21	0.001
Portable	-2.394	22	0.000
(Constant)	51.877		
		Model R^2	**0.262**

a. Dependent Variable: Math NCE 98

Table 24: Seattle Math Skylight Order

6.1.3 Fort Collins School District Tabular Results

Fort Collins Conversions	**reading**	**math**
High score	257	280
Low score	153	153
Range	104	127
Scalar to 1-99 scale	0.94	0.77
District Mean	213.39	219.41
Min to Mean	60.39	66.41
Normalized Mean	56.91	51.24
Daylight Code Ranges	B-coefficient multiplier	
Daylight 1-5	4	4
Window 0-3	3	3
Skylight yes-no	1	1

Table 25: Fort Collins Conversion Factors

Window Code	Number of Students	Daylight Code	Number of Students	Skylight Code	Number of Students
1	2092	1	2092	0	4027
2	3652	2	1106	1	2239
3	522	3	829		
		5	2239		
Grand Total	6266	Grand Total	6266	Grand Total	6266

Table 26: Count of Students by Daylight Code, Fort Collins

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Daylight Code	5204	1.000	5.000	2.893	1.715
Window Code	5204	1.000	3.000	1.752	.592
Skylight Code (0,1)	5204	.000	1.000	.364	.481
Open Rm	5204	.000	1.000	.314	.464
School Pop-per 500	5204	.233	.779	.603	.125
Vintage	5204	5.000	62.000	24.315	14.478
Econ 1	5204	.000	1.000	.146	.353
Econ 2	5204	.000	1.000	.061	.239
Ethnic 1	5204	.000	1.000	.091	.288
Ethnic 2	5204	.000	1.000	.028	.166
Ethnic 3	5204	.000	1.000	.008	.091
Ethnic 4	5204	.000	1.000	.012	.110
Gender	5204	.000	1.000	.527	.499
Grade 3	5204	.000	1.000	.226	.418
Grade 4	5204	.000	1.000	.244	.429
Grade 5	5204	.000	1.000	.261	.439
Lang Prog	5204	.000	1.000	.094	.292
Socio 1	5204	.000	1.000	.033	.179
Socio 2	5204	.000	1.000	.012	.107
Socio 3	5204	.000	1.000	.192	.394
Reading RIT	5203	153.000	257.000	213.390	13.708
Valid N (listwise)	5203				

Table 27: Fort Collins Reading Descriptive Statistics

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Daylight Code	5688	1.000	5.000	2.802	1.708
Window Code	5688	1.000	3.000	1.727	.596
Skylight Code (0,1)	5688	.000	1.000	.342	.475
Open rm	5688	.000	1.000	.335	.472
School Pop-per 500 students	5688	.233	.779	.609	.124
Vintage	5688	5.000	62.000	25.040	14.783
Econ 1	5688	.000	1.000	.150	.357
Econ 2	5688	.000	1.000	.062	.241
Ethnic 1	5688	.000	1.000	.091	.288
Ethnic 2	5688	.000	1.000	.027	.161
Ethnic 3	5688	.000	1.000	.009	.093
Ethnic 4	5688	.000	1.000	.012	.111
Gender	5688	.000	1.000	.521	.500
Grade 3	5688	.000	1.000	.233	.423
Grade 4	5688	.000	1.000	.254	.435
Grade 5	5688	.000	1.000	.256	.436
Lang prog	5688	.000	1.000	.094	.291
Socio 1	5688	.000	1.000	.034	.181
Socio 2	5688	.000	1.000	.013	.112
Socio 3	5688	.000	1.000	.195	.396
Math RIT	5687	153.000	280.000	219.406	15.481
Valid N (listwise)	5687				

Table 28: Fort Collins Math Descriptive Statistics

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	222.462	.908		244.989	.000
	Daylight Code	.996	.148	.125	6.736	.000
	Open Rm	2.911	.544	.099	5.348	.000
	School Pop-per 500	-4.532	1.420	-.041	-3.192	.001
	Econ 1	-7.070	.470	-.182	-15.046	.000
	Econ 2	-4.823	.648	-.084	-7.440	.000
	Ethnic 1	-5.515	.587	-.116	-9.400	.000
	Ethnic 3	-5.171	1.682	-.034	-3.075	.002
	Ethnic 4	-2.769	1.382	-.022	-2.003	.045
	Gender	.918	.304	.033	3.016	.003
	Grade 3	-18.728	.434	-.572	-43.115	.000
	Grade 4	-11.864	.426	-.372	-27.875	.000
	Grade 5	-4.555	.417	-.146	-10.925	.000
	Lang Prog	-1.846	.565	-.039	-3.268	.001
	Socio 1	-2.877	.851	-.038	-3.379	.001
	Socio 2	-3.354	1.426	-.026	-2.352	.019
	O07	-52.627	10.933	-.053	-4.813	.000
	O26	-62.162	10.951	-.063	-5.676	.000
	O38	-57.764	10.948	-.058	-5.276	.000
	O55	-56.895	10.948	-.058	-5.197	.000
	O84	-51.415	10.934	-.052	-4.702	.000
	O88	-52.769	10.944	-.053	-4.822	.000
	O91	-49.545	10.933	-.050	-4.532	.000
	O107	-64.113	10.934	-.065	-5.864	.000

a. Dependent Variable: Reading RIT

Table 29: Fort Collins Reading Daylight Model R^2=0.368

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	218.087	1.121		194.565	.000
	Window Code	3.612	.556	.156	6.493	.000
	Open Rm	4.043	.695	.137	5.817	.000
	Vintage	-.087	.012	-.092	-7.510	.000
	Econ 1	-6.985	.459	-.180	-15.213	.000
	Econ 2	-4.828	.645	-.084	-7.485	.000
	Ethnic 1	-5.282	.584	-.111	-9.050	.000
	Ethnic 3	-5.334	1.678	-.035	-3.179	.001
	Ethnic 4	-2.839	1.378	-.023	-2.060	.039
	Gender	.935	.304	.034	3.080	.002
	Grade 3	-18.947	.435	-.578	-43.513	.000
	Grade 4	-11.977	.426	-.375	-28.113	.000
	Grade 5	-4.532	.416	-.145	-10.896	.000
	Lang Prog	-2.044	.565	-.044	-3.620	.000
	Socio 1	-2.770	.848	-.036	-3.265	.001
	Socio 2	-3.246	1.422	-.025	-2.282	.023
	O07	-52.811	10.907	-.053	-4.842	.000
	O107	-63.946	10.907	-.065	-5.863	.000
	O26	-63.875	10.933	-.065	-5.843	.000
	O38	-58.613	10.928	-.059	-5.364	.000
	O55	-58.245	10.926	-.059	-5.331	.000
	O84	-51.598	10.907	-.052	-4.731	.000
	O88	-51.613	10.915	-.052	-4.729	.000
	O91	-49.746	10.907	-.050	-4.561	.000

a. Dependent Variable: Reading RIT

Table 30: Fort Collins Reading Skylight Model R^2=0.371

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	233.088	.928		251.288	.000
	Daylight Code	1.112	.151	.123	7.350	.000
	Open rm	3.955	.552	.121	7.172	.000
	School Pop-per 500	-5.288	1.451	-.042	-3.645	.000
	Econ 1	-6.534	.499	-.151	-13.107	.000
	Econ 2	-3.328	.658	-.052	-5.058	.000
	Ethnic 1	-6.172	.562	-.115	-10.987	.000
	Ethnic 2	3.650	.966	.038	3.778	.000
	Ethnic 3	-5.346	1.660	-.032	-3.220	.001
	Ethnic 4	-4.725	1.393	-.034	-3.392	.001
	Gender	-1.755	.309	-.057	-5.679	.000
	Grade 3	-24.269	.441	-.664	-55.009	.000
	Grade 4	-16.537	.432	-.465	-38.324	.000
	Grade 5	-7.511	.431	-.212	-17.440	.000
	Socio 1	-4.122	.864	-.048	-4.771	.000
	Socio 2	-6.566	1.391	-.047	-4.721	.000
	Socio 3	-1.329	.424	-.034	-3.132	.002
	O08	42.142	11.615	.036	3.628	.000
	O09	-42.790	11.630	-.037	-3.679	.000
	O25	44.084	11.653	.038	3.783	.000
	O30	45.724	11.615	.039	3.936	.000
	O53	49.234	11.615	.042	4.239	.000
	O60	44.951	11.615	.039	3.870	.000
	O72	47.595	11.653	.041	4.084	.000
	O95	-54.002	11.616	-.046	-4.649	.000
	O195	44.247	11.613	.038	3.810	.000

