Sidelighting Photocontrols Field Study

Final Report 11/1/05

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In further analysis of the relationship of window head height to control zone depth we concluded that the proper unit of analysis for this relationship should be [control zone depth]/[window head height], rather than the inverse used in the report. In the process of revising the analysis we also discovered three problems with the data used in this report, and corrected them as described below:

1. The control zone depth had been defined incorrectly in 29 spaces (out of 123). In spaces with daylight provided from two sides (bilateral), where all of the lights in the room are on photocontrols, the control zone depth should typically be the depth from the window to the middle of the room. However, we had defined the control zone depth to be the entire width of the room.

2. The window head height did not include the height of associated clerestories in the same wall in 39 of the 123 spaces.

3. The window head height was recorded erroneously in 4 cases.

4. Three spaces were excluded as outliers; the two spaces with the greatest control zone depth (41' and 58') were very anomalous in terms of architectural design and layout compared to all other spaces studied. One had a ziggurat type roof with staggered overhead clerestories, and the other was an enormous space with continuous high windows encircling the space on all four sides. A third space had a non-orthogonal geometry with windows of different shapes and sizes oriented along various curved surfaces. We decided to consider these three spaces outliers relative to control zone depth and deleted them from the subsequent analysis.

As a result, the original report's findings regarding the depth of controlled zone the window head height, and the ratio between them required re-analysis. Specifically, two conclusions should be discarded:

- Page 84 "Spaces that were functioning tended to have deeper control zones that spaces that were not functioning."
- Page 85 "The bigger the ratio, i.e. higher windows relative to shallower control zones, the more likely the system was not working."

Revisions to Original Results

Figure 1 shows the revised results for the three variables affected by the corrected data. All three are significantly correlated with multiple measures of energy savings, and the window head height is also significantly correlated with whether or not systems are functional. Values **in bold** indicate a positive direction of effect on the outcome variable.

Characteristic	Functional (RSR=0 vs. RSR>0)	Energy Performance (for space with RSR>0)			
		RSR	FLH	EUI	Demand
Ratio of ctrl zone depth to window head ht				0.0700	0.0400
Depth of control zone (ft)		0.0310	0.0040	0.0030	0.0480
Window head height (ft)	**0.0016**	**0.0897**			**0.0214**

Figure 1: Revisions to Original Results

The full revised table of findings is attached as Figure 4 at the end of this report.

For the ratio of control zone depth to window head height, the coefficients of X are all negative (see Figure 1). This means that as the ratio increases (i.e., for deeper rooms or shorter windows) the energy savings decrease. These results are in line with published design guidance and with our prior expectations. Since $p = 0.138$ for the linear regression of RSR as a function of the ratio of head height to control zone depth, there is a 86% probability that the ratio of control zone depth to window head height is also negatively correlated with RSR.

Based on the corrected data the values for the three characteristics in this analysis of 120 spaces were:

Characteristic	Mean	Standard deviation
Depth of control zone	17.5 ft	9.19
Window head height	11.9 ft	4.78
Ratio of control zone depth to window head height	1.57	0.86

Figure 2: Mean and Standard Deviation of Revised Values

Recommended Values for the Ratio of Control Zone Depth to Window Head Height

We divided the sample of 120 spaces into three subsamples:

- 63 spaces with RSR = 0 (non-functioning spaces)
- 31 spaces with 0<RSR<0.5 (low-functioning spaces)
- 26 spaces with RSR > 0.5 (high-functioning spaces)

Figure 3 shows the ratio of the control zone depth to head height. There is a clear progressive pattern, such that the spaces with better working systems tend to have smaller ratios. The best functioning systems (RSR>0.5) have ratios averaging 1.3 with a standard deviation of 0.4. Thus, 0.9 to 1.7 was the normal ratio for well functioning systems, with a ratio of 2 as the maximum observed, i.e. a control zone depth that was twice the window head height.

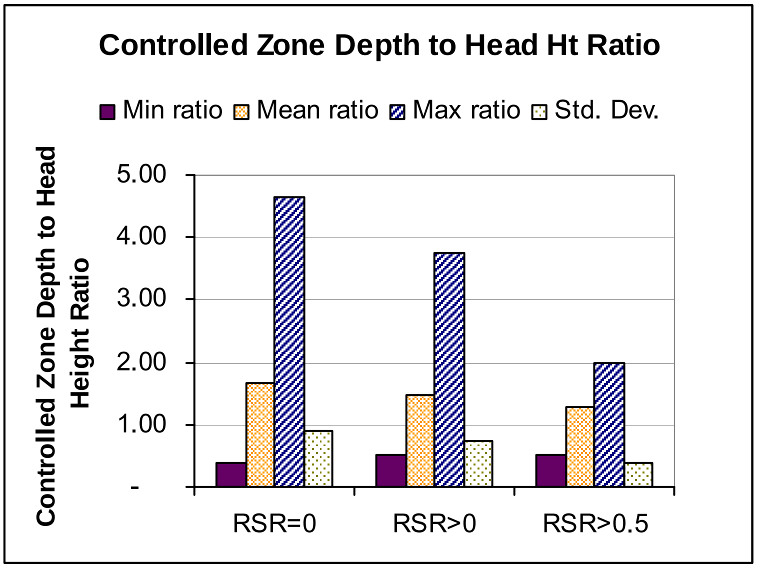

Figure 3: Revised ratio of control zone depth to head height – relationship with RSR

These results suggest that limiting the photocontrolled zone depth to 1.7 or 2 times the window head height would be a reasonable design guideline.

Figure 4: Revised Summary of Results (replaces Figure 45 in report)

Significance levels (p-values) and direction of effect for explanatory variables. Values in bold show a positive direction of effect on the outcome.

Explanatory Variable	Functional (RSR=0 vs. RSR>0)	Energy Performance (for space with RSR>0)			
		RSR	FLH	EUI	Demand
Control zone					
Distance of photosensor to window (ft)		0.0047	0.0010	0.0011	0.0062
Area of daylit control zone (sf)	**0.0000**				
Ratio of ctrl zone depth to window head ht				0.0700	0.0400
Depth of control zone (ft)		0.0310	0.0040	0.0030	0.0480
Size of controlled load (Watts)					
Controls					
Dimming vs. switching	**0.0118**	0.0088	0.0598	0.0835	0.0298
Photosensor is looking down	**0.0307**	0.0309	0.0801		
Multiple circuits vs. single controlled circuit	0.0000				
Fenestration Design					
Ratio of (net Tvis * window area) to ctrl area			**0.0021**	**0.0000**	**0.0015**
Ratio of window area to control area			**0.0056**	**0.0000**	**0.0159**
Space has high windows (>8') vs. low only	**0.0325**				
Net Tvis of windows w blinds					
Window head height (ft)	**0.0016**	**0.0897**			**0.0214**
Tvis of glass					
Luminaires/illuminance					
Luminaires use direct light distribution	0.0088				
Illuminance ratio, horizontal min to max	0.0163				0.0776
Illuminance ratio, vertical min to max					
Illuminance ratio, from front to back of room	0.0008				
Illuminance ratio, horizontal std. dev./average	0.0002				
Occupancy					
Library space v all others	0.0207		**0.0969**	**0.0004**	**0.0046**
Classroom space	**0.0005**		0.0841		
"Other" type space			**0.0868**		
Office space	0.0074				

Explanatory Variable	Functional (RSR=0 vs. RSR>0)	Energy Performance (for space with RSR>0)			
		RSR	FLH	EUI	Demand
Open office vs. all others	0.0107				
Owner occupied building	**0.0008**				
Private office space vs. all others					
Operator					
Building was commissioned			0.0074	0.0282	
Building has off-site management					**0.0549**
Occupants were trained about PC system	**0.0009**				
Site host believes system is working (1-7)	**0.0000**				
Site host is satisfied w system (1-7)	**0.0012**				
Space and Building Design					
Number of years of photocontrol operation			**0.0004**	**0.0001**	**0.0139**
Room size (sf)	**0.0000**			**0.0000**	
Small bldg (<15,000 sf) vs. all others		**0.0105**	**0.0284**		
K-12 school building	**0.0012**		0.0669		
Large bldg (>50,000 sf) vs. all others	0.0002				
Office building	0.0019				
Space has partitions	0.0000				
Number of yrs building has been occupied					
Weighted reflectance of surfaces					
Ceiling height in room					
Office building or K-12 school					
Windows					
Space has clerestory (vs. no clerestory)			0.0553	0.0923	
Daylight comes from only one direction	0.0150				
Space has north facing windows	**0.0937**				
Windows have blinds			0.0133	0.0295	

1. EXECUTIVE SUMMARY

This study set out to describe the current status and performance of photocontrols in those daylit buildings utilizing a "sidelighting strategy", i.e. with daylight entering a space from windows along the walls rather than from above. Since the study was funded by two California utilities and the Northwest Energy Efficiency Alliance, it focuses on buildings in California, Oregon and Washington State along the west coast of the USA.

Daylighting has the potential to greatly reduce energy use for electric lighting and peak electric demand in commercial buildings. The technical potential of daylighting energy savings has been estimated as high as 2 to 5 kWh/sf·yr, based on monitored performance[1]. In this field study, we found that the top performing quartile of photocontrol systems averaged 51% lighting energy savings (1.1 kWh/sf·yr), and a net peak demand reduction of 0.6 W/sf in daylit areas that they controlled. These values provide a reasonable approximation for the "achievable potential" of sidelit control savings, based on current design, installation, and operating conditions in west coast buildings.

If these savings could be achieved in one quarter of the applicable area in new construction in California, about 9 GWh[2] of new savings would be added *each year*, along with 5 MW of demand reduction. In the Northwest these numbers are about 2 GWh and 1 MW. If the same assumptions were applied to the existing national commercial building stock at 58 billion sf, the savings would be 3,190 GWh per year and 1,740 MW, or about the capacity of four medium-sized power plants.

In order to gather candidate buildings for this field study, extensive professional networks were tapped to identify 369 buildings that would potentially fit the study criteria, with daylight provided primarily from the side, and photocontrols installed to reduce electric lighting energy use. A phone survey was conducted with the building managers of 162 of these buildings to verify the status of daylighting, to collect preliminary information and to recruit sites for more detailed on-site surveys. Ultimately, 56 of these buildings were visited, and the monitored performance of 123 spaces in 49 of these buildings was included in the analysis.

[1] Case Studies from the PG&E Daylighting Initiative, 1998. posted on www.pge.com/pec/daylight. The high values are for toplit retail installations.

[2] Assumes 157 million sf added per year in California X ¼ with daylighting controls X 20% of area daylit (15' from exterior wall) X 1.1 kWh/yr·sf savings from well performing photocontrols = 8.6 GWh/yr each year's worth of new building stock. California construction forecast from CEC. National forecast from CBECs.

157 million sf X ¼ with daylighting controls X 20% of area daylit X 0.6 W/sf savings from well performing photocontrols = 4.7 MW new demand savings each year's worth of new building stock

The Phone Survey

The phone survey included about equal numbers of schools, offices, and buildings with other occupancy types. Most of these buildings had been recently constructed. Slightly more than half were less than 3 years old at the time of phone survey (fall of 2004). The oldest system in the sample was 16 years old. The sample is biased towards newer buildings because it was decidedly more difficult to find viable contact information for older buildings.

View windows were present in almost all the surveyed buildings (92%), and clerestories were also quite common (71%). Skylights were reported in 55% of the sample.

From the phone survey we received more reports of switching systems (56%) than dimming systems (41%). However the building managers were more likely to be satisfied with the performance of the dimming systems (5.7 on a scale of 1-7) than the switching systems (5.0). The largest number of complaints were logged against the complexity of operation and/or the difficulty in initial calibration of the photocontrol systems (15 out of 41 complaints), followed by far fewer complaints that the electric lighting was not kept bright enough (6 out of 41). Schools were the most likely to have someone trained in how to use the system, and were also mostly likely to have their building managers report they were pleased with the operation of the system.

The On-site Survey

Surveyors collected data and monitored performance between October 2005 and March 2005 in 123 sidelit spaces that had installed photocontrol systems, averaging 2.5 spaces per building. The sample of spaces had the following characteristics:

- 45% were offices, 28% classrooms and 28% other types of spaces
- 15% were in OR or WA, 33% in Southern CA and 52% in Northern CA
- 45% of the spaces had windows facing only north or south, while 55% included windows facing other directions
- The average window head height was nine feet
- 65% of the control systems were dimming and 35% switching
- The installed lighting power density for the surveyed spaces averaged 1.2 W/sf and for the photocontrolled areas 1.0 W/sf

Electric lighting energy use and illumination patterns were monitored over a two week period. Data was collected sufficient to create a detailed DOE-2.1.e model of each space and its lighting system. HVAC systems were modeled with default values. Lighting schedules were based on monitored operation of un-controlled circuits. A first DOE-2 model was run, using local weather tapes from the same time period as the monitored data. The lighting energy savings from the monitored data was compared to that predicted by the DOE-2 model, generating a Realized Savings Ratio (RSR), interpreted as the difference between monitored versus predicted energy use. A second DOE-2 run was done for each space, using annual weather data (TMY-2) to generate predictions of annual energy impacts. These values were corrected by the RSR for each space.

General Findings

Of the 123 spaces with installed photocontrols, the average RSR was 0.23, meaning that on average the systems were saving 23% of expected savings, given the design of the space and system. However, 64 (52%) of these systems were not functioning at all. Of the 59 (48%) functioning systems, the average RSR was 0.53, suggesting that they were actually saving about one half of what they might be expected to save.

The average lighting energy savings per square foot of photocontrolled area was 0.4 kWh/sf·yr for the whole population, 0.7 for the functioning systems, and 1.1 for the top quartile high functioning systems with (i.e. those with RSR>0.5). We also calculated whole building demand savings of the systems during peak summer electricity use, and found the whole population averaged 0.2 W/sf, while the functioning systems averaged 0.4 W/sf and the high functioning systems averaged 0.6 W/sf of photocontrolled area.

The DOE-2 analysis predicted that on average the 123 spaces should be saving 4.3 Full Load Hours (FLH) of lighting energy per day, or 57% of their normal 7.5 hrs of lighting energy use. However, monitored use showed an average of only 1 FLH of savings, or only 14% energy savings. The 59 functional systems were saving 2.2 FLH out of 6.8 hrs of normal use, or 32% savings. The highest performing system in our study, a gymnasium corridor, was saving 10.8 FLH, or 90% of all daylit hours per year.

Failure Modes and Characteristics

We did not find any evidence that any photosensors or photocontrols had failed on their own after they had been observed to be working. Indeed, the older systems we studied were more likely to be saving more energy than younger systems, suggesting that there is good persistence in savings once a functional system is established. For those systems where we could diagnose a specific failure mechanism, the majority (35/50) had been intentionally disabled: by setting the sensor setpoint too high (17), taping over the sensor (7), disconnecting the wire to the sensor (4), or inactivating the whole system (7).

Other reasons why systems did not function included the system had never worked (5), the system had never been initiated (4), not enough daylight for various reasons (4), incompatibility with the overall building energy management system (1).

Occupant complaints seemed to be the most common reason for disabling a system, while incomplete or improper installation was the second most common cause a system was not working.

Characteristics Associated with Success or Failure

Spaces with more uniform daylight distribution and with higher levels of daylight were more likely to be functioning. Spaces with partitions were highly likely to not functioning. Open offices and very large buildings were also more prone to failure. Classrooms were least likely to fail, but saved the least energy when functional. Training occupants in the operation of the system significantly reduced risk of failure. Owner-occupied buildings clearly dominated our sample (80%) and also strongly predicted that a system would be functional.

Control system characteristics were interesting, in that characteristics that predicted greater likelihood of failure also predicted greater energy savings in those systems that were working. Dimming systems failed less often than switching systems, and sensors looking down failed less often then sensors looking other directions, but both dimming and sensors-looking-down saved significantly less energy when they were functional. Spaces with a single controlled circuit failed more often than those with multiple controlled circuits. Finally, the closer a sensor was located to the primary window the better the energy performance.

We did not find that the manufacturer of a photocontrol system could be used to predict failure or better performance. While two manufacturers dominated our survey, both were equally represented among poorly and well performing systems.