a. Dependent Variable: Math RIT

Table 31: Fort Collins Math Daylight Model R^2=0.439

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	229.594	1.690		135.883	.000
	Skylight Code (0,1)	2.082	.710	.064	2.935	.003
	Window Code	3.043	.597	.117	5.095	.000
	Open rm	5.182	.764	.158	6.800	.000
	School Pop-per 500 students	-3.048	1.580	-.025	-1.946	.052
	Vintage	-.037	.019	-.035	-1.962	.050
	Econ 1	-6.547	.502	-.151	-13.081	.000
	Econ 2	-3.320	.663	-.052	-5.030	.000
	Ethnic 1	-6.211	.565	-.116	-11.010	.000
	Ethnic 2	3.617	.972	.038	3.726	.000
	Ethnic 3	-5.465	1.671	-.033	-3.276	.001
	Ethnic 4	-4.873	1.402	-.035	-3.483	.001
	Gender	-1.799	.311	-.058	-5.757	.000
	Grade 3	-24.525	.445	-.670	-55.112	.000
	Grade 4	-16.752	.436	-.471	-38.481	.000
	Grade 5	-7.563	.433	-.213	-17.432	.000
	Socio 1	-4.113	.869	-.048	-4.731	.000
	Socio 2	-6.502	1.400	-.047	-4.644	.000
	Socio 3	-1.462	.427	-.037	-3.424	.001
	O29	-69.629	11.689	-.060	-5.964	.000
	O53	47.883	11.699	.041	4.099	.000
	O72	47.311	11.728	.041	4.038	.000
	O95	-55.410	11.698	-.047	-4.739	.000

a. Dependent Variable: Math RIT

Table 32: Fort Collins Math Skylight Model R^2=0.434

Variable	B	Order of Entry	Change in R^2
Grade 3	-18.728	1	0.162
Grade 4	-11.864	2	0.081
Econ 1	-7.070	3	0.047
Ethnic 1	-5.515	4	0.017
Grade 5	-4.555	5	0.014
Students pop-per 500	-4.532	6	0.008
Econ 2	-4.823	6	0.008
107	-64.113	7	0.004
26	-62.162	8	0.004
38	-57.764	9	0.004
55	-56.895	10	0.004
84	-51.415	11	0.003
07	-52.627	12	0.003
88	-52.769	13	0.003
91	-49.545	14	0.002
Daylight Code	0.996	15	0.002
Open Room	2.911	16	0.002
Ethnic 3	-5.171	17	0.001
Lang prog	-1.846	18	0.001
Socio 1	-2.877	19	0.001
Gender	0.918	21	0.001
Socio 2	-3.354	22	0.001
Ethnic 4	-2.769	23	0.000
(Constant)	222.462	.	.
		Model R^2	**0.374**

a. Dependent Variable: Reading RIT

Table 33: Fort Collins Reading Daylight Order

Variable	B	Order of Entry	Change in R^2
Grade 3	-18.947	1	0.162
Grade 4	-11.977	2	0.081
Econ 1	-6.985	3	0.047
Ethnic 1	-5.282	4	0.017
Grade 5	-4.532	5	0.014
Econ 2	-4.828	6	0.008
107	-63.946	7	0.004
26	-63.875	8	0.004
Vintage	-0.087	9	0.004
38	-58.613	10	0.003
55	-58.245	11	0.003
07	-52.811	12	0.003
84	-51.598	13	0.003
88	-51.613	14	0.003
91	-49.746	15	0.002
Ethnic 3	-5.334	16	0.001
Socio 1	-2.770	17	0.001
Lang prog	-2.044	18	0.001
Gender	0.935	19	0.001
Window Code	3.612	20	0.001
Open Room	4.043	21	0.004
Socio 2	-3.246	22	0.001
Ethnic 4	-2.839	23	0.001
(Constant)	218.087		
		Model R^2	**0.371**

a. Dependent Variable: Reading RIT

Table 34: Fort Collins Reading Skylight Order

Variable	B	**Order of Entry**	**Change in R^2**
Grade 3	-24.269	1	0.200
Grade 4	-16.537	2	0.118
Econ 1	-6.534	3	0.041
Grade 5	-7.511	4	0.029
Ethnic 1	-6.172	5	0.014
Econ 2	-3.328	6	0.004
Gender	-1.755	7	0.003
Ethnic 2	3.650	8	0.003
95	-54.002	9	0.002
Socio 2	-6.566	10	0.002
Socio 1	-4.122	11	0.002
53	49.234	12	0.002
30	45.724	13	0.002
95	44.247	14	0.002
72	47.595	15	0.001
08	42.142	16	0.001
60	44.951	17	0.001
09	-42.790	18	0.001
25	44.084	19	0.001
Ethnic 3	-5.346	20	0.001
Ethnic 4	-4.725	21	0.001
Socio 3	-1.329	22	0.001
Daylight Code	1.112	23	0.001
Open Room	3.955	24	0.004
School pop-per 500	-5.288	25	0.001
(Constant)	233.088		
		Model R^2	**0.439**

a. Dependent Variable: Math RIT

Table 35: Fort Collins Math Daylight Order

Variable	B	Order of Entry	Change in R^2
Grade 3	-24.525	1	0.199
Grade 4	-16.752	2	0.117
Econ 1	-6.547	3	0.041
Grade 5	-7.563	4	0.029
Ethnic 1	-6.211	5	0.014
Econ 2	-3.320	6	0.004
29	-69.629	7	0.004
Gender	-1.799	8	0.003
Ethnic 2	3.617	9	0.003
Vintage	-0.037	10	0.003
95	-55.410	11	0.002
53	47.883	12	0.002
Socio 2	-6.502	13	0.002
Socio 1	-4.113	14	0.002
72	47.311	15	0.002
Socio 3	-1.462	16	0.001
Ethnic 4	-4.873	17	0.001
Ethnic 3	-5.465	18	0.001
Open Room	5.182	19	0.000
Window Code	3.043	20	0.004
Skylight Code (0,1)	2.082	21	0.001
School pop-per 500	-3.048	22	0.000
(Constant)	229.594		.
		Model R^2	**0.434**

a. Dependent Variable: Math RIT

Table 36: Fort Collins Math Skylight Order

6.2 Report on Classroom-level Analysis for Capistrano

This memo reports the added classroom level analysis, as suggested by Bob Clear at the LBNL review on June 3rd. The main results are the classroom-level analysis of the math and reading skylighting models for Capistrano schools. The correlations between the skylight, window and daylighting variables relative to grade level are also reported.

Summary of Classroom-Level Models

The following table compares the results of the classroom level analysis with the original student level analysis. The table shows the regression output for the Skylight Type A explanatory variable for the math and reading models.

Math	B	Std Err	t	Sig
Student Level	2.556	0.469	5.449	0.000
Class Level	2.451	0.830	2.953	0.003
Reading	B	Std Err	t	Sig
Student Level	1.668	0.560	2.979	0.003
Class Level	1.932	0.728	2.655	0.008

Appendix Figure 1: Classroom vs. Student Level Results

The following points are important:

- The coefficient remained stable. The math coefficient dropped slightly but the reading coefficient rose a fair amount. Neither change was statistically significant.
- The standard errors increased as we expected.
- The t-statistics fell and the significance levels became somewhat poorer. But both variables are still highly significant.

As might be expected, the R-square statistic was much higher at the class level. The math model explained 67% of the variance at the class level. The reading model explained 47% of the variance at the class level. This illustrates the fact that the R-square statistic is strongly affected by the level of aggregation.

We did not repeat the analysis of the daylight models but we would expect the results to be similar.

In developing the classroom analysis, we estimated the components of variance associated with common classroom factors and student-specific factors.

In the case of math performance, the classroom component of the variance was about 20% of the total variance, while the student component of the variance was about 80%. In the case of the reading model, we found no classroom component of variance. We may postulate that the classroom effects are associated with differences between teachers. In this case, these results suggest that teachers are equally good at teaching reading but vary in their ability to teach math. More details are in the section on methodology that follows.

Correlations with Grade

We also calculated the Pearson correlation coefficients between student grade and the various skylighting and daylighting variables used in the models. We did this analysis at the student level. The table below shows the results. The correlations range from 0.01 to 0.06, on a potential scale of 0.0 to 1.0, i.e. they are all quite small. Some of the correlations are statistically significant, but this must be qualified by two observations. First, as usual, the sample size is very large, 8,268 students, increasing the probability for achieving statistical significance even for very small effects. Second, the skylighting variables are indicator variables so they do not satisfy the usual assumptions behind the Pearson test of significance.

It should be noted that our models did include indicator variables for grade so the models adjust for the correlation between grade and skylighting or daylighting. While we could attempt to estimate a model with interaction between these variables, we doubt that the sample would support the analysis.

Skylight Type AA	-0.035
Skylight Type A	-0.059
Skylight Type B	0.034
Skylight Type C	0.016
Skylight Type D	-0.013
Daylight_revised	0.047
Window_revised	-0.022

Appendix Figure 2: Skylight Model Pearson Correlations

Math Skylight Model – Class Level

The following table shows the full class-level model for math performance. The original student-level model was shown in Table 8 of the appendix to the report. With the exception of the indicators for the outliers, we have used exactly the same explanatory variables as the original student-level model so that the two models can be directly compared. The coefficients (B) are generally very similar as one would expect. Also, as expected, the significance levels (sig.) are generally numerically larger. In fact several of the explanatory variables are no longer significant and could be dropped from the model. Of course this would not change the main conclusion that the Type A skylighting variable remains highly significant with this classroom-level of analysis.

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	8.019	.888		9.027	.000
	Window Code	.399	.136	.103	2.943	.003
	Skylight Type A	2.451	.830	.133	2.953	.003
	Operable Windows	.915	.333	.103	2.745	.006
	School Pop-per 500	-.337	.350	-.033	-.963	.336
	GATE Prog	-.161	.760	-.007	-.212	.832
	Lang Prog	1.453	.985	.063	1.475	.141
	Absences Unv per 10	-11.159	5.536	-.068	-2.016	.045
	Absences Unexc per 10	-.263	.896	-.010	-.294	.769
	Grade 2	9.417	.409	.953	23.048	.000
	Grade 3	5.533	.412	.549	13.439	.000
	Grade 4	1.699	.421	.157	4.037	.000
	SCH59	-1.872	.779	-.074	-2.403	.017
	SCH60	-2.464	.680	-.116	-3.623	.000
	SCH62	1.745	.715	.081	2.440	.015
	SCH70	-2.353	1.003	-.098	-2.346	.019
	SCH72	-2.588	.666	-.147	-3.885	.000
	SCH74	-.477	.676	-.022	-.706	.481
	SCH82	1.625	.651	.081	2.498	.013
	SCH85	-.777	.786	-.042	-.988	.324

a. Dependent Variable: MATHDEL_

Appendix Figure 3: Math Skylight Model - Classroom-level Results

Reading Skylight Model – Class Level

The following table shows the full class-level model for reading performance. The original student-level model was shown in Table 6 of the appendix to the report. Again this is very similar to the original student-level model. Again, the significance levels (sig.) are generally numerically larger. In fact several of the explanatory variables are no longer significant and could be dropped from the model. In particular, the Type B skylighting variable has become insignificant.

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	2.152	.493		4.368	.000
	Window Code	.453	.131	.181	3.458	.001
	Skylight Type A	1.932	.728	.166	2.655	.008
	Skylight Type AA	.550	.640	.035	.860	.390
	Skylight Type B	.056	1.354	.004	.041	.967
	Operable Windows	.981	.315	.184	3.114	.002
	School Pop-per 500	.295	.314	.077	.939	.348
	Gender	2.204	1.005	.158	2.194	.029
	GATE Prog	.693	.645	.046	1.073	.284
	Lang Prog	.445	.775	.026	.574	.566
	Grade 2	8.504	.533	.829	15.944	.000
	Grade 3	3.328	.342	.474	9.744	.000
	Grade 4	.964	.300	.161	3.210	.001
	SCH60	-1.260	.596	-.090	-2.116	.035
	SCH61	.850	.543	.068	1.566	.118
	SCH62	1.619	.642	.106	2.521	.012
	SCH64	1.767	1.129	.065	1.566	.118
	SCH66	-.361	.831	-.019	-.434	.665
	SCH67	.716	.554	.055	1.292	.197
	SCH72	-1.311	.541	-.116	-2.421	.016
	SCH77	.660	.538	.050	1.227	.221
	SCH81	.962	1.217	.074	.791	.430
	SCH82	1.457	.562	.109	2.591	.010
	SCH85	-1.057	.683	-.092	-1.549	.122
	SCH173	1.387	.700	.080	1.983	.048

a. Dependent Variable: READDEL_

Methodology

We created a new analysis database at the class level by calculating the average of the dependent and explanatory variables of each model within each classroom. For example, the number of absences was calculated as the classroom average value of the absences of each student. In the case of an indicator variable, the average is identical to the fraction of students in the classroom. For example, since Gate_N was an indicator variable in the original model, its average value is the fraction of the students in the classroom that are in the Gate program. The same is true for the gender and the grade indicators. In the case of any class-level variable, such as the skylighting indicators, we simply used the value for the class.

We excluded the students that had earlier been identified as outliers in the student level analysis. Dropping a student from the database is essentially equivalent to including an indicator variable for the student-level analysis. We also calculated the number of students in each class and the residual standard deviation of the original student-level models.

We used weighted least squares to fit the models. We used a maximum likelihood estimation methodology to identify the most appropriate model for the residual variance of the classroom-level models. We postulated a variance-component model for the student-level model. Specifically we assumed that the random component of the test performance of each student is the sum of a classroom-specific effect that is common to all students in a given classroom, and a student-specific effect. We can write this as:

$$e_{ij} = d_j + h_{ij}$$

Here the following notation is used

$e_{ij} =$ random error in student-level model, representing the random deviation of student *i*'s performance from the expected value given the explanatory variables.

$d_j =$ common random component of variance for all students in classroom *j*, representing teacher and other classroom effects.

$h_{ij} =$ student-specific component of variance for each student *i* in classroom *j*:

We assume that d_j and h_{ij} are statistically independent, that d_j are identically distributed, that h_{ij} are identically distributed for all students *i* from each classroom *j,*
that $E(d_j) = 0$, and $E(h_{ij}) = 0$. Using the usual notation for the mean of all students from each classroom, we have

$$Var(e_{ij}) = Var(d_j) + \frac{Var(h_{ij})}{n_j}$$

Here n_j denotes the number of students in class *j*. Now we used the within-class residual variance of the student level models to estimate $s_j^2 = Var(h_{ij})$ and we used maximum likelihood methods to estimate $t^2 = Var(e_{ij})$.

In the case of the math model, we found that the maximum likelihood estimate of t^2 was about 0.25. By contrast the average value of $s_j^2 = Var(h_{ij})$ across all classrooms was about 1.0. This suggests that in the case of math performance, the classroom component of the variance was about 20% of the total variance, while the student component of the variance was about 80%. In the case of the reading model, we found that the maximum likelihood estimate of t^2 was 0. In other words, we found no classroom component of variance. We may postulate that the classroom effects are associated with differences between teachers. In this case, these results suggest that Capistrano teachers are quite uniform in their ability to teach reading, but vary in their ability to teach math. Alternatively, classroom effects may be a function of grouping students into classrooms by abilities. It may be that the district is more likely to assign students to a given classroom based on their math ability, but actively does not track children into classrooms based on their reading ability.

6.3 Sample Illumination Readings

6.4 Classroom Plans and Sections

6.5 Photographs of Schools and Classrooms

Illumination Readings

Capistrano, Skylight Type A, under bright sun, mid day, no electric lights

Dotted areas show **diffusing** 6’ x 6’ skylight and 14’ x 14’ skylight well

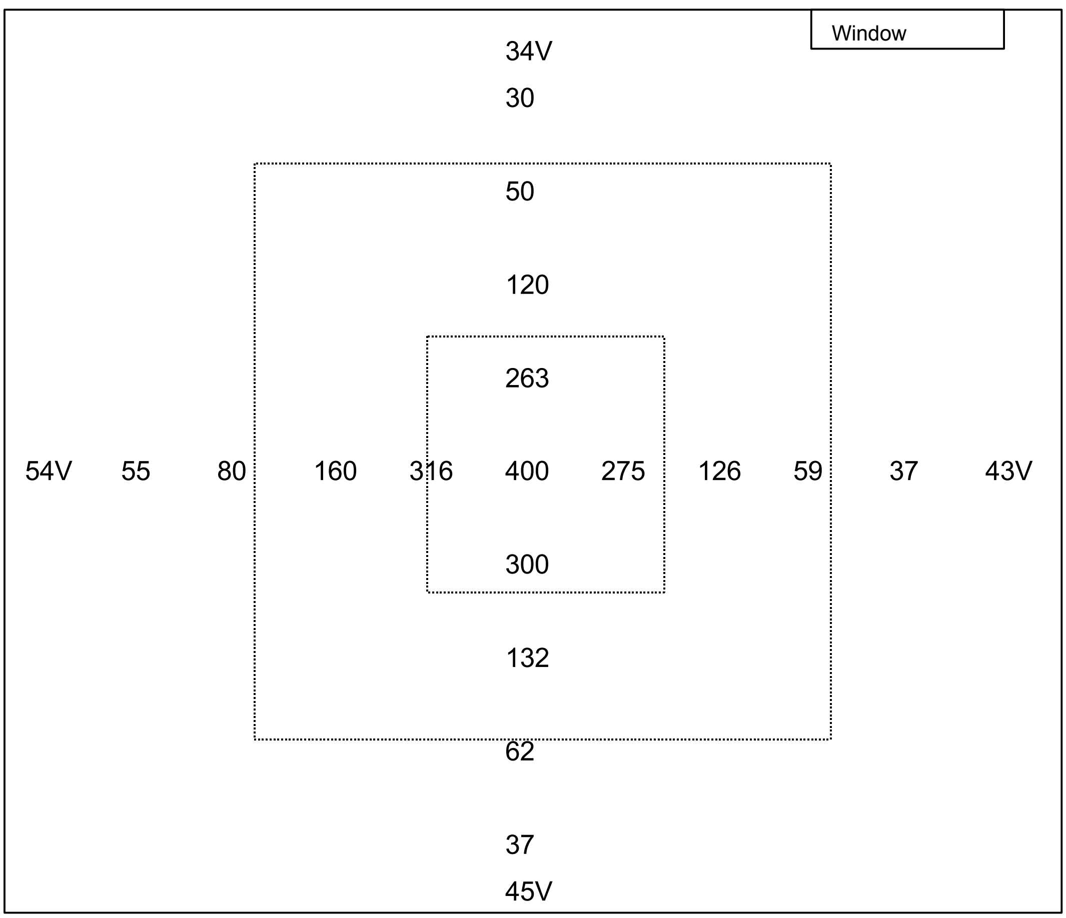
Window Code 1, Skylight Type A, Daylight Code 5