Better energy performance seems to be most attributable to appropriate application and design of the daylighting system as a whole. Spaces that had more daylight illumination available per square foot of control zone (window area*net Tvis/control area) consistently saved the most energy. 83% of our study sample had window blinds, but those few spaces without blinds performed the best. They were typically facing north and/or large open spaces. A few sites noted that they had specifically retrofitted blinds to solve lighting quality problems, and others noted that the blinds were troublesome to control properly. Overall, occupants' choice of the setting for their blinds is clearly an important factor in the energy performance of the systems, since net visible light transmittance accounting for the blinds setting was a better predictor of energy savings than simple glazing Tvis.

Conclusions and Next Steps

Sidelit spaces with *installed* and *operating* photocontrols are more rare than expected. Based on the success rates of our phone survey and site survey, such controls were only operating at 36% of those sites where some "expert" designer or program manager believed them to be installed. Our best estimate is that, as of December 2004, there were about 200 sidelit buildings with installed photocontrols on the west coast. However this number is growing rapidly, with most of those buildings less than three years old. There are clearly many more daylit buildings without installed photocontrols. Thus, the market for sidelit photocontrols is still in its infancy, and the technology should continue to be considered “emerging” until higher success rates and greater market penetration are achieved

We found that only half of the installed systems are currently saving any energy. This is a certainly an opportunity for retro-commissioning. Systems seem to be mostly disabled due to occupant complaints, and secondarily due to frustration with the complexity of the system. At this point in the market, solutions for correcting many of these non-functioning systems are likely to involve changes to the physical system or space, rather than simple adjustments to control settings.

It is important to note that the systems that are working well are saving significant amounts of energy, and convincingly reducing peak electric demand impacts on their buildings. These savings impacts are on a par with those possible with toplighting (skylighting) per square foot of controlled area. These savings also persist over time. Therefore, working photocontrol systems in sidelit spaces offer an important opportunity program for energy and demand savings, especially once higher success rates are achieved.

The best applications for sidelighting with photocontrols seem to be owner-occupied buildings, with large open spaces with no partitions, and with daylight provided from more than one direction. Control systems which don’t try to completely maximize energy savings, but take a slightly less aggressive approach, also seem to have a better chance of success.

The challenge of getting better performing photocontrol systems seems to be one of training designers to create more appropriate daylight applications, and training installers how to insure the system performs well. Manufacturers could do a much better job in communicating the functionality and appropriate application of their systems to these two groups. Demystifying the design, installation and commissioning of daylighting controls would greatly aid the field.

Building design options that create more uniform, non-glaring daylight in spaces will increase the chance of success for daylight energy savings from associated controls. Window blinds are pervasive and their operation by occupants is a key factor in daylight energy savings. Window systems that optimize both occupant visual comfort and daylight distribution would likely greatly increase the success rate of photocontrol systems in sidelit spaces.

Navigating the Report

The body of the report provides detailed information on the study context, the methodology of the phone survey, the on-site survey, and the analysis of the monitored data. The report appendices provide even more detail, with copies of the survey instruments, and table of findings. Those readers interested in only the study findings and its implications may wish to read only Section 2, the Introduction, and Sections 6 and 7, Study Findings and Lessons Learned.

2. INTRODUCTION AND BACKGROUND

This field study was designed to determine the energy impacts of daylight-harvesting photocontrols in a large sample of sidelit spaces under current market conditions. It builds on a previous field study of photocontrol performance in toplit spaces, conducted using a similar methodology[1]. The goal was to find out 1.) how much energy photocontrols are actually saving as installed and operated in real spaces 2.) if they are serving to reduce peak electricity usage 3.) how these impacts compare to the expected impacts as predicted by simulation models, and 4.) if there were any particular characteristics of the buildings or the daylighting systems that are more likely to contribute to success or failure.

While the above goals are fairly simple to describe, achieving them is actually quite challenging, given the realities of measuring and monitoring system performance in the field. There were no existing baseline studies of daylit buildings, nor an established population of daylit buildings from which to draw the study. Thus we had to identify this population as best we could, and create a baseline for the study by estimating (using monitored data) how much lighting energy would have been used in the sample buildings if photocontrols had not been installed.

Because this is the first large-scale study of the field performance of photocontrol systems, we could not use previous research as a starting point. We have therefore collected a very wide range of information about the sample buildings, to find out which factors might be associated with successful photocontrol system performance.

The energy efficiency community has been hesitant to require photocontrol systems in sidelit buildings due to many anecdotal reports of photocontrol failure. But, while intriguing, anecdotes often distort the picture of what is actually happening out in the field. They also do not allow one to confidently predict the average energy savings that can be accrued from a typical installation. One should consider a number of questions: Do these anecdotes represent typical sidelit photocontrol installations, or are failures more widely publicized? Furthermore, are these anecdotes representative of current market conditions, or earlier immature technologies? Is it possible to identify certain characteristics of control systems that most reliably save energy? Are the savings more a function of control system specification, or space design and occupancy patterns?

This study sets out to answer these questions by conducting a survey of as many existing sidelit photocontrol applications as we could afford to include given time and budget limitations. Analysis of the resulting data is used to generate information that will be useful to program managers in targeting efforts to achieve greater energy savings from daylit buildings. Secondarily, it is hoped that some

[1] Heschong Mahone Group, *Photocontrol System Field Study*, report submitted to Southern California Edison, 2002

of the analysis will prove useful in developing guidance on best practices in selection, installation and operation of photocontrol systems in sidelit spaces for both designers and manufacturers.

This study is jointly funded by the Northwest Energy Efficiency Alliance (The Alliance), Pacific Gas and Electric Corporation (PG&E) and Southern California Edison (SCE). The goals and methodology for this study were developed in conjunction with a fifteen-member "Photocontrols Advisory Board" (PAB) consisting of clients' representatives, designers, academics, commissioning agents, and members of the lighting controls industry. A full list of PAB members can be found in the Appendix.

The telephone survey and the on-site visits were conducted between October 2004 and March 2005 with schools, office buildings and "other" types of buildings located in California, Oregon and Washington State. The telephone survey provides a snap shot of the current status of daylit buildings in this region, especially building operators understanding of the daylight systems in those buildings. The on-site survey and analysis provide more detailed information about the performance of photocontrol system in sidelit spaces within those buildings.

2.1 Study Goals

This study involved several distinct phases:

- Identify a population of existing buildings with sidelit spaces and installed photocontrol systems
- Conduct telephone surveys to describe the physical parameters, daylight design characteristics, and types of photocontrol systems installed in these spaces, along with an occupant assessment of their performance
- Conduct onsite surveys of a sample of these applications, both working and non-working, to establish how well they are functioning and how much lighting energy they are using
- Create a DOE2 model for each space, and compare the monitored lighting energy use with the simulation estimate of the theoretical use, to derive a "realized savings ratio" for each space
- Determine average observed energy savings and demand impacts of photocontrol systems, by space type, and/or other useful topologies.
- Conduct a statistical analysis to determine which characteristics of the spaces or of the control systems are correlated with greater success or failure of systems
- Provide guidance on how to select daylighting applications that are most likely result in sustained energy savings

2.2 Study Context

2.2.1 Previous Research Studies

Over the years, a variety of studies have been performed to assess the status of the market for daylighting, the potential for savings, and the effectiveness of photocontrols.

A 1997 study of the California baseline for efficient lighting technologies[1] found that "photosensors were found only in trace amounts", substantially less than 1% of buildings had photocontrols across all categories, with the exception of "small offices" in which slightly more than 1% had photocontrols.

In 1998 the *Skylighting Market Base Line*[2] study was conducted as part of the Skylight and Productivity market transformation project for Pacific Gas & Electric Company. The study measured attitudes towards skylighting among the professionals and decision makers who have an influence on the decision to adopt skylighting for commercial buildings in California. It was designed both to inform the market transformation project at that time, and to sufficiently describe market attitudes so that future shifts in attitude could be measured in comparison. 95 telephone interviews were conducted, which showed that, in general, skylights are seen favorably by all design professions surveyed and for almost all commercial building types. Attitudes towards photocontrols, however, were more reserved, with a majority of interviewees expressing concerns and reservations about implementing daylighting control systems. Similarly, the potential non-energy benefits, were not well understood or acknowledged.

The *Photocontrols Operation Study*[3], conducted in 1998, was a technical survey of market actors who have been involved with the installation of at least one photocontrol system. Seventy interviews were conducted. Most of the interviewees had experience with only a few projects (apart from a handful of controls manufacturers' sales representatives). They also found it difficult to judge whether the controls were working as designed, because unlike HVAC controls, failed photocontrols do not reduce occupant comfort and thus they received few complaints about dysfunctional systems. Most importantly, very few designers had ever been on-site to their buildings to observe operation, and thus received no feedback on the performance of their specified systems. In this context, the study found widespread skepticism about the sustained energy savings from photocontrols, especially among electrical engineers. Offices and schools, in which space is more "owned" by the occupants, were ranked by most respondents as applications where photocontrols were most likely to be

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[1] Heschong Mahone Group, *Lighting Efficiency Technology Report Volume 1:California Baseline*, submitted to California Energy Commission, contract #400-95-012, May 1997

[2] Heschong Mahone Group, *Skylighting Market Base Line, Survey Report*. Submitted to Pacific Gas and Electric, contract #460 000 8215. 1998.

[3] Heschong Mahone Group, *Photocontrols Operation Study*. Submitted to Pacific Gas and Electric. February 2000

successful. Motivated building owners were also reported to be a significant benefit to achieved savings. Human factors (people irritated by photocontrols) and difficulties with commissioning were seen as the leading causes of photocontrol failure.

In 1999 the *Advanced Lighting Guidelines*[1] were substantially revised and updated, with information about the latest lighting research, technologies and design strategies, including daylighting and lighting controls. This effort made it clear the limited state of knowledge about the actual performance of daylighting systems, especially lighting controls.

During the same time period LBNL had been monitoring photocontrol performance in the GSA building in San Francisco at 455 Golden Gate. Jennings et al[2] (2000) reported that in 11 private offices, a dimming photocontrol system saved an average of 27% of the energy that would have been used if only wall switches had been installed.

In 2000 PG&E developed and tested protocols for recommissioning services for toplit photocontrol systems[3] in preparation for developing a daylight recommissioning program. The first phase of the program was directed at encouraging no-cost or low-cost recommissioning of the photocontrol systems, and the second phase on encouraging customer investment in new or better photocontrol systems. A pilot audit of three large toplit buildings identified highly cost-effective energy savings, but the implementation barriers proved too high for the owners, who choose not to implement the recommendations.

In 2002 the *Photocontrol System Field Study*[4] for SCE investigated the effectiveness of photocontrols in toplit spaces and found that the 33 monitored systems were achieving 98% of their projected savings, with a wide range of variation (from 20% to 144%). 21 of the 33 spaces were working under fully automatic control, 11 were working with occasional or frequent manual enhancement (users turning lighting off to save more energy) and one site had been permanently disabled with the lighting in the "on" state.

In a 2002 evaluation of the Betterbricks Lighting Design Lab[5], 52 interviews were conducted with people who had received design assistance from the Lab on daylighting projects. These people were mainly architects, though engineers and building owners were also represented. The evaluation found that the Lab was

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[1] New Buildings Institute, *Advanced Lighting Guidelines.* NBI .2003

[2] Jennings, Rubinstein, DiBartolomeo, Blanc, *Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed.* Journal of the Illum. Eng. Soc. Summer 2000

[3] Heschong Mahone Group, *Photocontrols Dimming System Re-commissioning Program, Task 2b - Audit Procedures Manual*, Project number 0006f2. Submitted to Pacific Gas & Electric Marketing Products & Services, January 2002.

[4] Heschong Mahone Group, *Photocontrol System Field Study*. Report submitted to Southern California Edison Company. 2002.

[5] Heschong Mahone Group, *NEEA Lighting Design Lab Daylighting Lab Evaluation,* report submitted to Northwest Energy Efficiency Alliance and EMI. 2002

influencing architects to design better daylit buildings, helping designers to avoid visual quality problems and overheating, but that photocontrols seemed to be rarely part of the projects. While building owners and architects expected electrical engineers to address this issue, the electrical engineers rarely received information about the daylight design intent and also rarely implemented daylighting controls.

In 2003 SCE commissioned a study examining the use of bi-level lighting and permanently installed task lighting for open office spaces in office buildings in California[1]. The purpose of this study was to determine the operating patterns of bi-level switching, and specifically to rate the effectiveness of the Title 24 requirement for bi-level switching in non-residential buildings. This study examined 256 spaces in 79 buildings. A significant number of occupants (27%) claimed they would be less likely to switch their lighting on during summer than during the winter, and 30% of occupants in non-retail spaces said that they sometimes switch their lighting on or off "to compensate for daylight". Furthermore, light switch use was strongly correlated with daylight availability as judged by the percentage of daylit floor area. This suggests that occupants commonly take action to improve their visual conditions, and that therefore they are likely to complain if control systems create uncomfortable visual conditions.

A 2004 evaluation of the Schools Target Market for the Northwest Energy Efficiency Alliance[2] (The Alliance) investigated the types of energy-efficient technology and design strategies used in schools in the northwest, and found that budget constraints led most schools not to consider photocontrols. In the few cases where photocontrols were considered, they were usually value engineered out of the project. The lower price of electricity in the northwest, as compared with California, was cited by many interviewees as part of the reason. Nevertheless many buildings adopted "daylight design" for human performance reasons even if photocontrols were not installed.

In addition to these studies of photocontrol systems, there is also a great deal of data from lighting preference studies that indicates that uniform, low-glare environments with a certain amount of "visual interest" are preferred, and that occupants prefer daylit to non-daylit spaces[3]. The relative size of windows and window surrounds affects visual comfort[4]; sunlight can be a source of discomfort, but occupants prefer spaces with some limited amount of sunlight presence[5].

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[1] ADM Associates Inc, *Lighting Controls Effectiveness Assessment*, Submitted to Southern California Edison Company, HMG project managers, 2002.

[2] Heschong Mahone Group, *Evaluation of the Northwest Energy Efficiency Alliance's Commercial Sector Initiative: Schools Target Market,* report submitted to Northwest Energy Efficiency Alliance. 2004

[3] Bordass, W, Heasman, T, Leaman, A, Perry, M, *Daylight use in open-plan offices: The opportunities and the fantasies*. Proceedings of the CIBSE National Lighting Conference 1994

[4] Boubekri, M and Boyer, LL. (1992). *Effect of Window Size and Sunlight Presence on Glare.* Lighting Research and Technology 24(2) 69-74

[5] Markus, TA. 1967. *The significance of sunshine and view for office workers*. Sunlight in Buildings, ed. Hopkinson, Boewcentrum International, Rotterdam.

There is clear evidence from a number of studies that occupants prefer to have a high degree of control over their lighting[1], and prefer lighting to be controlled in small zones rather than large zones[2].

2.2.2 Northwest Energy Efficiency Programs

The Northwest has instituted very aggressive daylighting programs in the past few years, with daylighting being one of the featured concepts of the Better Bricks program, which seeks to motive building owners and designers to implement more energy efficient building designs through case studies, analysis and education. In support of these efforts four regional Daylighting Labs have been established to provide design education and assistance to local design teams. The first was set up at the Seattle Lighting Design Lab. This was then expanded to include satellite facilities in Oregon, Idaho and Montana each affiliated with a nearby university architecture department. These daylighting labs have conducted extensive educational efforts and provide some technical consultation services.

In addition, the City of Seattle adopted a code provision that all new commercial buildings would include photocontrols in daylit spaces. Other programs include the Washington Sustainable Schools Protocol that gives points for the inclusion of daylight design and lighting controls in schools, and requirements that all state owned buildings in Oregon meet LEED Silver standards.

Most likely due to these various efforts, we found an enormous upsurge in interest in daylighting design in the Northwest during our recruitment efforts for this study. Whereas there were only a handful of knowledgeable practitioners available for interviews conducted in 1998, and in 2002 we could only identify 25 daylit sites that might eventually be available for study, in the 2004-2005 period of this study, we quickly generated a list of 136 potential daylit sites.

2.2.3 California Energy Efficiency Programs

The California utilities have been actively promoting daylighting for at least the last twenty years. Both SCE and PG&E have customer education centers that feature daylighting as part of their demonstration and education programs, and have featured many seminars teaching the basics of daylighting design and promoting new technologies. PG&E promoted the “Daylighting Initiative” during the 1997-2000 time period, developing a variety of tools and case studies to encourage better daylight design. Both companies have supported the development of various daylighting analysis tools and guidelines, freely available

[1] Escuyer, Fontoynont, 2001. *Lighting Controls: A Field Study of Office Workers' Reactions*. Lighting Res. Technol. 33(2) 95-114

[2] Moore, T, Carter, D, Slater, A. 2000. Conflict and Control: The use of locally addressable lighting in open plan office space. Proceedings of Dublin 2000 20 20 Vision. Dublin, London: Chartered Institution of Building Services Engineers, 2000

over the Energy Design Resources website, and provide technical assistance and incentives through the Savings by Design program.