(This is brightest room measured. More typical is illumination peak of 250fc.)

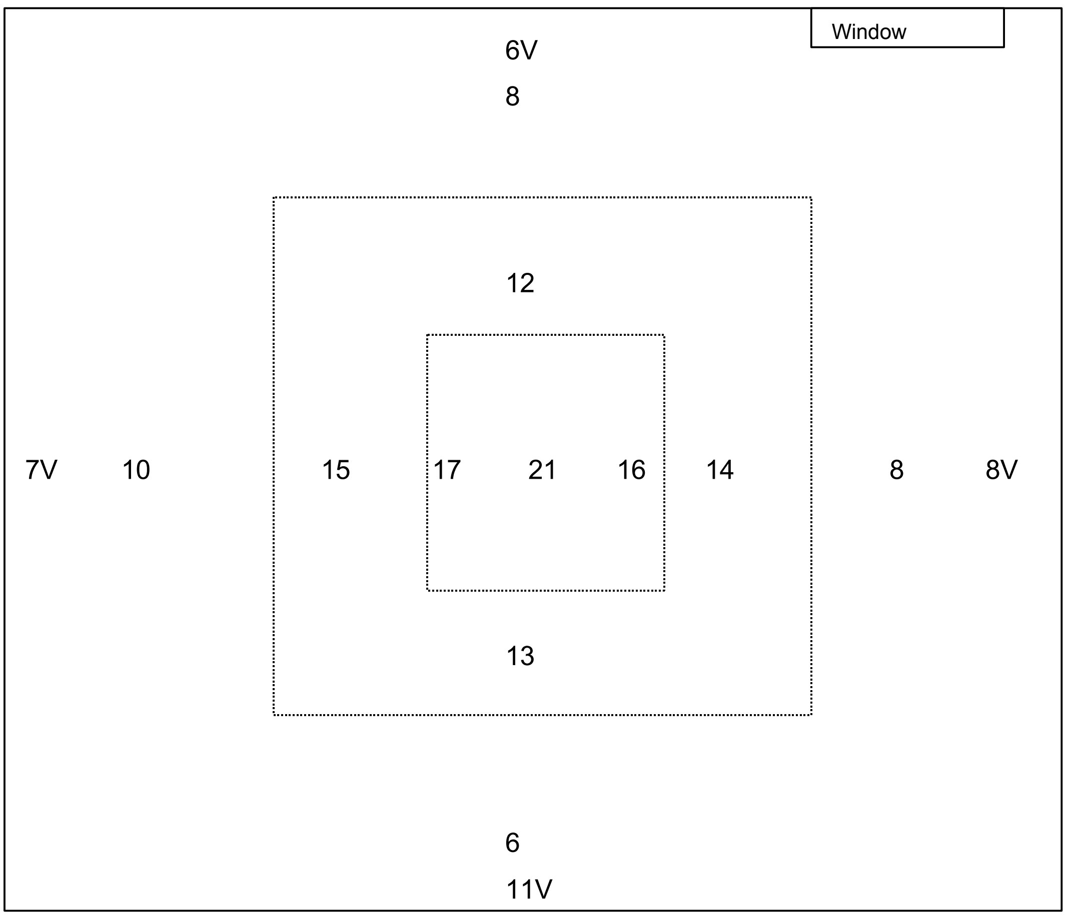
All measurement in footcandles. V = vertical measurement at 5’0’

All other measurements horizontal at desk height = 26”+/- for elementary school

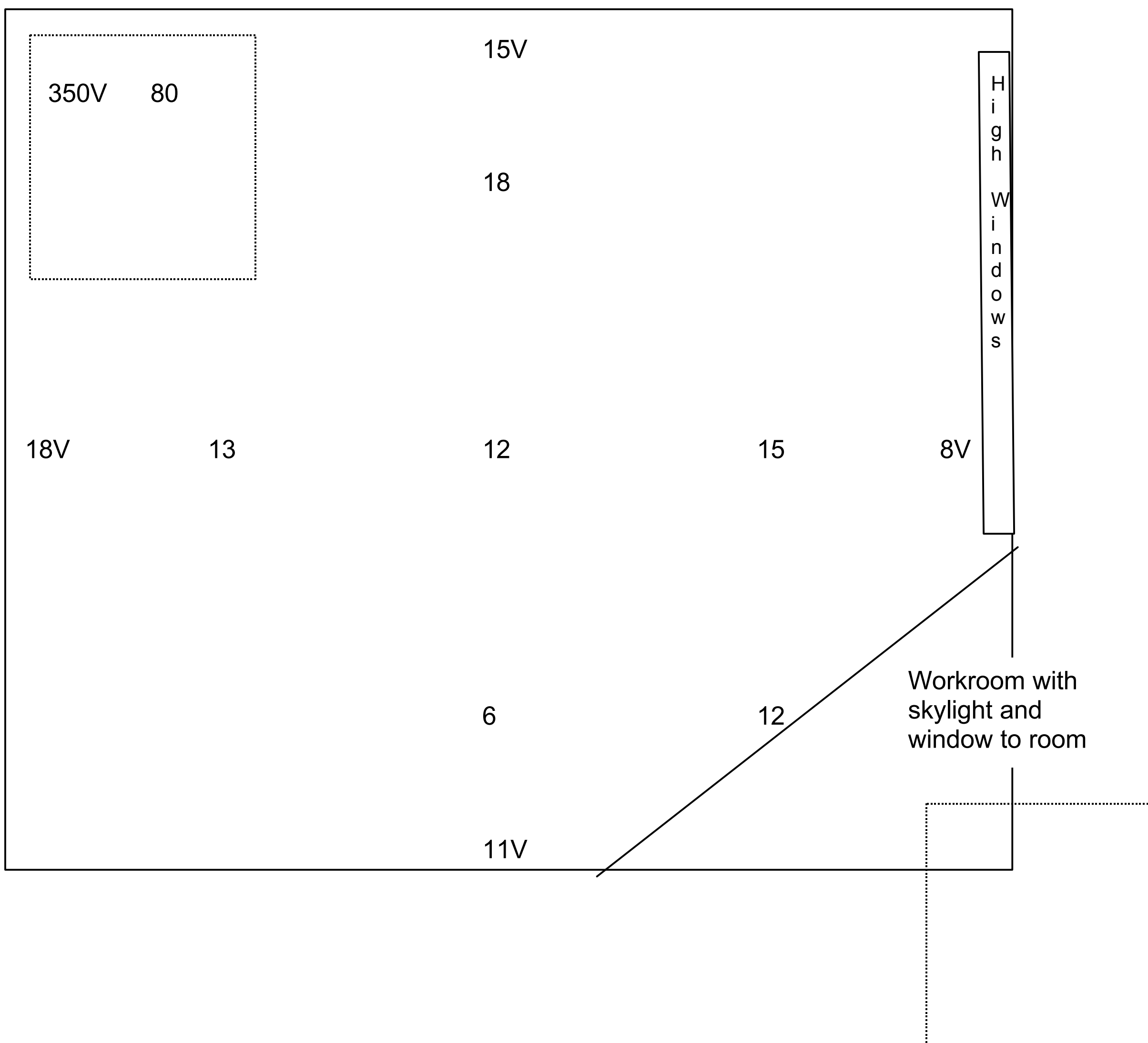
Classroom 30’ x 30’ August 98



Capistrano, Skylight Type A, under bright sun, mid day, **Louvers Closed**
Dotted areas show diffusing 6' x 6' skylight and 14' x 14' skylight well
Window Code 1, Skylight Type A, Daylight Code 5
All measurement in footcandles. V = vertical measurement at 5'0'
All other measurements at desk height = 26"+/- for elementary school
Classroom 30' x 30' August 98



Capistrano, Skylight Type B, light overcast, 3PM, no electric lights
Dotted areas show 6' x 6' **clear** skylight (square of sunlight on northeast corner)
Window Code 2, Skylight Type B, Daylight Code 4
All measurement in footcandles. V = vertical measurement at 5'0'
All other measurements horizontal at desk height = 26"+/- for elementary school
Classroom 30' x 30' August 98



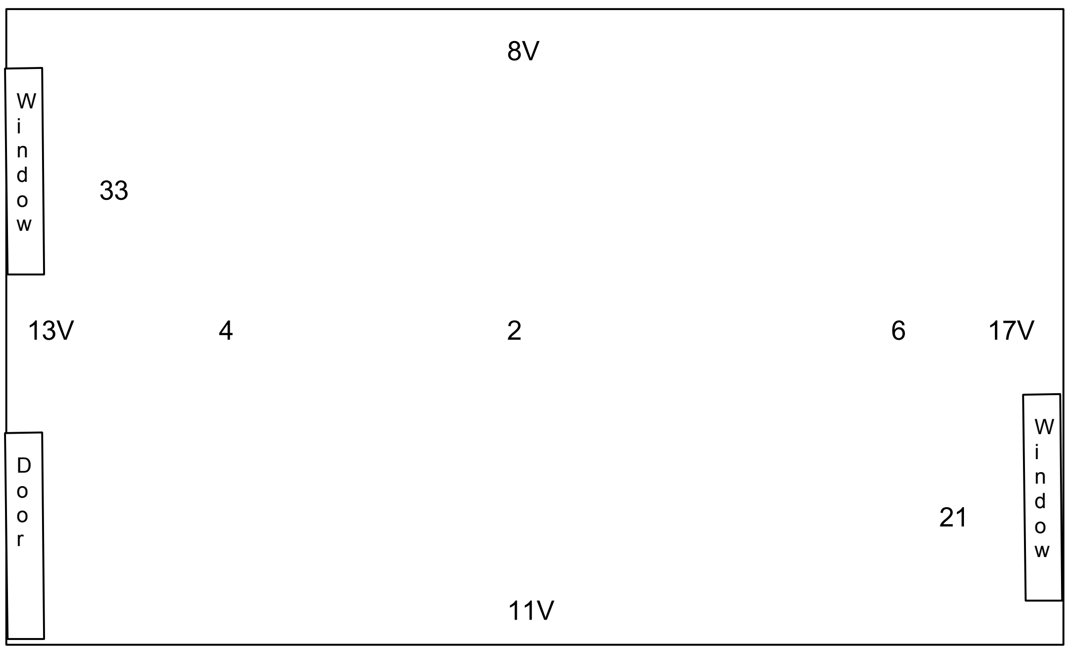
Capistrano, Portable, bright sun, 2PM, no electric lights, **door closed**

Window Code 1, Daylight Code 2

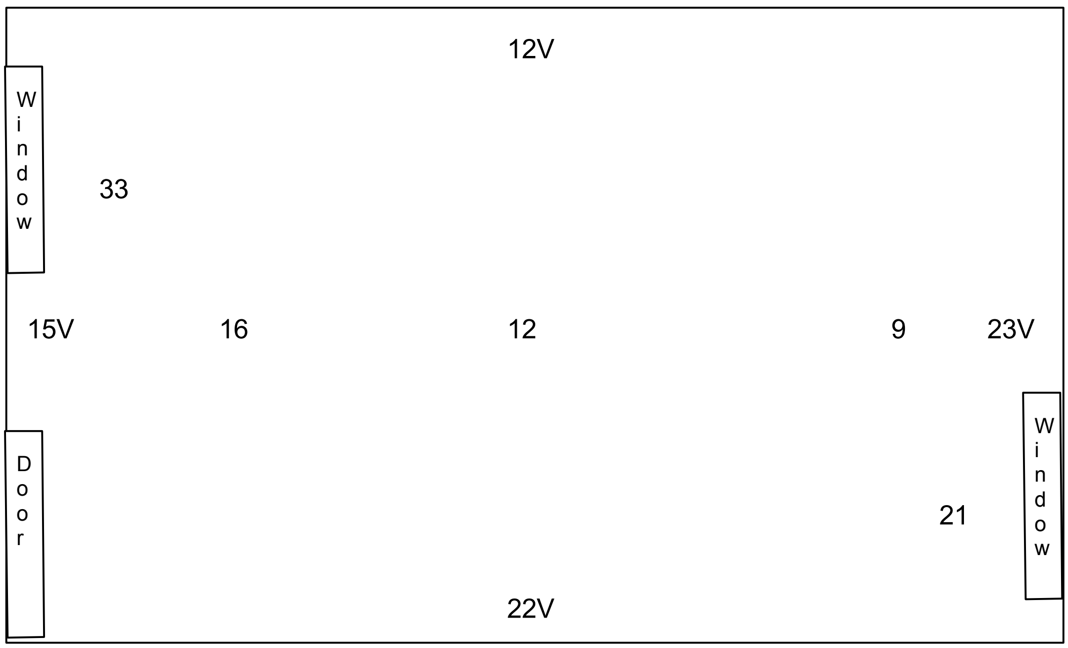
All measurement in footcandles. V = vertical measurement at 5'0'

All other measurements at desk height = 26"+/- for elementary school

Classroom 24' x 40' August 98



Capistrano, Portable, bright sun, 2PM, no electric lights, **door opened**
Window Code 1, Daylight Code 2
(Sunlight reflected off of entry porch and floor at doorway)
All measurement in footcandles. V = vertical measurement at 5’0’
All other measurements at desk height = 26”+/- for elementary school
Classroom 24’ x 40’ August 98



Capistrano, Modular Classroom, bright sun, 11AM, no electric lights

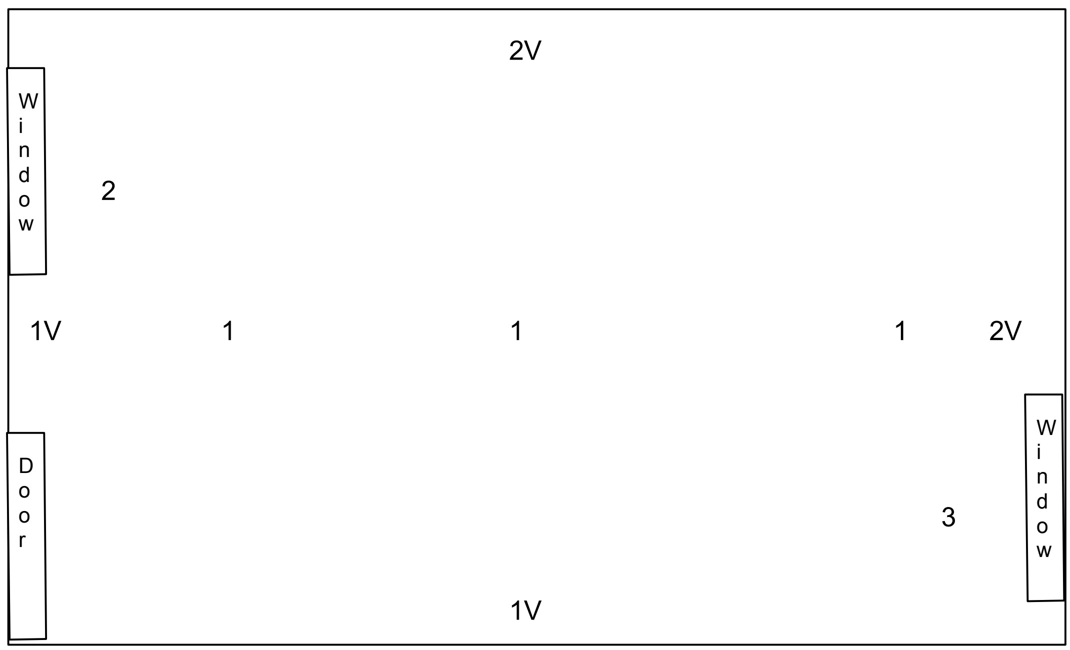
12% transmission glass, overhangs at walkway

Window Code 1, Daylight Code 1

All measurement in footcandles. V = vertical measurement at 5'0'