Evaluations of the Savings by Design program have shown that daylighting controls have played an increasingly significant role in providing energy savings to the state. Toplit buildings, especially warehouses and big box retailers in Southern California have constituted a very large proportion of these savings. In 2001, daylighting controls, as a stand alone measure, were estimated to provide 8% of the energy savings of the Savings by Design program, while "integrated design" including some portion of the whole building energy savings for daylit buildings, provided another 28%[1].

The Collaborative for High Performance Schools (CHPS), begun in California in 2000, has also featured daylighting as a primary component of a high performing school. The point system for CHPS, derived from an earlier LEED point system, attempts to provide guidance and credit for good daylighting design and resulting energy savings. CHPS has sponsored an award program that has featured a number of aggressively daylight new schools.

2.2.4 California Codes and Standards

The California Energy Standards Title 24 2001 require that a separate switching circuit be provided for luminaires that are in (or partially in) the "daylit area", when the daylit area is greater than 250 square feet in size. This switching circuit must control at least half the lighting power in the daylit zone, and control only the luminaires in the daylit area. There is no circumstance under which Title 24 requires that the lighting in any sidelit space should have a photocontrol system.

However, Title 24 does allow "power adjustment factors" (PAFs) for daylit spaces that have photocontrols. PAFs allow the "actual" lighting power density used for compliance purposes to be less than the installed power density. To calculate this reduction, the installed lighting power density in each zone is reduced by an amount equal to the LPD multiplied by the PAF. This allows the installed LPD to be increased, which gives an incentive for designers to specify lighting controls if their clients want to use more luminaires or less efficient luminaires such as recessed cans. These PAFs vary from 0 to 0.4 depending on the size and transmittance of the windows.

The 2005 revision of Title 24 requires skylights and photocontrols in high ceiling, single-story buildings with spaces of 25,000 square feet or larger as the default condition[2]. This code change proposal was based upon the utilities' successful experiences in encouraging these kinds of toplit daylighting controls applications and the SCE sponsored field monitoring of photocontrol systems in toplit spaces

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[1] RLW Analytics Inc. *2002 Building Efficiency Assessment Study,* submitted to Pacific Gas and Electric, San Diego Gas and Electric, and Southern California Edison, 2002

[2] California Energy Commission, *2005 Building Energy Efficiency Standards ("Title 24 "), section 143(c). CEC 2004.*

also demonstrated that energy savings from photocontrols was robust and persistent.

For the first time, Title 24 2005 contains acceptance testing requirements for lighting controls[1]. Before an occupancy permit is granted for a new building or space, or before a new lighting system is put into use, all lighting controls in the building or space must be certified as meeting the relevant provisions of Title 24. These provisions cover the design, performance, calibration, commissioning and functioning of control systems.[2] These requirements are designed to enhance the reliability and usability of photocontrols.

Refinements and expansions of the daylighting requirements are currently under consideration for the 2008 version of Title 24.

2.3 Project Significance

Daylighting has been touted as having a great potential to reduce the use of electricity for lighting, and to secondarily reduce internal gains in commercial buildings that contribute to peak air conditioning loads. Lighting energy consumption in commercial buildings is approximately 33% of all commercial energy end-uses in California[3]. Thus, reducing electric lighting loads, and their associated internal heat gains, is potentially one of the most fertile areas of energy conservation in commercial buildings.

Daylight is potentially widely available as a lighting source. It can be introduced through those windows normally provided for views of the outdoors, and/or through more specialized daylight apertures such as clerestory windows or skylights. The “daylit zone” in a sidelit building as currently defined by Title 24 is assumed to be 15 feet in depth, measured perpendicular to the window. This represents approximately 47% of all existing commercial floor area.[4] Given that not all perimeter spaces have windows, we estimate that the likely range of sidelit spaces is somewhere in the range of 20% to 40% of all commercial floorspace. In addition approximately 90% of existing commercial floor space in California is directly under a roof, and thus could be potentially skylit from above. For the United States, based on estimates form the CBEC database, this value is estimated to be 67%. If it is assumed that 50% of this floor space could actually be successfully daylit, then somewhere on the order of 45% to 65% of existing commercial square footage could potentially see savings from daylighting controls. At six hours per day x five days a week x 1.2 W/sf of lighting power

[1] California Energy Commission, *2005 Building Energy Efficiency Standards (“Title 24 “), section 131(f). CEC 2004.*

[2] California Energy Commission, *2005 Building Energy Efficiency Standards (“Title 24 “), section 119(e,h,i). CEC 2004.*

[3] RLW Analytics, *RNRC Baseline Report,* June 2000

[4] P. 5, Table 2 “Estimate of Building Area within the Perimeter Daylit Zone” in Jon McHugh, et al. *Modular Skylight Well for Suspended Ceilings Research*, PIER Technical Report CEC Contract No. 400-99-013

density, this suggests that a reasonable estimate of average lighting energy savings in these areas might be about 1.8 kWh/sf·yr Buildings with longer hours of operation and/or higher lighting power densities could save proportionately more, up to a theoretical limit of 4368 daylit hrs per year * installed lighting power density.

These estimates, of course, are all predicated on functional, persistent and effective daylighting controls that are widely accepted by building occupants and operators. The challenge of this study was to find out how close we have come to these estimates in the current market for photocontrols.

3. TELEPHONE SURVEY

The main purpose of the telephone survey was to identify and screen buildings that might be qualified for the onsite surveys conducted later in the study. A secondary purpose was to gather information about the physical characteristics of these buildings, their lighting systems, and the interviewees' opinions of the control systems.

The buildings in the telephone survey were all suggested to us as being "daylit" by experts such as architects, program managers and controls manufacturers, who understood that we were looking to identify sidelit buildings with installed photocontrols. As it turned out, many of these recommended buildings did not include installed photocontrols, and quite a few of those suggested also included skylights, or other features that disqualified them from our on-site portion of the study. However, as a group, the buildings described in the phone survey provide a somewhat useful sample of the current status of daylit buildings on the West Coast.

This section presents the telephone survey methodology and findings. The telephone survey findings provide a snap shot of the characteristics of daylit buildings on the west coast, and a basis of comparison to the characteristics of the buildings that were ultimately included in our on-site surveys and analysis.

3.1 Methodology

In this section, first we describe how a sampling frame for the study was created, and then how the phone interview was developed and implemented. In the next section we describe the findings form the phone survey, specifically the characteristics of the buildings and their daylighting systems, and their operators' satisfaction with them.

3.1.1 Sampling Frame

The criterion for inclusion in the study was that a non-residential interior space should be intentionally designed to use daylight as a primary source of illumination. The space should be "sidelit", ie. the daylight should enter the space from windows or other apertures in the vertical walls, rather than from above as with skylighting or roof monitors. And photocontrols should have been installed at some point with the intention to turn off the electric lighting when there was sufficient daylight present.

At the beginning of this study we took a snapshot of an initial list of 86 potential sidelit sites developed from previous studies, which showed that 44% of the buildings on the early list were schools, 28% were offices and 28% were "other" building types. A sampling frame, shown in Figure 5, was proposed for the onsite surveys to roughly reflect these proportions and balance the sample in the three sponsor's territories based on their funding resources. Given the lack of a definitive baseline population study of daylit buildings, we felt this was the best we could do to create a balanced sample.

The Project Advisory Group agreed that one of the project goals should be to investigate as many types of buildings and systems as possible, rather than concentrating on one building or system type. It was agreed to attempt to balance the sample with roughly one third of surveyed spaces each devoted to the three building type categories. The assumption was that the final on-site survey population, as described by space types rather than building types, would include sufficient diversity, since a given building type such as "school" would include many space types.

It was also agreed by the Project Advisory Group that we should not differentially focus on systems that were more likely to be working or not working, but rather should actively seek to include both functioning and non-functioning systems in our study. The hope was that we would be able to detect some of the reasons why some systems were not functioning, and also why some systems were functioning better than others.

	Spaces for On-site Surveys			
Utility service territory	Classroom	Office	Other	Totals
SCE	20	14	16	**50**
PG&E	20	16	14	**50**
NEEA	8	6	6	**20**
Totals	48	36	36	120

Figure 5 – Sampling Frame for Onsite Surveys

In order to find enough candidates for the on-site survey it was felt that we would need two to three times the number of respondents to the telephone survey. Thus, at an average rate of two daylit study spaces per building, this represented a goal of 60 buildings for the on-site survey. In order to achieve this we believed that we would need to complete at least 170 phone surveys, hence the telephone survey sample frame shown in Figure 6.

	Buildings for Phone Survey			
Utility service territory	School	Office	Other	Totals
SCE	12	24	36	75
PG&E	18	24	36	75
NEEA	8	4	8	20
Totals	38	54	78	170

Figure 6 – Sampling Frame for Telephone Surveys

3.1.2 Identification of Potential Study Sites

We used a broad range of channels to identify potential sites for telephone surveys. We searched pre-existing databases of energy-efficient buildings, followed up on recommendations from members of the Project Advisory Board, and contacted known lighting designers, architects, lighting controls manufacturers, utility program staff, and others working in the daylighting field. To further expand our list of potential sites we also sent out notices to local chapters IESNA, AIA and ASHRAE to include in their newsletters or announce at their meetings; conducted web searches for references to daylit buildings; and reviewed all available case studies. In general, secondary sources were less productive and less reliable in their information than personal contacts.

Our initial list of contacts included 83 names. Each time we called a contact to ask for their help in identifying sites we asked two questions: first whether they had first-hand knowledge of any qualified sites, and second whether they knew of anyone else who might know of any potential sites. By asking both these questions we were able to continuously expand our pool of contacts while populating a list of potential sites. The total number of individuals who suggested at least one potential study site eventually reached 173. A breakdown of their locations and roles is shown in Figure 7.

Compared with past daylighting studies, we found that there was now a much larger pool of people who were knowledgeable about daylit buildings. For instance, in the Photocontrols Operation Study[1] that we conducted in 2000, we could find only 80 contacts nationally who we considered knowledgeable about daylit buildings, compared to the 173 sources four years later. This suggests that

[1] Heschong Mahone Group, *Photocontrols Operation Study*. Submitted to Pacific Gas and Electric. February 2000 (op sit)

knowledge about daylighting has recently been expanding in the building industry.

	North West	Northern California	Southern California	Other areas	Total
Energy efficiency program managers	12	8	9		29
Lighting designers	4	6	1	1	12
Lighting controls manufacturers	2	3	2	5	12
Architects	2	25	8		35
Electrical engineers	9	15	5		29
Manufacturer's representatives	2	3	1		6
Electrical contractors	1	1	1		3
Energy consultants	3	11	2	2	18
Daylighting consultants / academics	3	4	3	2	12
Building owners	2	10	5		17
TOTAL	40	86	37	10	173

Figure 7 – Number of People who Provided Potential Sites for the Telephone Survey, by Area and by Industry Role

For each building of which a contact had first-hand knowledge, we asked them to describe the design of the building, to describe which spaces had daylight controls, and how the controls worked. This information was very useful in helping us prioritize potential sites, to verify information later during the telephone survey, and in helping us identify all potential spaces within a building. We also asked each contact whether they could help identify a site contact for the building, who would be a likely participant in the telephone survey.

We created a tracking spreadsheet of our expanding list of potential sites so that we could cross-check, sort and prioritize our list. We assigned an initial priority on a simple 0-3 scale according to how likely we thought a given site was to meet our study objectives.

The primary function of each building was also categorized, using the 13 building types from the Nonresidential New Construction (NRNC) database. If the building contained spaces that performed many functions (such as a school building that contained both classrooms and office space) only the primary activity was recorded. The NRNC categories were chosen as the most comprehensive and compatible with classifications used in other database, such as CBECS/EIA; Savings by Design; and F.W. Dodge.

Ultimately, we collected a list of 369 potential sidelit sites on the West Coast.

3.1.3 Telephone Survey Instrument

A draft telephone survey instrument was developed with the goal of collecting sufficient information in a 20 minute interview. The interviewer conducted several practice surveys with HMG staff and local architects, and the project team made revisions to the instrument based on practice survey responses and advisors' comments. A copy of the survey instrument is included in the Appendix.

The questions were asked in three sections, first with a qualifying section, to minimize the amount of time spent by the interviewer on non-qualified sites, and then in order of importance, to ensure that the most important questions were answered first in case the interviewee had to cut the interview short, or did not want to proceed.

In the initial "qualifying" section the interviewer established whether she was speaking to the proper person and whether the site indeed contained sidelit spaces with installed photocontrols. If the interviewee recommended that the interviewer should speak to a different person about that building, the interview was terminated and a new call made. All interviewees were guaranteed that the information they provided would remain confidential, and that information from the study would only be reported in aggregate.

Once an appropriately knowledgeable person was identified for the interview, data was collected about the building, its daylighting systems, and their operation. At the end of the interview, for qualified buildings, the surveyor asked permission to schedule an onsite survey. At the completion of the interview, the surveyor subjectively rated each participant for their apparent level of knowledge and enthusiasm for the project, and assigned a probability that the site would meet our survey goals.

The telephone surveys were conducted between October 2004 and March 2005. The answers were entered in real time to an Excel database. This data was then exported to an Access database for analysis.

3.1.4 Qualifying for the Telephone Survey

To qualify for a telephone survey, each site had to contain at least one space that had both sidelighting and photocontrols. Details of these eligibility criteria are shown below:

- "Photocontrols" includes any automatic system that controls interior electric lighting in response to the availability of daylight.
- "Sidelit" includes any space that is lit predominantly by view windows or clerestories.

Conveying these criteria clearly to the interviewees was a challenge for the interviewer, since many people though that she was talking about occupancy sensors or automatic louvers on skylights. After several interviews the interviewer settled on the following concise description, that qualifying spaces should contain "A control system that dims or switches off the lighting in response to daylight coming in through the windows": When the interviewer wasn't sure that the interviewee understood the criteria, she asked more detailed questions about the system to probe their level of understanding.

As we conducted the telephone surveys, we began to fill out the sampling frame and continued to conduct surveys until we were confident that we had enough sites to meet the target value in each element of the sampling frame

3.1.5 Ensuring Quantity and Quality of Information

The critical element in ensuring quality of information was to find the right person to answer the questions. At the start of each call, the interviewer asked the interviewee whether they were the right person to answer questions about the building's lighting control system; if not, she took contact details for the proper person, and called them instead. Often it took several attempts for the telephone interviewer to reach the most knowledgeable person.

Sometimes there was a disparity between the information given by the site interviewee and the information previously given by the building's architect, engineer or lighting designer, or by utility program staff. In these cases the interviewer made additional follow-up calls to resolve specific questions and to make a final judgment of whether the site was qualified.

During the interviews, once we established that the site was qualified for the telephone survey, we offered to send a $25 gift certificate to each interviewee who completed a telephone survey, both as a thank you for their time investment, and to encourage participation. Many interviewees declined the offer, often because their employers had rules about staff accepting gifts. Ultimately gift certificates were sent out to 48 out of 162 interviewees (30%)

Several sites required a great deal of persistence in finding the right person to interview and in following up on messages left and requests for additional information (see Figure 10). We did not set a maximum number of call attempts before giving up—rather a judgment was made about whether each site was worth pursuing, based on the importance of a particular site to our sample frame and the quality of other information available about that site.

Manufacturers of lighting controls were one of our more problematic sources of information. Even though they might have long lists of customers, they often did not know the location or other details about the actual buildings. Manufacturer's reps were also a problematic source of information because they could not easily produce lists of which projects had photocontrols installed, and they rarely knew information about the building design or current site contact information.

To maximize the consistency of the information gathered, only one person conducted all the telephone surveys. Information exported to the database was checked for completeness, format consistency and appropriate ranges.

3.2 Telephone Survey Findings

A site was included in the phone survey if we had been told by a reliable source that it was a sidelit building that included a photocontrol installation, and we were able to complete at least part of the phone interview.

A site was considered "qualified" for an onsite survey if the interviewer was able to verify to her satisfaction that the building was sidelit (and not toplit), that photocontrols had indeed been installed and the building had been occupied for more than six months.