All other measurements at desk height = 26"+/- for elementary school

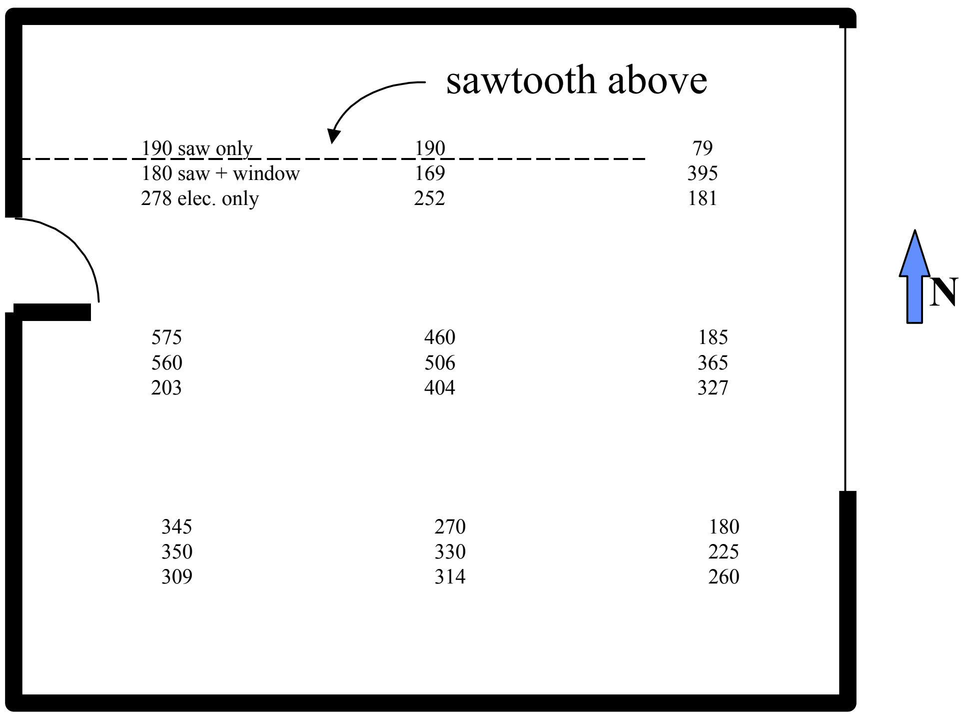
Classroom 24' x 40' August 98



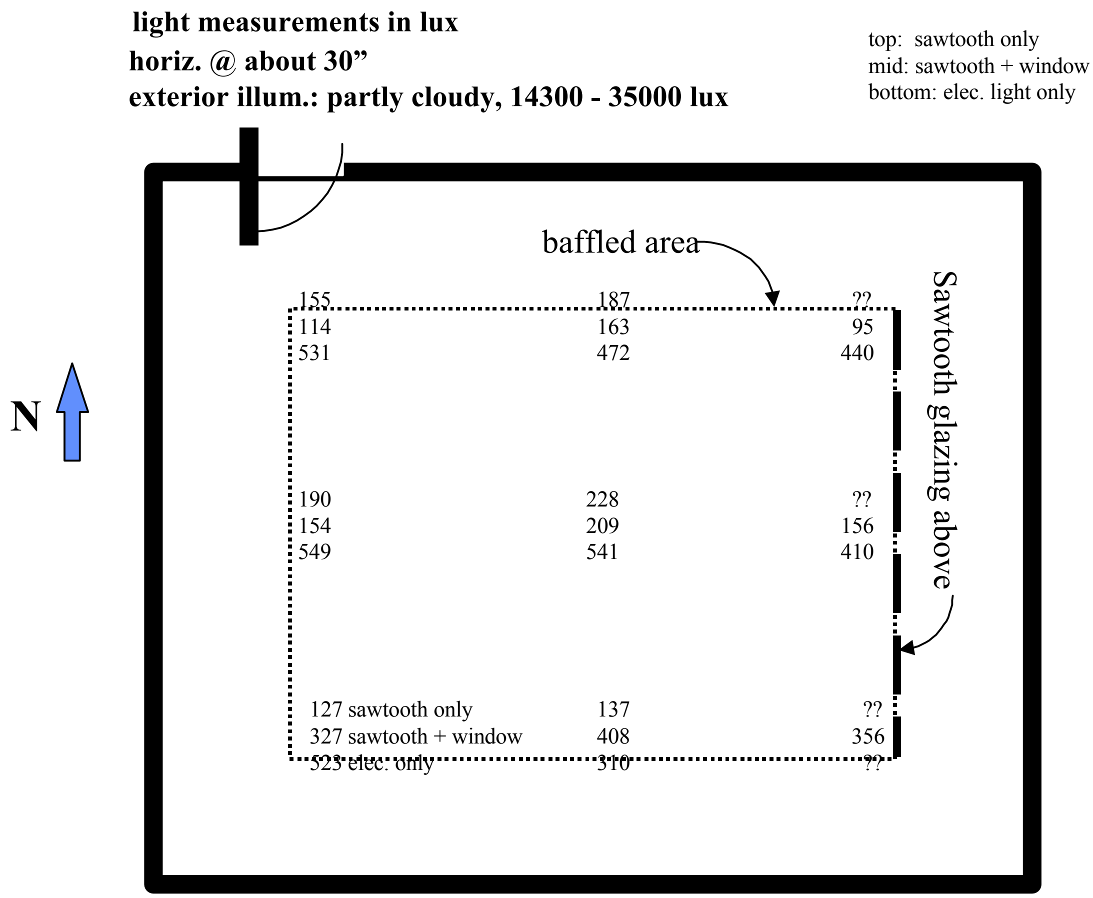
Dunlap: new addition, room 6

light measurements in lux
horiz. @ about 30"
exterior illum. partly cloudy 24000-29000 lux

top: sawtooth only
mid: sawtooth + window
bottom: elec. light only



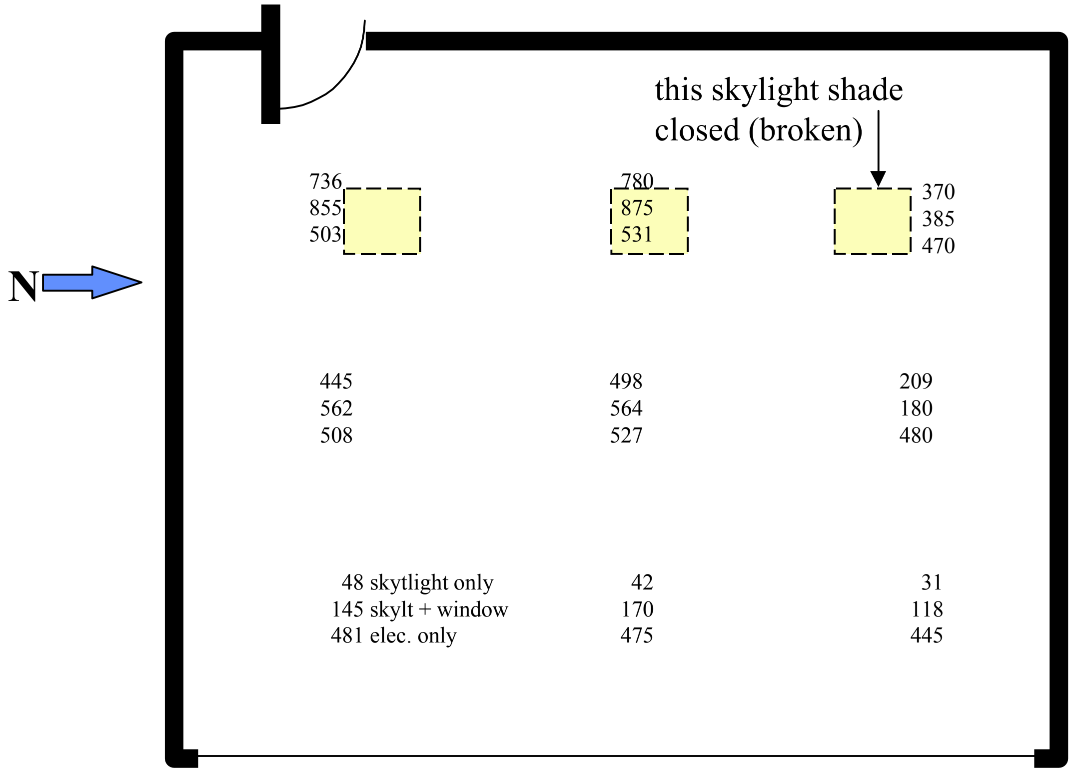
Lafayette: room 22



Rogers Elementary: rooms 9 and 4

light measurements in lux
horiz. @ about 30"
exterior illum.: high overcast, 27000 - 29000 lux

top: skylight only
mid: skylight + window
bottom: elec. light only



Fort Collins

Notes from the Elementary School Tour

The following are a crisscross of illuminance readings at 30" in a few select classrooms. All results are in footcandles and should be read with north as up, west as left and so on. Readings taken in February partially sunny weather. 1500+/- fc =10% daylight factor +/-

McGraw Elementary School

Media Center

			75			
			105			
			143			
101	109	127	135	135	124	81
			146			
			100			

Room 20

		100		
		133		
61	82	95	78	50
		46		
		66		

Miscellaneous Notes

20 fc in the center of the room with the shades drawn and lights on.