As it turned out, we conducted on-site surveys at almost every qualified site, thus there is relatively little difference between the "qualified" and the "on-site surveyed" results.

However, the sample of buildings in the telephone survey can be taken as only somewhat representative of the stock of daylit buildings in the Pacific Northwest and California. We were not able to draw a sample from a pre-existing list of daylit buildings, and there is no general data about the population of daylit buildings, thus we cannot know if our sample is representative of any larger population. As a result, we have not scaled up or weighted our findings to derive any conclusions about the overall population – the results are presented only for our sample.

In the Pacific Northwest we accumulated a list of candidates about twice as large as the number of buildings as we eventually surveyed, whereas in California we surveyed almost every qualified building that we were able to identify. In Southern California, especially, we completely exhausted our list. This suggests that the total population of buildings in California with sidelighting and photocontrols may not be much larger than our phone survey sample.

All information is presented in an aggregate format, and sites are identified by a site number assigned for the study, and not by the name of the owners or tenants in order to protect their privacy.

The findings in this section characterize this population of sidelit buildings:

- In what building types photocontrol systems have been installed
- What types of photocontrols have been commonly installed
- Typical daylight design strategies
- Whether the controls are considered by their operators to be working properly, or working at all
- Whether building operators are satisfied with the performance of the controls

3.2.1 Number of Telephone Surveys Completed

162 telephone interviews were initiated. In 77 of these the interviewee answered all (or almost all) the questions, and these are classified as "complete" interviews. The other 85 interviews are classified as "partial" because the interview was terminated part-way through, either by the interviewee or by the interviewer. In many cases the interviewer terminated the interview after determining that the building did not have a photocontrol system. For this analysis, we report on the number of responses to each question, regardless of whether the building was finally "qualified" for the on-site study.

	Building Type			
Utility service territory	Schools	Offices	Other	Total
SCE	22	23	16	61
PG&E	29	18	13	60
NEEA	12	16	13	41
TOTAL	63	57	42	162

Figure 8 – Number of Telephone Surveys

Figure 8 shows the distribution of phone surveys by building types and utility territory, and can be compared to the initial sample frame for the telephone surveys shown in Figure 6

3.2.2 Disposition of Telephone Calls

60% of the calls we initiated resulted in a phone survey being filled out. This percentage did not vary significantly between building types or between geographical areas, as shown in Figure 9.

		Schools	Offices	Other	TOTAL
Northwest	Calls initiated	32	22	26	80
	Surveys competed	12	16	13	41
	Success rate	38%	73%	50%	51%
Northern California	Calls initiated	44	34	23	101
	Surveys competed	29	18	13	60
	Success rate	66%	53%	57%	59%
Southern California	Calls initiated	32	33	24	89
	Surveys competed	22	23	16	61
	Success rate	69%	70%	67%	69%
TOTAL	Calls initiated	108	89	73	270
	Surveys competed	63	57	42	162
	Success rate	**58%**	**64%**	**58%**	**60%**

Figure 9 – Detailed Breakdown of Call Totals

Figure 10 shows the rate of attrition as we progressed through the phone surveys. Of the 99 sites that were not called, 54 were in the Northwest where we fulfilled the required sample frame early on. Of the remaining 45 sites (all in California), 8 sites were judged inappropriate to the study, and 21 sites had outstanding questions that had to be answered before the interviewer could make a call (such as, finding a site contact or designer, in the case of buildings where we only had a building name and location), and the remaining 17 did not have sufficient information to locate the building.

369 potential sites identified	99 sites not called	8 judged inappropriate
		21 with questions to be resolved before call could be made
		70 not called by end of survey
	270 initiated calls	4 sites where interviewer needed to follow up
		7 refusals to participate in survey
		18 requests to call back later
		60 messages out but not returned
		19 judged inappropriate
		162 completed surveys

Figure 10 - Disposition of Calls

We specifically choose to avoid including airports and other public transportation facilities in our study in order to avoid excessive security issues. This resulted in only one site being dropped form our list of potential sites.

Of the 270 initiated calls, 19 were immediately judged unlikely to be appropriate to the study, so in the interests of time the interviewer terminated the call. There were 60 sites for which we had one or more voicemail messages but our calls had not been returned by the end of the survey period, and 22 sites for which we needed to follow up either with further questions (4) or by calling back at a more convenient time (18). Only seven interviewees refused to participate in the telephone survey; this was usually because of time constraints, although in two cases it was against their company policy to respond to telephone interviews.

Number of Responses to Each Survey Question

Figure 11 reports on the number of responses to each survey question, for those questions that were relevant to the daylight characteristics of the building. There were very few interviewees who terminated the interview after question 11, once it had been established that the building was appropriate for the study.

Categorization of questions:

Q1-Q8:	Addresses, contact names, building type
Q9-Q20:	Questions about the photocontrol system
Q21-Q30:	Questions about the photocontrolled spaces

Several questions received fewer answers due to the nature of the questions themselves. Questions 13 and 18 required an answer only if the interviewee had a specific complaint about the daylight in the building, or about the photocontrol system; Question 22 asked what brand of photocontrol system was installed, and many interviewees did not know that information.

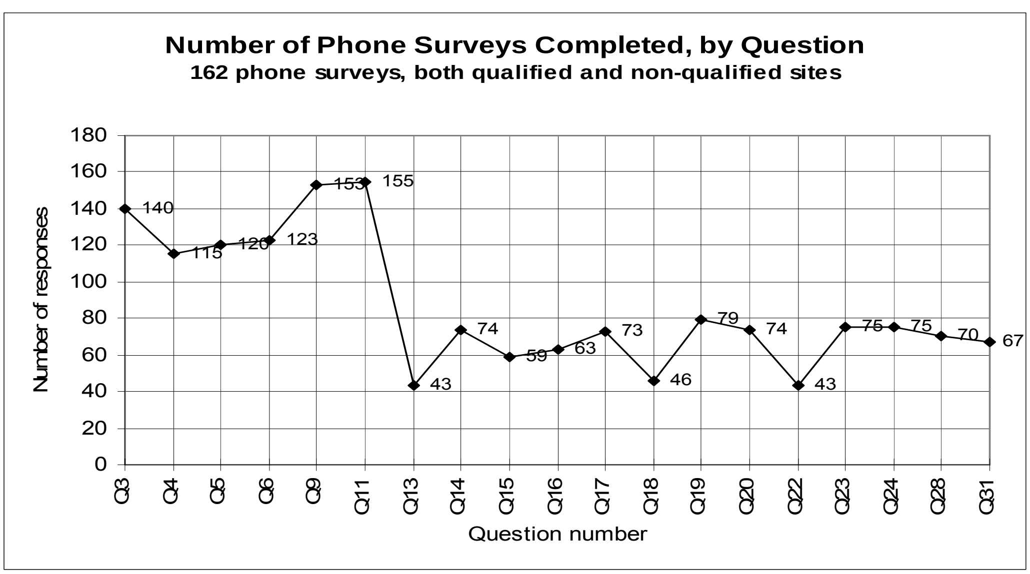

Figure 11 – Number of Responses to Each Survey Question

3.2.3 Site Characteristics

In the onsite surveys, we categorized buildings into three occupancy types – schools, offices and “other”, since this makes statistical analysis more significant. “Other” includes libraries, gymnasia and multi-use buildings, among other types. However, in some of the graphs below we have retained a larger number of categorizations because this produces a more detailed description of the sample.

Number of Buildings Surveyed

Figure 12 shows that for each building type, a large number of telephone surveys were conducted to find a pool of qualified sites at which on-site surveys could be conducted. Of three building types in the telephone survey, offices were most likely to have photocontrols installed, or else the interviewee was more likely to know about them if they did exist. We did observe that it was often easier to identify the person knowledgeable about the building’s lighting system in a large office building than a school or “other” building type. The types of building represented in the “other” group in the telephone survey included libraries (13 out of 42), community centers (5), and retail spaces (5). Many of the buildings in the “other” category were mixed-use.

The figure also shows that the pool of qualified buildings from which the on-site surveys were taken was barely larger than the number of on-sites we conducted, so our choice of buildings was highly constrained for the on-site portion of the study.

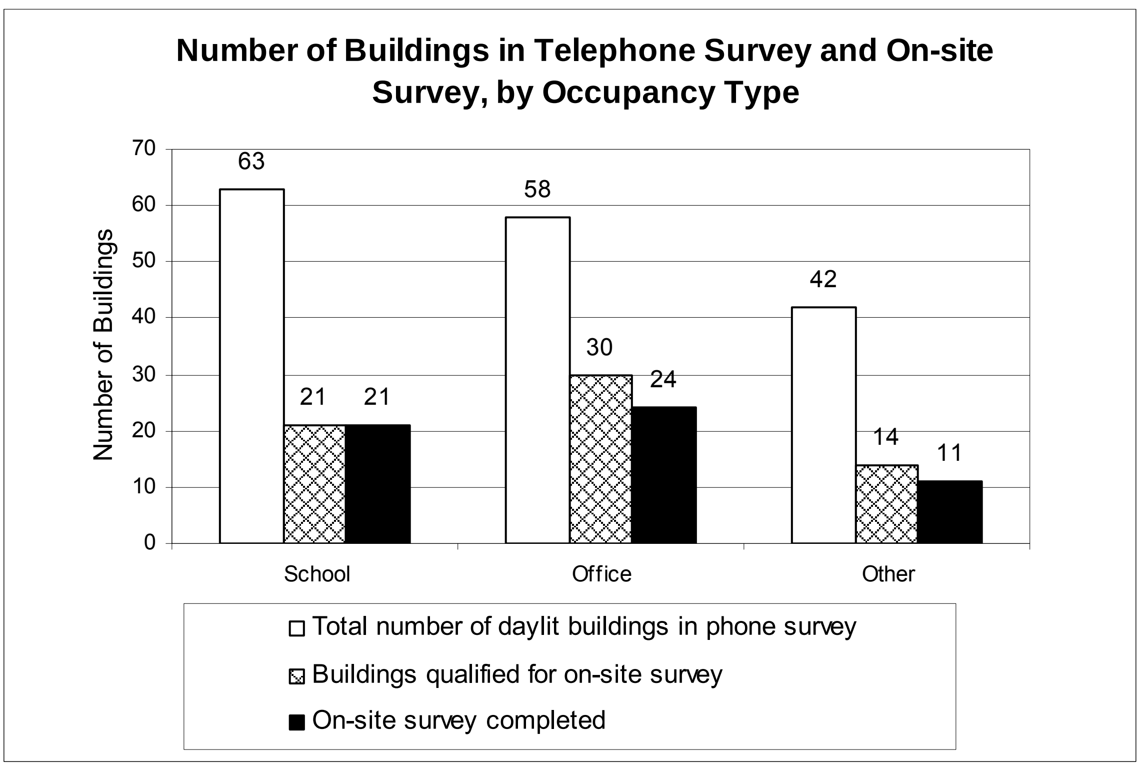

Figure 12 – Number of Surveyed Buildings, by Occupancy Type

Reasons for Disqualifying Potential Sites

64 of the 162 sites qualified for on-site surveys, and 98 did not qualify. The reasons for non-qualification are shown in Figure 13. In several cases, a site was non-qualified for two or even three reasons, so the totals in the figure below add to more than 100%. The most common reason was that the site did not have photocontrols installed. The interviewer confirmed that, in many of these cases, the photocontrols had been dropped from the design before construction. In other cases the interviewee simply did not know anything about a photocontrol system, and so the history could not be determined.

The second most common reason was that the building had skylights or some other form of toplighting. Since our study was designed to determine the effectiveness of photocontrols in sidelit applications, we had to exclude buildings with substantial toplighting contributions. It is interesting that 23% of our recommended "sidelit sites" were also reported to include skylights, indicating a potential increased use of skylights in daylighting design.

Reasons classified as "other" included that the building was residential, or that the building was vacant. On one site the photocontrols had been removed several years previously.

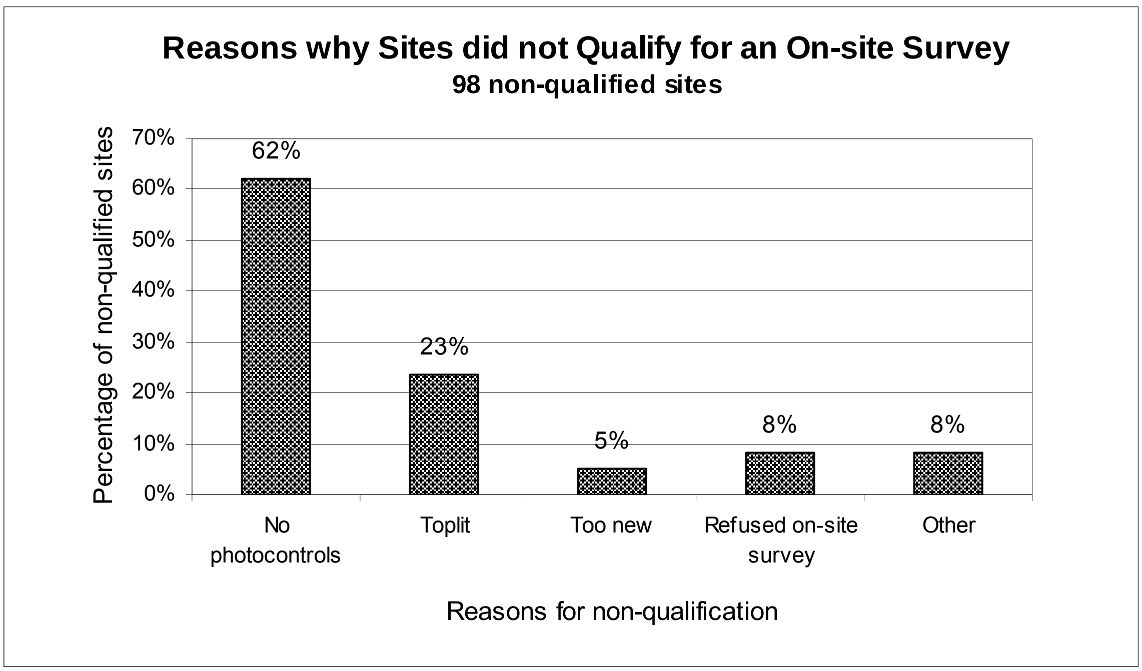

Figure 13 - Reasons why Sites did not Qualify for an On-site Survey

Square Footage of Buildings

The average size of the buildings in our phone survey is 159,000 square feet. Figure 14 shows that most of the buildings surveyed are in the range of 10,000 to 500,000 square feet, with a few very small buildings and a few very large buildings; the largest building in the telephone survey is 1,500,000 square feet.

The largest group (17%) is the 50,000-100,000 square foot range. Although buildings were not screened for their square footage, we hoped to include a wide range of building sizes in the sample.

Figure 14 also shows that the distribution of building size is similar for offices and for “other” buildings. The distribution of building size is similar for schools in the lower ranges, but there are no schools in the two largest size categories. The largest school in the sample is 270,000 square feet.

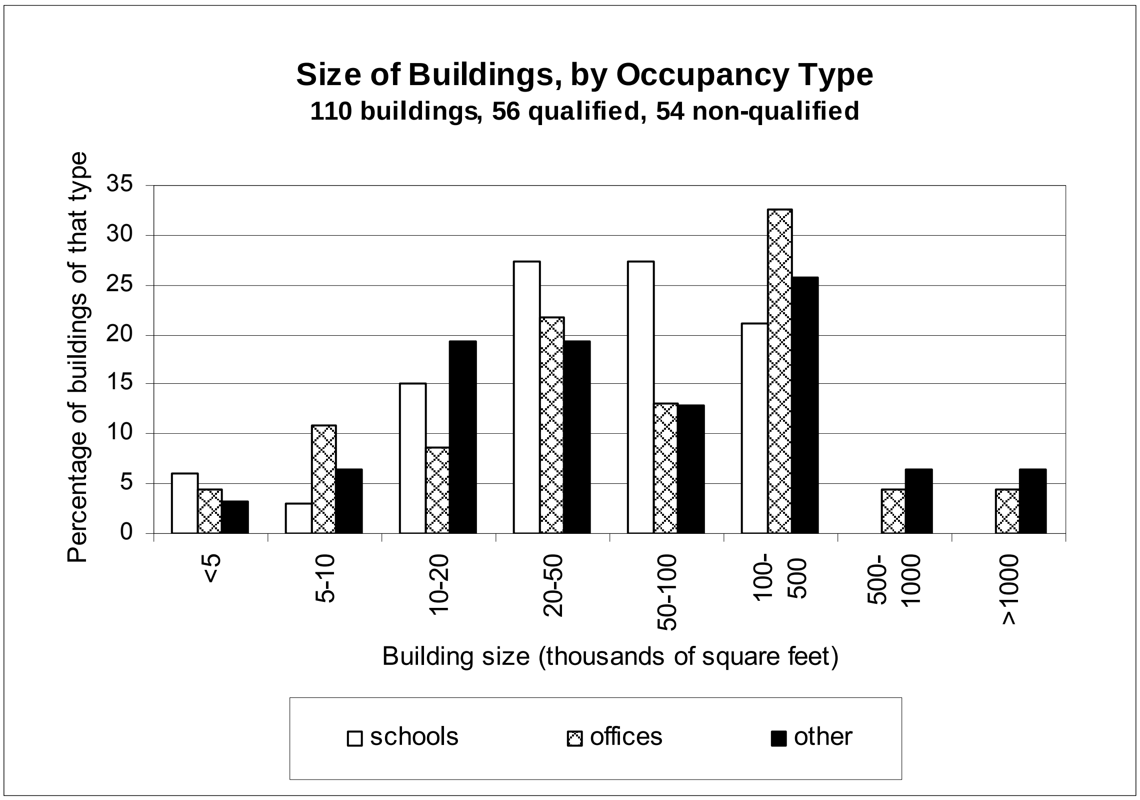

Figure 14 – Square Footage of Phone Survey Buildings, by Occupancy Type

Number of Stories

The average height of buildings in the phone survey is 2.9 stories. Figure 15 shows that, for every building type, more than 50% of the sample consists of one- and two-story buildings (56% for schools, 84% for offices, 70% for “other”). The distribution of building heights is similar for schools and “other” buildings, but there are proportionally fewer one-story offices, and proportionally more very tall office buildings.

It is interesting that such a large proportion of these sidelit sites are low-rise, and thus also likely candidates for top-lighting. Program managers often assume that sidelighting is important as a daylighting solution for high-rise buildings; however this sample shows that it is much more commonly applied in low-rise buildings.

The age of the building for our purposes was defined as the number of years since the date of occupation. The average age of buildings in the survey was 7.6 years.

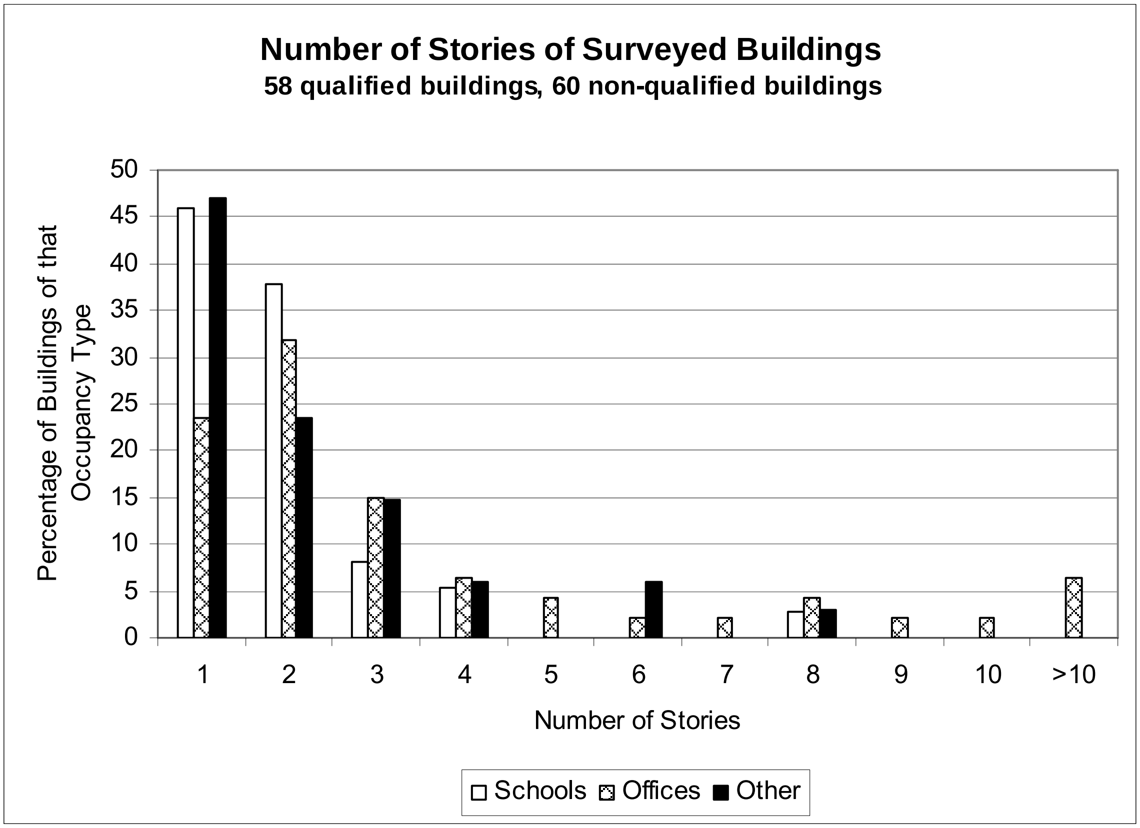

Figure 15 – Number of Stories of Phone Survey Buildings

Age of Buildings

Figure 16 shows that the age distribution in the on-site survey succeeded in being very similar to the phone survey. Over 50% of the buildings in the sample are less than 3 years old, and one quarter were over ten years old, as shown in Figure 16. There are two likely reasons why this may be the case. First of all, the use of photocontrols may be becoming more common as daylight grows in popularity and the price of controls falls. However, it is also clear to us that it was much more difficult to get sufficient information on older installations to include them in our survey. Designers' interest is largely in the projects currently "on the boards" and their memory for past projects is surprisingly short. Similarly, contacts suggested for older buildings had often changed jobs and were difficult to find for the interviews.

The distribution of building ages is similar to that found in HMG's 2002 study of photocontrols in toplit spaces (sited earlier), in which 67% of the buildings were less than three years old. The same potential explanations for the newness of the buildings apply to both studies.

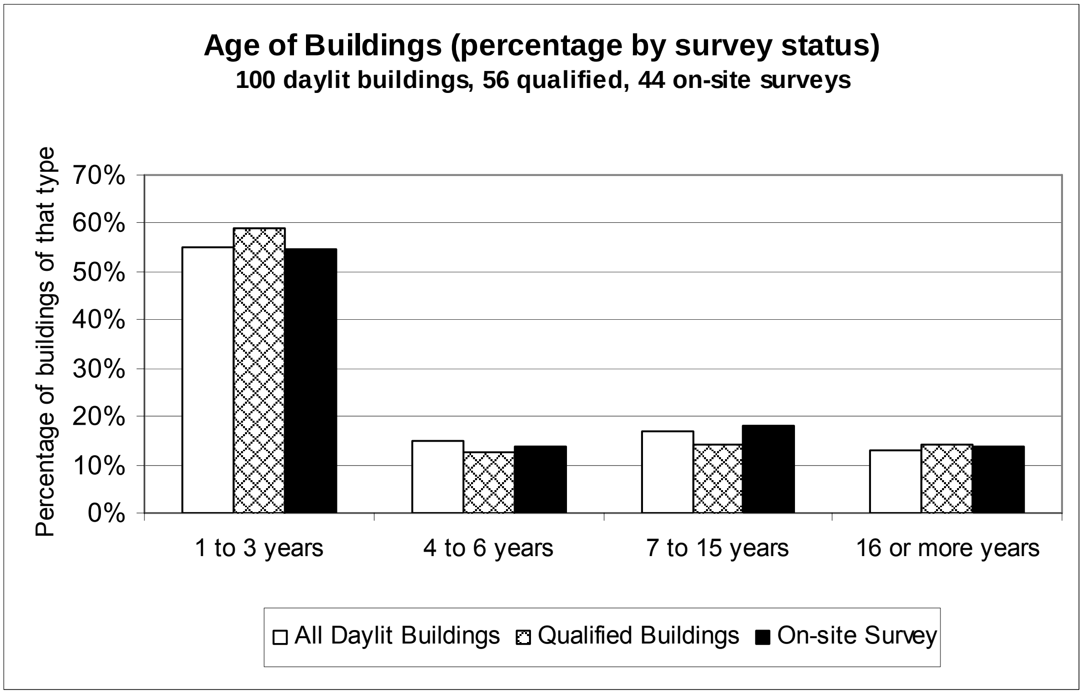

Figure 16 – Age of Surveyed Buildings (percentage by survey status)

Figure 17 shows that the distribution of the age of buildings is similar for each occupancy type.

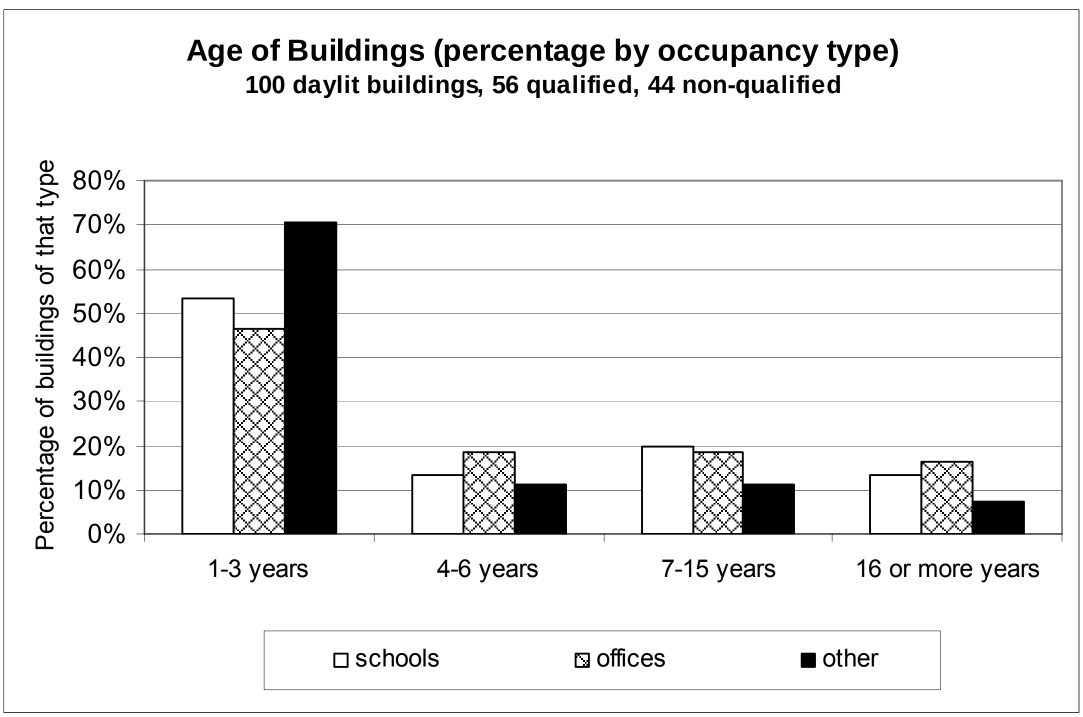

Figure 17 - Age of Phone Survey Buildings (percentage by occupancy type)

Figure 18 shows that the average size (black diamonds) of the buildings surveyed does not change significantly or systematically according to their age.

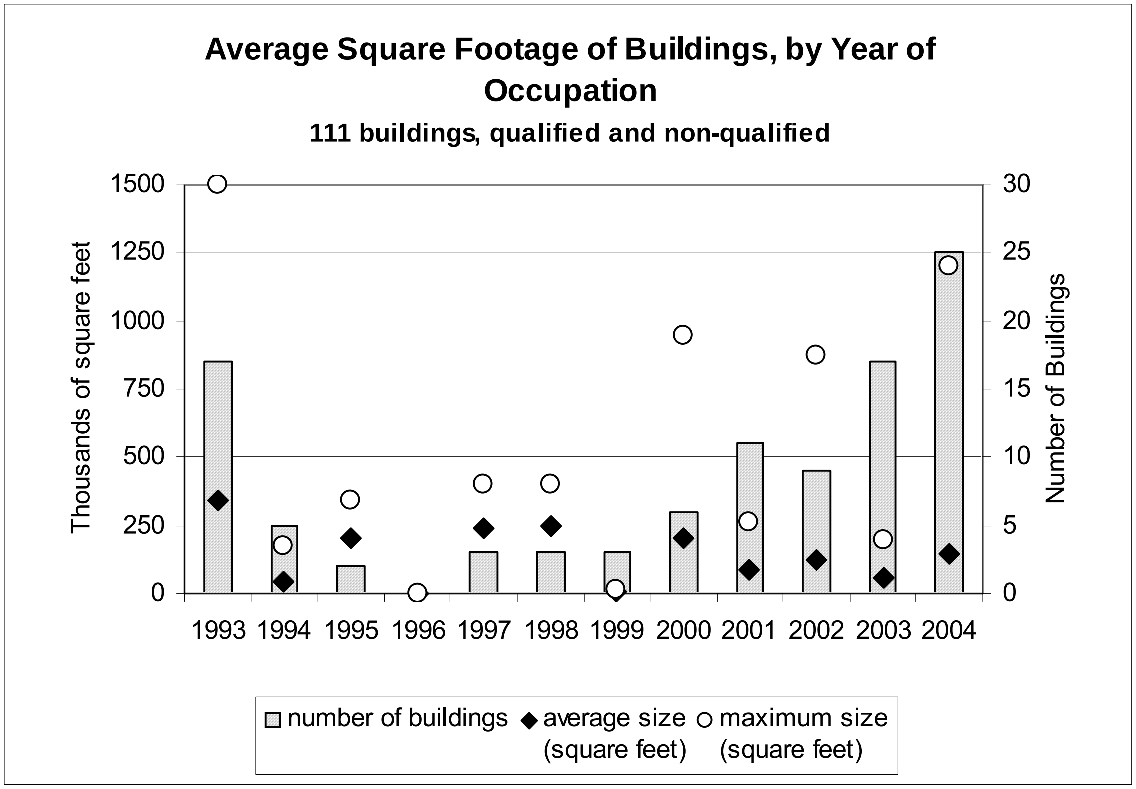

Figure 18 – Number of Buildings in Phone Survey, Total Square Footage and Average Square Footage of Buildings by Year Constructed

Daylight Strategies

The phone interview asked about the kinds of daylight strategies employed at each building site. View windows are defined as glazing area from desk height up to 8' above the floor. Clerestories are glazing areas in the wall above 8'. The results presented in Figure 19 give some sense of the prevalence of daylight strategies by building type for this sample of buildings that was pre-filtered as being "buildings designed with an intentional sidelighting daylight strategy with automatic photocontrols." In general, there would seem to be a surprisingly high proportion of clerestories and skylights within this population.

We found that almost all of the buildings in the survey have some view windows. 15% of the survey population had <u>only</u> view windows. Half of the buildings with any view windows also have some clerestories. Clerestories are more prevalent in schools than in offices or "other" buildings, and 13% of schools in the sample have no view windows.

Note that the answers given are for the whole building rather than for a particular space. Thus, for example, while 41% of sidelit school buildings had at least one space with skylights, this does not mean that 41% of classrooms had skylights. There could have been one skylight anywhere within the building complex.

Two of the buildings in Figure 19 have atria bounding the photocontrolled spaces. Both of those buildings also have view windows, clerestories and skylights. None of the buildings surveyed had roof monitors.

	Schools	Offices	Other
View Windows Only	8	14	3
View and Clerestories	12	11	6
View and Skylights	3	6	10
All (View, High and Skylights)	11	15	15
Clerestories Only	3	0	0
Skylights and Clerestories	2	2	1
Skylights Only	2	0	3
No Answer	22	9	4
TOTAL	63	57	42
Percentage of all sidelit* sites with <u>any</u> view windows	87%	96%	97%
Percentage of all sidelit sites with <u>any</u> clerestories	72%	58%	63%
Percentage of all sidelit sites with <u>any</u> skylights	41%	48%	74%

*sidelit buildings are defined as those that have view windows, clerestories, or both.