Johnson Elementary School

Room 5

		30		
		83		
59	136	140	90	60
		414		
		86		

Miscellaneous Notes

65 fc on chalkboard
Southeast corner very bright during sunlight – maximum of 445 fc on the horizontal

Kruse Elementary School

Room 24

		22		
		34		
65	69	65	54	60
		57		
		17		

Miscellaneous Notes

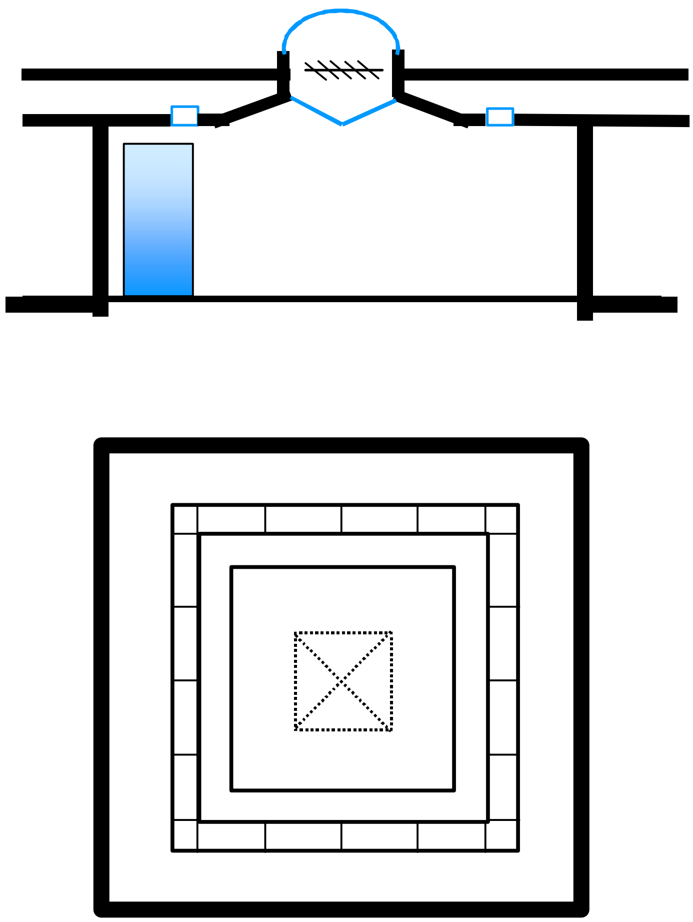
38 fc on chalkboard

Other Notes

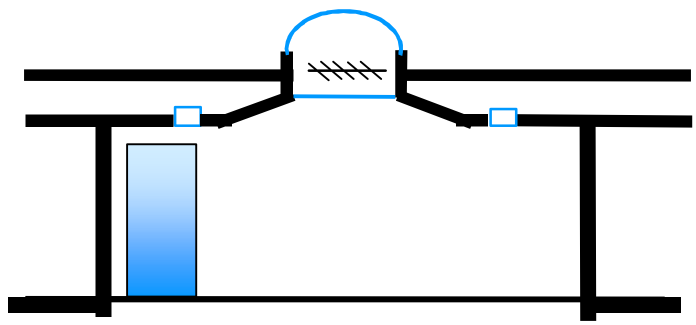
Classroom windows are roughly 75% transmittance in all buildings except for the windows on the west side of Werner Elementary. Werner has tinted glass which we estimated to have a 50% transmittance.