Figure 19 – Modes of Daylight Admission into Phone Survey Buildings

Interviewee Assessment of Daylight Design of Building

Phone interviewees were asked whether there was anything unsatisfactory about the daylight design of the building. If the response was "yes, there is something unsatisfactory", then the interviewer listed seven specific problems to which the interviewee could answer yes or no, the first seven responses shown in Figure 20. The interviewer then asked whether there were any <u>other</u> daylight-related problems with the building. These free-form responses were later categorized, and are shown at the end of the table.

Response	Schools	Offices	Other
Number of interviewees for question	26	37	21
No complaints	**58%**	**46%**	**29%**
Pre-categorized complaints			
Too much sunlight	4%	16%	19%
Too much glare	8%	22%	14%
Too hot	8%	8%	5%
Too Cold	0%	0%	0%
Not enough light	12%	3%	19%
Too much contrast between light and dark areas	4%	5%	0%
Dissatisfaction with curtains or blinds	0%	0%	5%
Free-form complaints (grouped)			
Had to install blinds or awnings, rearrange the furniture etc. to correct daylight problems	4%	19%	14%
Too much glare specifically on computer or TV screens	4%	8%	10%
Occupants would like more windows	0%	0%	5%
Individual preferences differ, making it hard to adjust the daylight to please everyone.	0%	3%	0%
One or more occupants find the building too brightly daylit	0%	0%	5%
Water leaks through windows	0%	0%	5%
Initial problems with occupant acceptance	8%	0%	0%

Figure 20 - Is there Anything Unsatisfactory About the Daylight Design of the Building?

Figure 20.shows the percentage of people who gave each answer; several people gave more than one answer. On average across building types, 55% of interviewees made at least one complaint about the daylight design of their building. Schools had the largest percentage of interviewees with no complaints (56%), followed by offices (46%), then other buildings (30%). Schools also had the lowest average number of complaints per interviewee (0.48), followed by offices (0.81) then other buildings (1.05). The difference between offices and other buildings is not significant (p=0.4). From this, we conclude that in general schools are experiencing fewer daylight design problems than other building types.

The responses in Figure 20 suggest that the most common problems perceived by the site hosts were too much glare from sunlight, and secondarily insufficient daylight. The problem of glare and sun penetration are also reflected in the top free form responses about installing blinds or curtains, and problems with glare on computer screens. This suggests that glare control and avoiding sun penetration should be a top priority in promoting more successful daylit buildings.

Interestingly, other researchers have found that building occupants are extremely likely to complain about thermal comfort, relative to other problems in the environment, but in this case we received relatively few complaints about overheating and none about being too cold.

Percentage of Lighting Controlled by Photocontrols

Interviewees who reported their building had a photocontrol system installed were asked how much of the lighting in the building was controlled by a photocontrol system. The responses, as shown in Figure 21, show a bi-polar distribution, where it was either reported that the majority of the building area had photocontrols (51%-90%), or else that the minority of the building area was controlled (10%-25%). Despite this distribution, the average percentage of lighting on automatic photocontrols for the whole population fell in the middle for all building types: 45% for schools, 41% for offices, and 47% for “other” buildings.

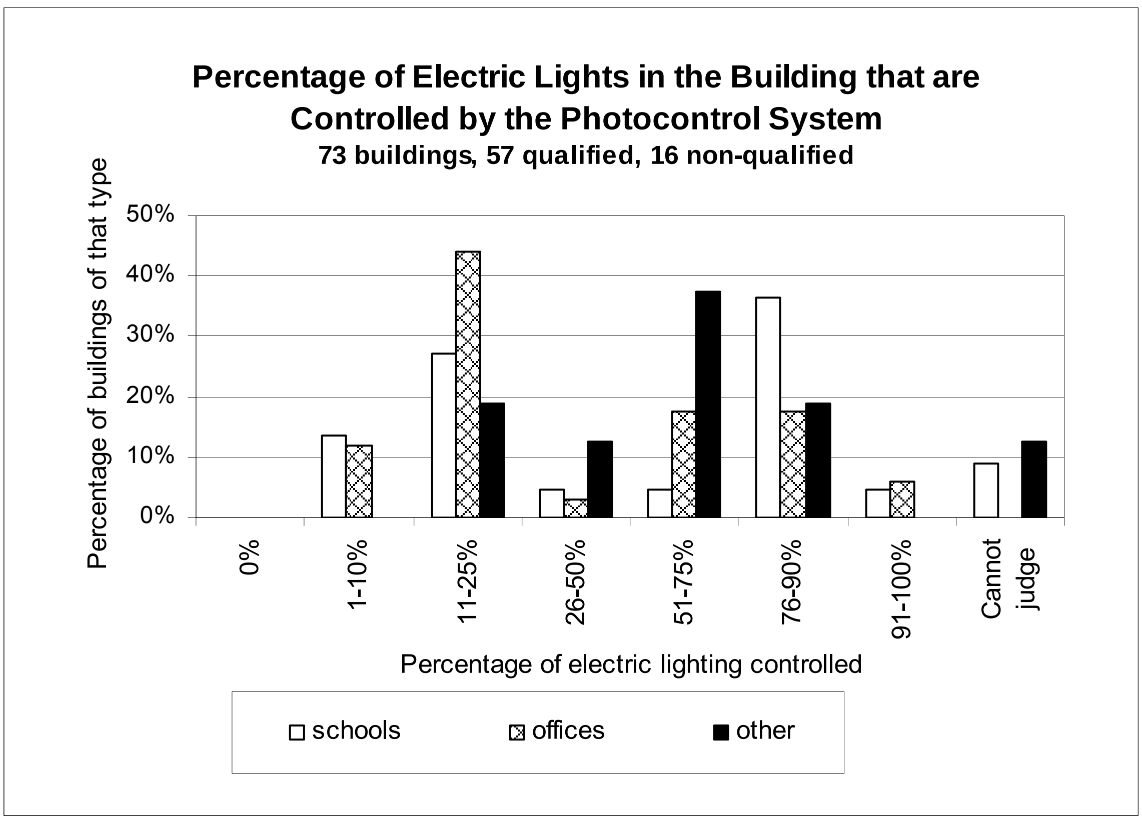

Figure 21 - Percentage of Electric lighting in the Building that is Controlled by the Photocontrol System

3.2.4 Photocontrol System Characteristics

Interviewees were asked whether their photocontrol systems used a dimming or switching strategy, or both, and whether any other control devices (such as occupancy sensors) were operating on the same circuits as the photocontrols. They were also asked about the status of the photocontrol system (i.e. whether they believed that the photocontrol system was working or not), and how satisfied they were with it.

The purpose of these questions was two-fold: to determine the characteristics of the photocontrol systems in the survey, and to find whether the reported status of the systems was correlated with any other variable, such as the type of lamp regulation (dimming or switching), the age of the building, or the occupancy type.

Type of Lamp Regulation

Figure 22 shows that the majority of the buildings for which an answer was received had switching systems (56%), while 41% had dimming systems. Only 3% of buildings had both dimming and switching systems; two of these buildings had been specifically constructed to be demonstration buildings, and the third was a university with many photocontrolled spaces. Switching systems predominated in schools and "other" buildings, whereas dimming predominated in offices.

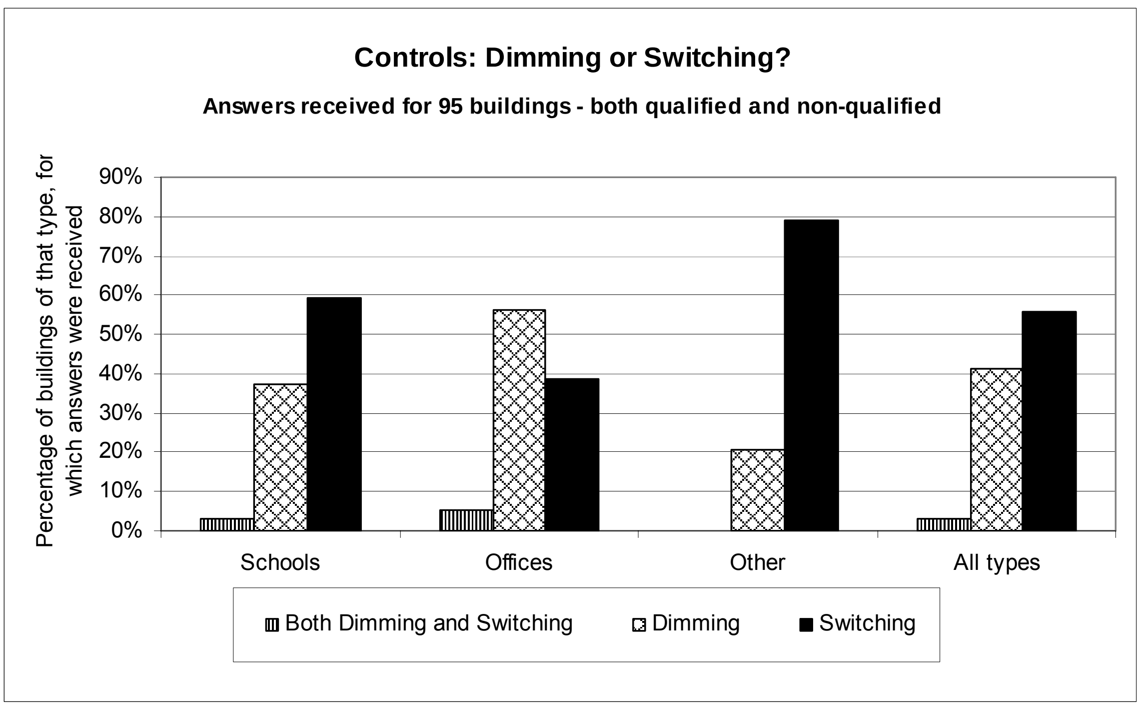

Figure 22 – Type of Lamp Regulation, by Occupancy Type

Interestingly, we found a different proportion of system types in our on-site survey, with 67% of spaces surveyed using dimming. Since almost all qualified sites were surveyed, it follows that a high proportion of the non-qualified sites included in Figure 22 were switching, implying photocontrols were more likely to actually be installed in buildings that also invested in dimming ballasts.

Other Types of Lighting Controls Installed in Survey Buildings

The values in Figure 23 show the percentage of buildings of each occupancy type that had other types of lighting control systems installed, in addition to automatic photocontrols. There were 56 buildings out of 162 for which no answer was received (almost all of these were non-qualified); the values presented are percentages of all those buildings for which an answer was received.

	Schools n=34	Offices n=44	Other n=28
Occupancy sensors	79%	68%	71%
Manual on and off switching by occupants	82%	77%	50%
Manual on and off switching by building manager	6%	11%	11%
Dimming by occupants	32%	11%	0%
Dimming by building manager	0%	2%	0%
Automatic time sweeps	32%	50%	32%
Connected to energy management system	12%	5%	18%
Programmable scene controller	0%	0%	0%

Figure 23 – Other Types of Lighting Controls Installed in Buildings

Figure 23 shows that occupancy sensors are extremely common, present in 68% to 79% of the buildings. Manual switching options for occupants are also extremely common at 50% to 82%. Automatic time sweeps are the next most common at 32% to 50%. Energy management systems and centralized dimming control by the building manager is fairly rare (0% to 18%). Note that these other types of control are present in the building but may not necessarily be in the same spaces as the photocontrols. However, the findings do suggest that making sure that photocontrols are compatible with other lighting control systems is likely to be important, and also that helping building operators and occupants understand the differences between the various control systems would be helpful.

Occupant Assessment of Photocontrol System Status

The interviewer asked the interviewees to describe how well the photocontrol system was working. The question was answered on a scale of one to seven, where one meant “not working at all”, and seven meant “working extremely well”. As shown in Figure 24, most of the interviewees thought that their photocontrols systems were working well. Few interviewees reported that they were uncertain about whether the photocontrol system was working. In general, offices had a lower overall score, as show in Figure 25. Interestingly, this finding was also born out in the on-site survey (see Section 6.2.1)

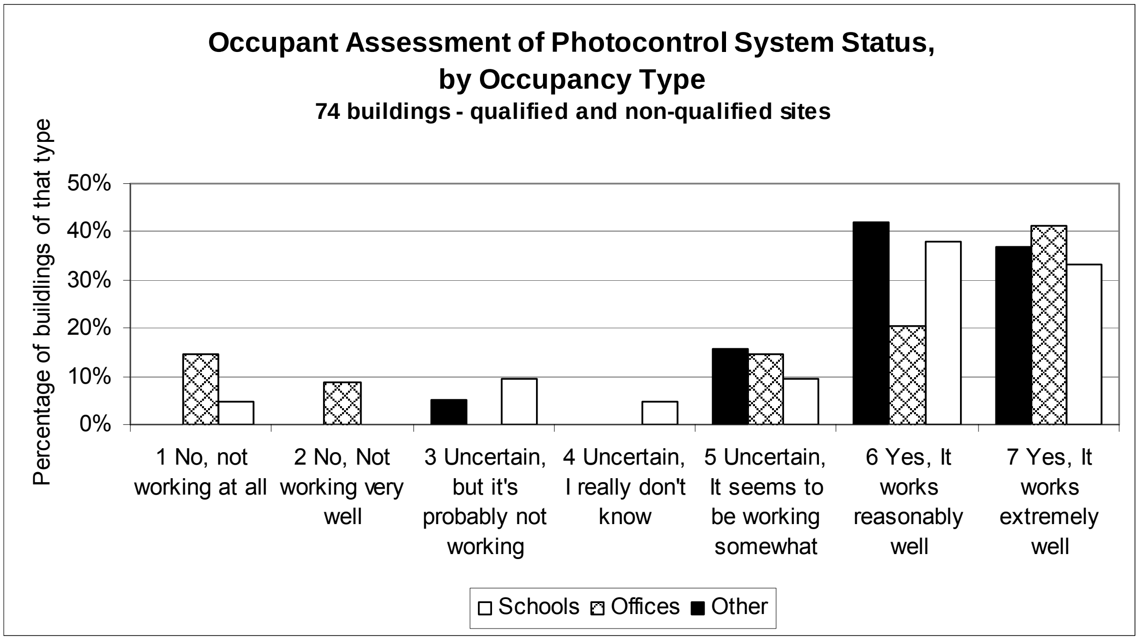

Figure 24 – Occupant Assessment of Photocontrol System Status

Building Type	Average rating of photocontrols condition (1=not working at all, 7=working extremely well)
Schools	5.1 (19 responses)
Offices	4.2 (34 responses)
Other	5.1 (19 responses)

Figure 25 - Average Values for Photocontrol System Status by Occupancy Type

We also analyzed whether there was a trend in how well the systems were reported to be working relative to the age of the building. The numerical averages of the responses (on a scale from 1 to 7) for each age category are shown in Figure 26. This shows that there is no general improvement or decline in the status of photocontrol systems with age.

Age category	Average rating of photocontrols condition (1=not working at all, 7=working extremely well)
1-3 years	4.8 (37 responses)
4-6 years	2.7 (6 responses)
7-15 years	4.2 (11 responses)
16+ years	4.3 (9 responses)

Figure 26 – Average Values for Photocontrol System Status by Age of Building

We also analyzed the report of the operating status of the system as a function of dimming or switching. Figure 27 shows that the operational status of dimming systems was ranked higher than the status of switching systems. For dimming systems a much higher percentage of respondents reported that the system was working “extremely” well; a chi-squared test showed that this difference was significant at the 10% level (p=0.095).

This result is different from the result obtained in SCE’s study of photocontrols in toplit spaces[1], in which dimming systems were ranked identically to switching systems (an average of 3.1 out of 4 on a scale from “overridden” to “working well”. However, the toplighting study only contained 7 sites out of 35 with dimming systems.

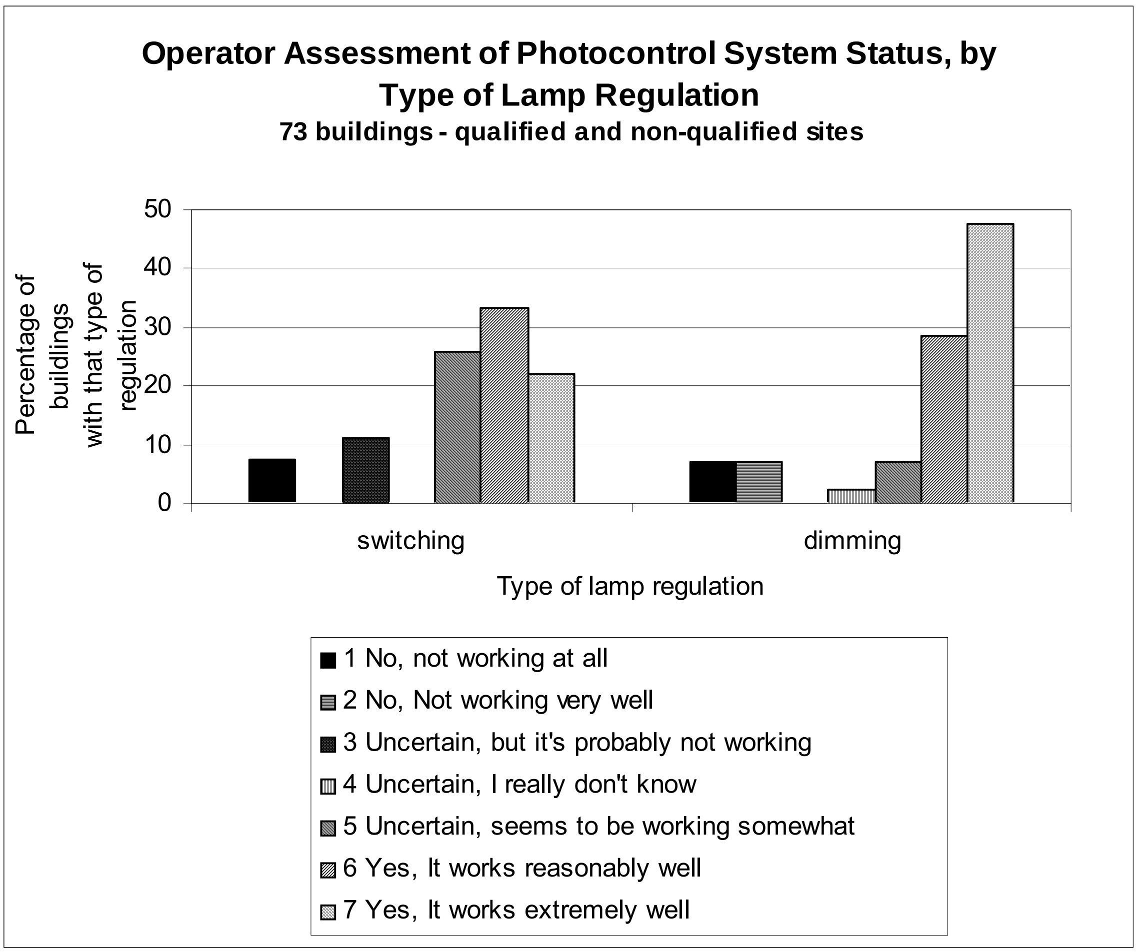

Figure 27 – Operator Assessment of Photosensor System Status, by Type of Lamp Regulation

[1] Heschong Mahone Group, *Photocontrol System Field Study*. Report submitted to Southern California Edison Company. 2002.

Interviewee Satisfaction with Photocontrol Systems

As well as asking about the status of the system, the interviewer asked whether the interviewer was satisfied with the system. Analysis showed that, as expected, of the 71 interviewees who responded to both questions, their satisfaction with their photocontrol systems was strongly correlated with their judgments of how well those systems work.

Whenever an interviewee expressed a specific reason for dissatisfaction with their system, the interviewer made a note of the reason given. 41 comments were received from the 73 interviewees who answered the question "how satisfied are you with the current operation of the control system?" These are characterized in Figure 28.

	Completely Satisfied	Satisfied or somewhat satisfied	Neither Satisfied nor Dissatisfied	Dissatisfied or somewhat Dissatisfied	Completely dissatisfied	I cannot judge	**Totals**
Too sensitive (dims the lighting more than is acceptable)		3		1	2		**6**
Not sensitive enough (does not dim lighting aggressively enough)		2		1			**3**
Stepped switching is annoying to occupants or there are not enough stages		1					**1**
Occupants ignore or override the system		3					**3**
Too complex for users		1	1				**2**
Occupants or managers initially found the system difficult to use		1					**1**
Would like a manual dimming override			1				**1**
Would like a manual on override			1				**1**
Calibration is difficult, time consuming		9		3			**12**
Wired incorrectly					1	1	**2**
Interface with EMS not working			1				**1**
Trouble with related entity (shades, cubicle, high partitions, placement of luminaires)		2		1			**3**
Sensor type and location seem incorrect		1		1			**2**
Premature ballast failures		2					**2**
Premature lamp failures		1					**1**
TOTAL		**26**	**4**	**7**	**3**	**1**	**41**

Figure 28 – Reasons for Dissatisfaction with Photocontrol Systems

People who gave a reason for dissatisfaction with their system had, on average, the same level of satisfaction (4.4 out of 1-7) with their systems as those who did not give a reason (4.5). Responses were categorized as shown in Figure 28. By far the most common reasons for dissatisfaction were difficulties associated with calibration (12) and/or overly complex systems (3). Dissatisfaction with "over-dimming" (6) was only slightly more common than "under-dimming" (3). Interestingly, there was only one specific complaint about step switching, while many designers believe that step switching will not be tolerated by occupants.

3.2.5 User Characteristics

These findings address issues that are not related to the physical space or to the control system equipment, but to the characteristics of the people operating and maintaining the system. After the interview was complete, the interviewer was asked to subjectively rate the interviewee for how "confident" they were in answering questions about the building lighting systems and if they provided believable and informed answers.

The interviewer judged most interviewees to be quite confident in answering questions about their photocontrol systems. Analysis showed that interviewees who were judged to be confident were not statistically more likely to be in one building type or another, nor were they more likely to give either higher, lower, or more polarized answers to the question "Is the photocontrol system in your building currently working".

Staff Training in How to use the Photocontrol System

The interviewer asked whether anyone had been specifically trained in the operation of the photocontrol system. This person could be a facilities manager, a custodian, an electrician, a member of the management, an occupant, or anyone else associated with the facility. Figure 29 shows that schools had the highest percentage of sites where someone was trained, while "other" buildings had the lowest percentage where someone was trained, and also the greatest uncertainty on the question.

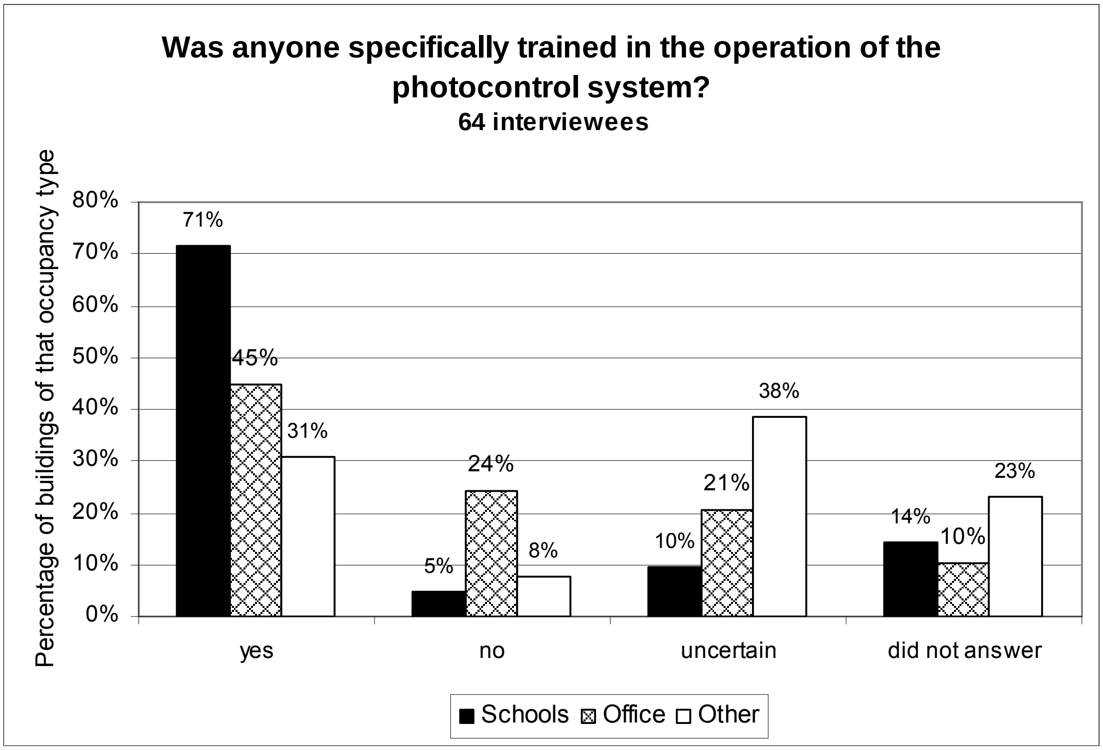

Figure 29 – Staff Training in Photocontrol System, by Occupancy Type

In total, there were 39 sites at which someone was reported to have received training, 15 where no-one was trained, and 11 where the interviewee was uncertain. Training did not predict if the respondent was more likely to be satisfied with the system or report it working well.

Adjustments to the Photocontrol System

The interviewer asked who would be most likely to make changes or adjustments to the photocontrol system, as a way to probe how the system was managed on site, and the level of expertise involved in managing the system. The majority (59%) of respondents gave the title of some one already on-site, such as themselves or another member of the facilities staff. The next largest group (38%) mentioned an electrical contractor or installer. Commissioning agents, manufacturers or architects or engineers were only mentioned by one or two respondents each.

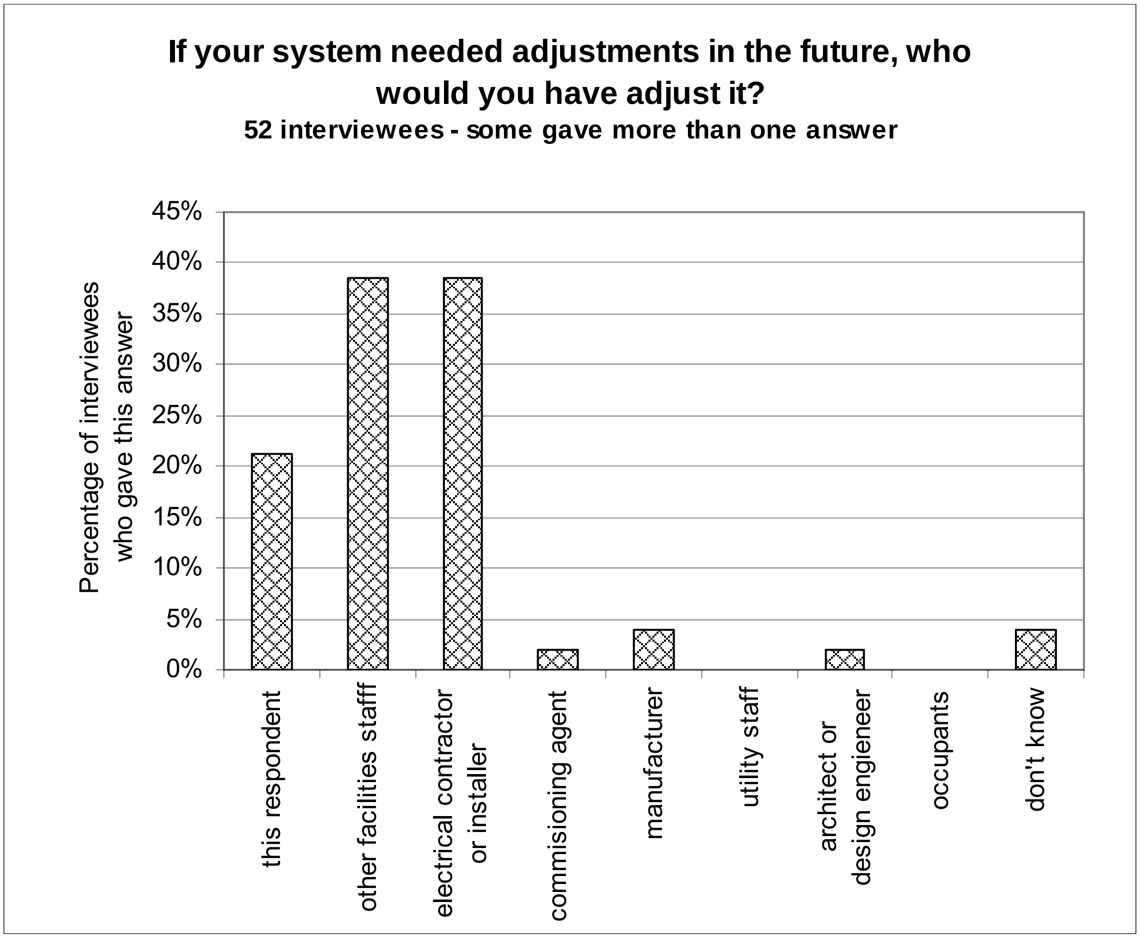

Figure 30 – Who Would Make Adjustments to Photocontrol Systems

There was no statistical significance in the difference between how well the photocontrol systems were reported to be working versus who was likely to make adjustments. In other words, whether on-site staff or an electrical contractor was likely to make the adjustments did not predict how well the system was thought to be working.

The answers to this question clearly suggest that photocontrol systems will be maintained primarily by local, site-based facilities staff, or secondarily by the normal site electrical contractor, and therefore these systems need to be understood by people working at that level.

4. ONSITE SURVEY METHODOLOGY

We began to conduct on-site surveys as soon as potential "qualified" sites were identified from the phone survey. Thus the two survey activities were conducted in parallel, with the phone survey just a few steps ahead of the on-site surveys.

The onsite survey methodology was based on the study of photocontrols in toplit spaces that HMG carried out for Southern California Edison in 2002. The survey consists of three components:

- An interview with the person who maintains or is responsible for the photocontrol system
- A survey of the space, including physical dimensions, illuminances, luminaire information, circuit currents, a digital luminance map, and occupant surveys.
- Positioning and calibration of data loggers that record illuminance and circuit current.

Data loggers were left in place for two weeks before being removed either by an electrician or by the site host, and were mailed by to HMG for downloading and processing.

After the onsite data had been collected and quality checked by the surveyors, it was entered into an Access database, where it was again quality checked by a data manager before being analyzed.

The onsite surveys were conducted from October 2004 and March 2005. Three HMG employees conducted all of the surveys. A licensed electrician was used to install data loggers in circuit panels or inside luminaires. About half of these electricians were employees of the site; the others were outside contractors hired by HMG.

4.1 Onsite Survey Protocol

A standard data collection protocol was developed to ensure that we could collect sufficient data from each site, in a sufficiently standardized way to allow energy modeling and comparisons between sites. The starting point for the protocol was the Photocontrols Field Study that HMG conducted for SCE in 2002. The protocol ensured that:

- There would be enough information from each site to create a DOE-2 daylighting model of each space.
- Sufficient data was collected to allow the data logger measurements to be calibrated to actual conditions in the space.
- Data was collected in a consistent manner on a variety of factors that were hypothesized to impact the performance of photocontrol systems such as

the management and occupancy of the space, features of the photocontrol system, the size of controlled zone, the type of electric lighting, features to control glare etc.

- Data collection on site would be as efficient as possible, with no duplication of data.

The onsite protocol was developed into an on-site data collection booklet, which the surveyors used to collect all the on-site data. This data collection booklet was drafted by the project team (see section 4.1), and then reviewed by the Photocontrols Advisory Board. It was further tested and developed during two trial onsite surveys before being finalized. The trial surveys also served to standardize measurement and recording techniques between the team of three surveyors.

A sample of the onsite data collection booklet is included in the Appendix. There were four main components to the onsite survey, as shown below

4.1.1 Onsite Interview

The interview was conducted with the "site host", the person who had been identified as having the best working knowledge of the photocontrol system. Sometimes this was a different person from the person who was interviewed in the telephone survey. Most often this person was a facilities manager. The interview was designed to collect historical and background information about the building and lighting control system that could provide insight useful in subsequent analysis. It addressed the following issues:

- Information about the building – its size, ownership, age, and whether any assistance had been received from incentive programs during the building's procurement.
- The history of the photocontrol system - when it was installed, who installed it, whether any components had been replaced, whether any records of the installation or commissioning process existed
- The site host's judgments about how well the system worked, how satisfactory it was, and how much energy it saved.
- Whether anyone had been trained in how to use or adjust the system.
- Who was responsible for maintenance and adjustments.
- Whether the control system exhibited any problems was and the interviewee's opinion on the cause of the problem.