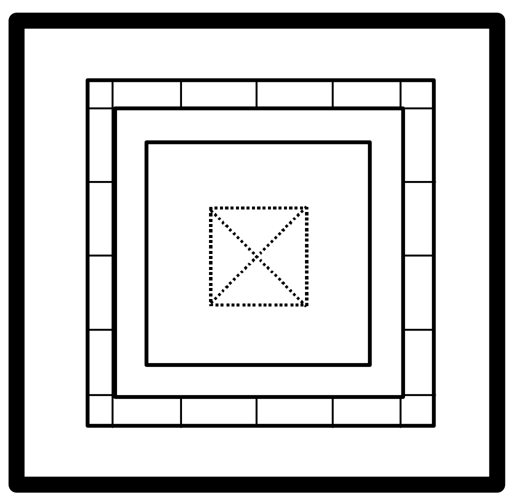
Classroom Plans

Capistrano: Skylight Type A

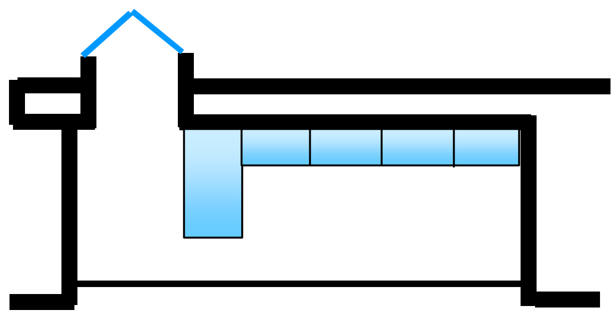


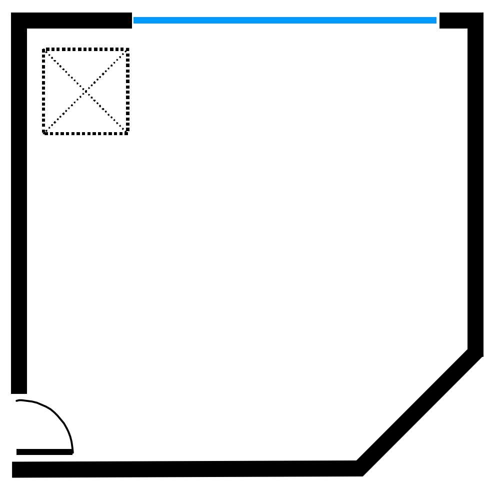
Capistrano: Skylight Type AA



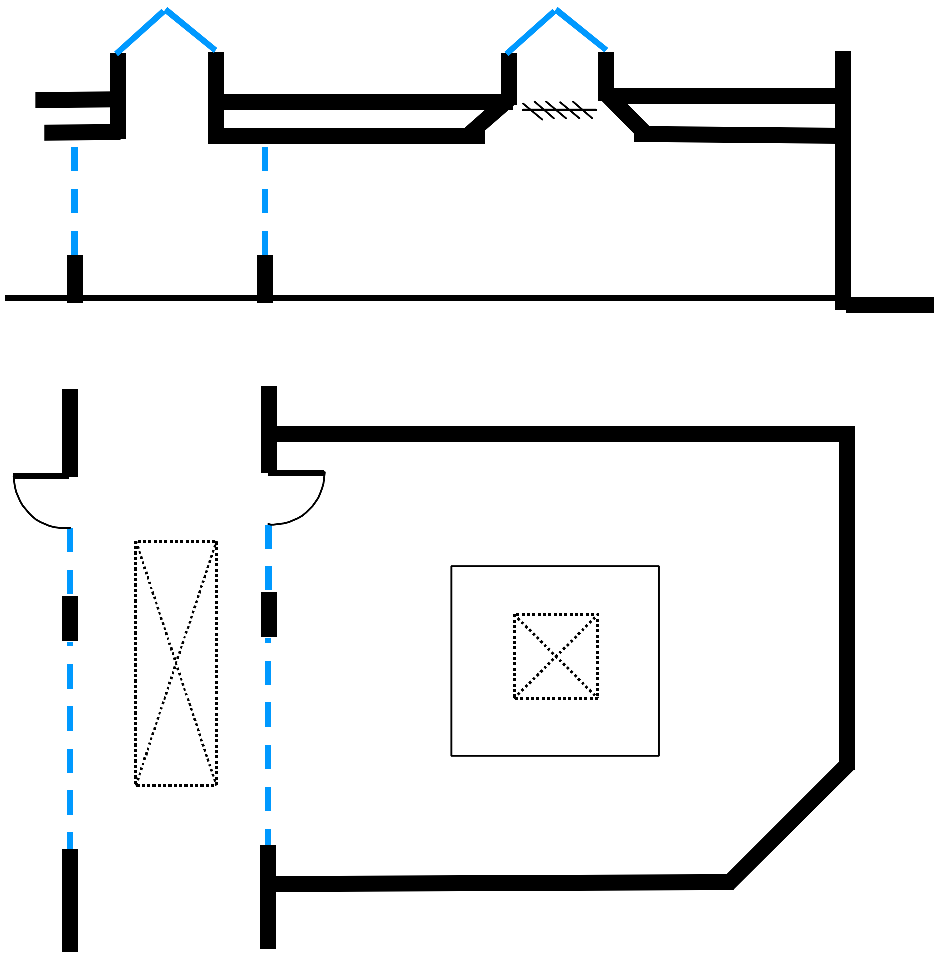


Capistrano: Skylight Type B

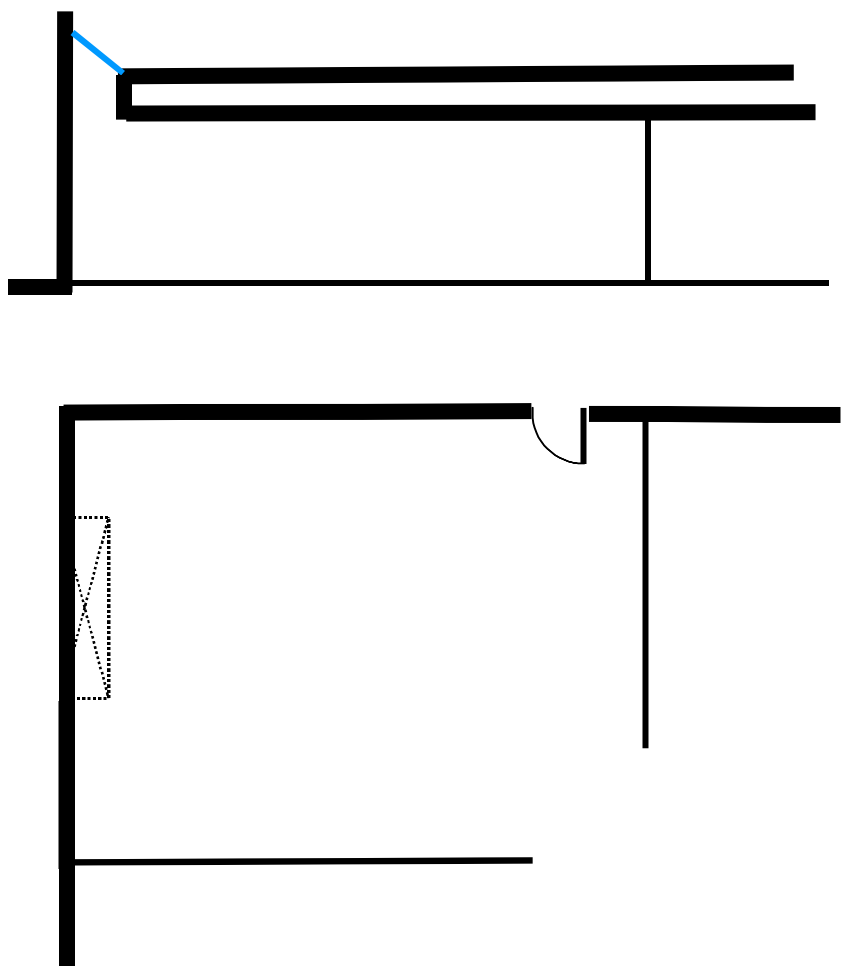




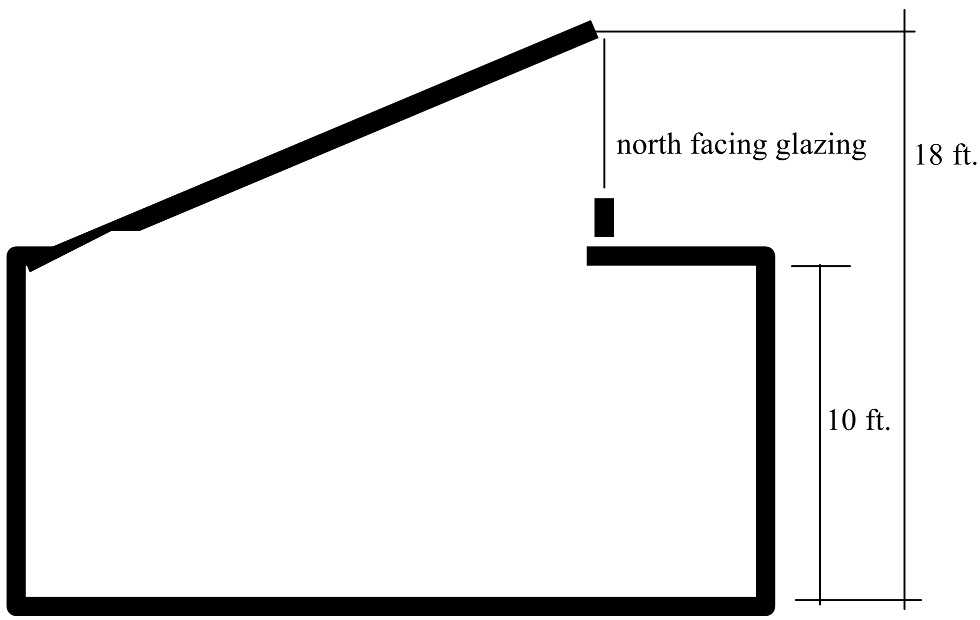
Capistrano: Skylight Type C



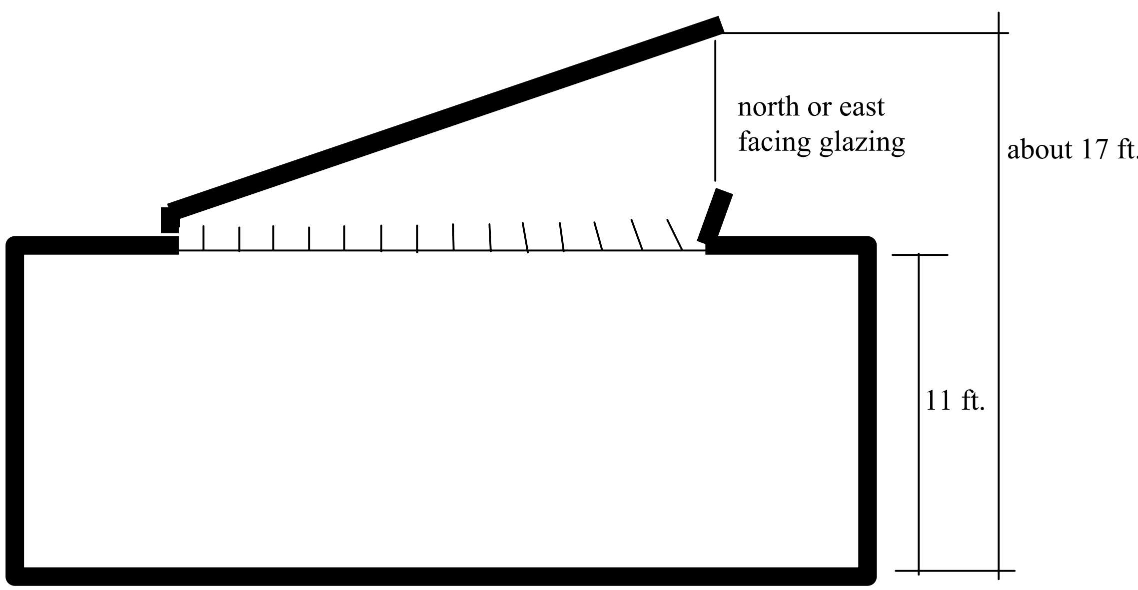
Capistrano: Skylight Type D



Seattle: Dunlap classroom section; Room 6; looking west



Seattle: Lafayette: section through sawtooth



Classroom Photographs

Capistrano Schools


Classroom with Maximum Daylight – Window 5


Classroom with Minimum Daylight – Window 1


Type A Skylight


Type B Skylight


Type B Skylight School


Type C Skylight


5 Window Code, and 5 Daylighting Code (South)


5 Window Code, and 5 Daylighting Code (North)


4 Window Code, and 3 Daylighting Code

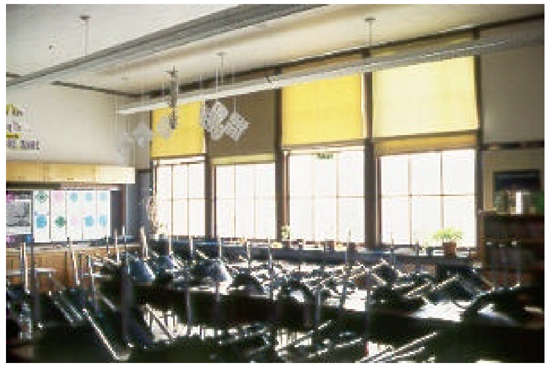

4 Window Code (North)


Portable Classroom Window 1, Daylight 2


Open Classroom Window 1, Daylight 1

Seattle Schools


Older Seattle School, Exterior


Interior of Classroom with Window Code 4


Classroom with Clerestory Windows


Central Skylight and Diffusing Louvers


Dunlap Elementary with Monitor


Rogers Elementary with Skylight

Fort Collins Schools


New School with Monitor Skylights


South Facing Monitor Skylights


Johnson Elementary School


McGraw Elementary School


South Facing Monitor Skylights


Same, without Electric Lights