4.1.2 Selecting Study Spaces

The main intent in selecting the study spaces was to ensure that the study sample represented a range of photocontrols operation, as well as a good diversity in terms of occupancy, geometry and size of the space. When we could survey only two spaces in a building, we usually surveyed a space that had the best functioning photocontrol system, and a space that had the poorest functioning photocontrol system. This judgment was usually made by the site host in discussion with the surveyor, following a review of the building plans.

When we were able to survey more than two spaces, we chose additional spaces that would add diversity to the sample population, in terms of the space usage, orientation, photocontrol system type or status, space size or geometry, fenestration, shading devices etc.

In many cases the choice of spaces was restricted by specific requirements of the site host or the occupants. For instance in some spaces it would have been very inconvenient to switch the lighting off or to disturb the occupants, so we chose not to survey those spaces.

4.1.3 Data about Each Space

The surveyor visited each candidate space in turn to make measurements and observations. The order in which these were made varied according to time constraints. Two of the most important time constraints were whether (or when) the surveyor was able to switch the lighting on and off, and when the electrician was available for installing monitoring equipment.

In each space the surveyor used a flashlight to determine whether the photocontrol system would dim or switch off the luminaires in response to bright light falling on the photosensor. The surveyor also operated the light switches to determine how the luminaires were circuited.

During the survey, the surveyor took photographs of the important features of the room and the photocontrol system, to act as a record of the space for future analysis.

For each space, three areas were defined, as shown in Figure 31, which were:

5. **The area of the whole space**. This is the whole area over which daylight conditions, electric lighting and photocontrol system operation are consistent. This might be one whole façade of an open office, or a row of book stacks in a library, measured to the first wall or ceiling-height partition.

6. **The study area**. This is the area bounded by the monitored lighting circuits, i.e. every photocontrolled circuit, along with one or more uncontrolled circuits. In small rooms, the study area would be the size of the room. In very large spaces, for instance open offices, the study area was sometimes a representative “slice” of the whole area; typically this would be approximately a 30’ wide by 30’ deep segment of the larger area.

7. **The photocontrolled area**. This is the part of the study area illuminated by the photocontrolled luminaires. The boundary of the photocontrolled area runs halfway between the photocontrolled controlled and non-controlled circuits.

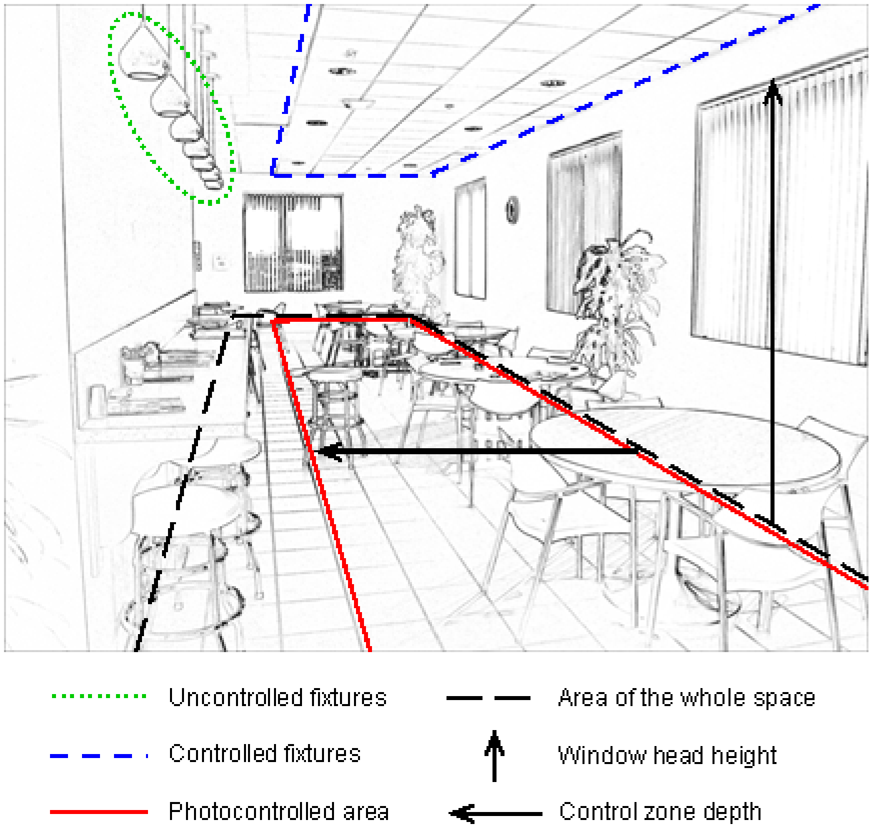

Figure 31: Schematic of key dimensions and survey areas

For each surveyed space, the following types of information were gathered:

- The physical dimensions and characteristics of the study area, including the position and orientation of windows, any key daylight distribution features, such as light shelves or shading, position and orientation photosensors, location of light switches, and luminaire layout .
- The reflectances of key surfaces - the floor, walls, ceiling and partitions.
- The transmittance of the windows, including the position and net transmittance of any blinds at the time of site survey.
- Illuminance values. This included horizontal at the critical task, horizontal at task level on a 3 x 3 grid across the space; vertical facing four directions in the center of the room four feet above the floor; and at the window.
- Information about the photosensor, including the make and model, physical condition, and a description of adjustment settings (when they could be discerned).

- Information about the photocontroller (when present). This included the make and model, the type of controller, and what other systems it was connected to.
- Information about the electric lighting system, including the types of light switches provided, whether occupancy sensors were installed, the number, type and wattage of lamps, the luminaire light distribution and what type of lens or reflector was installed.

4.1.4 Data Logger Performance and Calibration

Illuminance and current data was collected for the two week monitored period using Onset Corporation HOBO 8-bit and 12-bit loggers. Each HOBO logger had a built-in crude illuminance sensor, and a signal input for recording current measured by a current transformer. The current transformers we used were 20 Amp current transformers manufactured by Onset Corporation specifically for HOBO loggers.

The 8-bit and 12-bit loggers are different in three main ways; first, the 12-bit loggers can record 4096 (2^{12}) discrete levels of current or illuminance, whereas the 12-bit loggers can record only 256 (2^8) discrete levels. Second, the 12-bit loggers can record data for a longer period and third, the 12-bit loggers can record higher illuminance values before reaching saturation. Details of the loggers' capabilities are shown in Figure 32.

	8-bit	12-bit
Maximum illuminance value before saturation	600-900 fc (depending on model)	1500 fc
Step between discrete illuminance values	2.4-3.5 fc (depending on model)	0.4 fc
Maximum current value before saturation	20 A	20 A
Step between discrete current values	0.08 A	0.005 A
Maximum recording period (2 channels of data at 5-minute intervals)	13 days	75 days

Figure 32 - Data Logger Capabilities

The smaller step value of the 12-bit loggers made them more suitable for recording small changes in illuminance or current, so 12-bit loggers were used for recording the illuminance at the critical task, and for recording currents through single luminaires, or circuits with low currents. 8-bit loggers were used for circuits with higher currents, and for recording window illuminance.

HMG carried out a calibration of the loggers prior to the trial on-site surveys, and found that the illuminance measurements were highly linear, but only for a given light distribution. Different light distributions produced very different illuminance readings between the loggers and a cosine- and V(λ)-corrected illuminance meter. Because the light distribution varied significantly from one surveyed space to another, in each space we used a handheld illuminance meter to take calibration measurements for every data logger, to reduce the margin of error in the logger readings. Some error remained, however, because the changing balance of daylight and electric light in each space resulted in constant variations in light distribution.

In some cases, time-of-use (TOU) light loggers manufactured by Dent Instruments (previously Pacific Science and Technology) were used to record the operation of switching luminaires. These binary loggers record the times that the luminaire's output is above a threshold level, as set by the surveyor. The energy consumption of these luminaires was calculated by multiplying the hours of operation by the wattage of the lighting load on this circuit.

4.1.5 Data Logger Locations

The number of loggers installed in each space varied from three to eight, depending on the number of controlled and non-controlled circuits, and the complexity of the space. The locations in which loggers were installed are as follows:

The Photocontrolled Circuit(s)

Sufficient loggers were installed to monitor every photocontrolled circuit. Where possible, these loggers were placed in the circuit panel in conjunction with current transformers to log the current flowing to the photocontrolled luminaires. Where this wasn't possible, the current transformers were placed inside the junction box. In some of the early on-site surveys the current transformers were placed inside the luminaires, but unfortunately, we discovered after the fact that this caused high levels of interference to the signal (see section 4.1.6). In some cases it was impossible to get access to the junction box, and in these cases the logger was placed inside the luminaire a few inches from the lamp, to record illuminance as a proxy for current.

One or More Non-Controlled Circuits

Where the space had luminaires that were *not* controlled by the photocontrol system, we monitored those circuits as a proxy for the occupancy of the space, and to be able to work out energy savings (see section 5.1). Some spaces did not have non-controlled circuits; in these spaces we sometimes put a logger in an adjacent space to record occupancy. These "non-controlled" circuits could be ceiling-mounted luminaires, or task luminaires.

The Window

This logger recorded the amount of daylight entering the space. Where possible, this logger was shielded from direct sunlight to avoid saturating the logger. 8-bit loggers were used to record window illuminance, because the values were high and fine resolution was not required.

The "Critical Task" Area

The critical task area is a concept used in previous research, and is the least-daylit part of the photocontrolled area in which a work task is located. A person working at the critical task area would have the lowest level of task illuminance in the space, and would therefore be the most likely to switch their lighting on at times when daylight levels are low.

The critical task illuminance is used for two purposes – first as a measure of how well the photocontrol system maintains adequate task illuminance, and second as an input variable to the analysis of the savings achieved by the photocontrol systems, since occupants are more likely to switch lighting on and therefore reduce savings if the critical task illuminance is low.

In reality it was very difficult to locate a critical task logger in a location that would be safe for the duration of the monitoring period. For example, in corridors and gymnasiums there was no stationary fixed task. In classrooms, the teacher's desk was the only safe location to install a logger, but often the teacher's desk was not located in the daylit area, or alternatively was in the brightest part of the room next to the window. As a result, we judged that our critical task illuminance readings were not reliably consistent

The Photosensor

If sufficient loggers were available, the surveyor placed a logger next to the photosensor (i.e., on the ceiling) to record the amount of light reaching it. This logger provided more accurate information about how the photocontrol system responded to light, and gave an insight into the functioning of the photocontrol systems, but it was not essential for our analysis.

4.1.6 Data Logger Interference Problems

Some of the circuit current data recorded by loggers on the first ten sites was found to suffer from a high level of interference. This interference had not been evident from the two trial on-sites, and the pattern of the interference varied from one site to the next, and also from one space to another within sites.

Onset Corporation was not able to advise on a possible source for the interference, so HMG conducted a series of tests with a dimmable luminaire, using data loggers placed in different positions within and around the luminaire, to record current levels. These tests showed no interference to data recorded at 5-minute intervals (like the on-site data). However, an analysis of the logger and current transformer locations at the seven spaces with interference showed that the common factor was the data logger being placed within a luminaire.

From that point forward, the surveyors did not place loggers with current transformers inside luminaires; if a single luminaire had to be logged, the current transformer was placed in the junction box, or a logger *without* a current transformer was placed inside the luminaire to record illuminance from the lamp, as a proxy for current. Subsequently, we discovered that several of these "current proxy" loggers also suffered from interference, but this was not clear from our first analysis.

4.2 Onsite Recruitment and Scheduling

To schedule dates for on-site surveys, a follow-up telephone call was made to those sites where the interviewee had agreed to an on-site survey. We tried to group several sites together to minimize travel and accommodation costs, and maximize the rate at which we could complete surveys. After scheduling each group of surveys, and before scheduling the next, we reviewed the sample frame to balance out the sample of spaces by occupancy type and by geographical area.

The on-site surveys began in October 2004. Our goal was to survey sites in the Northwest as early as possible to avoid the cloudiest winter weather. After completing all the surveys in the Northwest, we moved on to California. However, unusual weather patterns for the winter of 2004-05 resulted in a draught in the Northwest, with sunnier weather than usual, and a long and stormy winter in California, resulting in persistent cloudy weather and the need to cancel a few scheduled surveys due to extreme storms.

To avoid distorting the sample, our goal was to average two spaces per building spaces. Sites in southern California were particularly difficult to identify, and the larger number of spaces surveyed in northern California is a consequence of this difficulty. At one Southern California college site there were a wide variety of space types available, so we surveyed eight spaces at that complex. Due to a shortage of K-12 classrooms in the sample toward the end of the study, we surveyed five or six spaces at a few school sites that had diverse conditions or multiple control types. In the final sample we averaged 2.5 spaces per building.

4.2.1 Number of Onsite Surveys Completed

Onsite surveys were completed for 129 spaces, at 51 sites. There were 14 qualified sites at which no on-site survey was conducted; two of these were because the contact refused an on-site survey, one was because we judged the building to be over-studied, and the remaining 11 were because the buildings were in remote locations with only one space available to study

In Southern California it was difficult to find qualified buildings, so we surveyed every potential site that we identified. We also surveyed almost every potential site we had identified in Northern California.

We excluded sites that had toplighting in conjunction with sidelighting or in spaces that were sidelit by receiving borrowed light from an atrium. We also specifically excluded airports, given current security concerns.

Of those 129 spaces, one was dropped from the final analysis because of problems with the data and five were dropped because there was no evidence that photocontrols had ever been installed. This left a final sample of 123 spaces at 49 buildings.

4.2.2 Spaces Types Surveyed

The final sample contains 45% office spaces, 28% K-12 classrooms, and 28% “other” spaces as shown in Figure 33. The proportion of spaces of each type is roughly constant across the three territories, except that a shortage of surveyed schools in Southern California is balanced out by a higher number of schools in Northern California. Compared with the original sampling frame, there are more offices in the final sample, but this was expected because the original sample was (necessarily) based on buildings and not on spaces, and several of the schools and “other” buildings types also contained daylit office spaces.

	Space Type			
Utility territory	Classroom	Office	Other	Totals
SCE	2	25	13	**40**
PG&E	28	20	16	**64**
NEEA	4	10	5	**19**
Totals	**34**	**55**	**34**	**123**

Figure 33 - Number of Surveyed Spaces by Occupancy Type and by Region

Of the 34 “other” spaces surveyed, 14 were libraries, and the rest were categorized as follows:

- Activity room
- Meeting room
- Dance Studio
- Dining room
- Project room
- Common room
- Community room
- Computer lab
- Corridor
- Kitchen
- Exhibition space
- Foyer
- Gymnasium
- Lab
- Lobby
- Teachers’ lounge

5. DATA PROCESSING

When data loggers arrived back from site, their data was downloaded and filed by space ID. The data was checked to assure that it met the surveyor's expectations for the magnitude of currents, levels of illuminance, and periods of operation. The values for maximum and minimum circuit current obtained from the logger data were compared with maximum and minimum values the surveyor had recorded on site using a handheld current meter. Missing data and interference problems were also identified at this stage.

Interference in logger data refers to the random data points that we believe are due to the influence of electromagnetic fields inside luminaires. Most frequently, interference was most problematic for dimming systems. In the rare case where we found interference on current data from switching circuits, it was still clear when the circuit was switched on and when it was switched off, so the data was sufficient for direct use. For dimming systems with interference the data was usually still good enough to tell whether the circuit was switched on or off, but not good enough to tell the level of current.

For dimming systems with interference, an attempt was made to determine the response of the system from another source. Illuminance data from the window and the critical task was used to "reconstruct" the missing logger data. The current draw by the controlled circuit could be induced from the window illuminance and the critical task illuminance, as described in the following paragraph. However, we have lower confidence in the savings calculated based on illuminance than those where we have reliable measured currents.

A typical graph of window illuminance versus critical task illuminance is shown in Figure 34; the diagonal line across the entire graph is illustrative of the amount of light on the task when the electric lighting is turned off: as the amount daylight incident of the window (the values on the x axis) increases, the amount of daylight at the critical task point increases proportionately. The horizontal line on the left side of the graph corresponds to illumination levels when the electric lights are turned on: as the amount of daylight incident on the window increases, the total combined electric light and daylight says relatively constant because the photocontrol reduces electric lighting in proportion to the amount of daylight available at the critical task. The intersection of the horizontal line and the diagonal line identifies the point for a well-performing photocontrol system where the control system has dimmed the luminaires to their minimum setting. The area to the right of this intersection point indicates where the luminaires are fully dimmed but the amount of daylit continues to increase above the design illuminance.

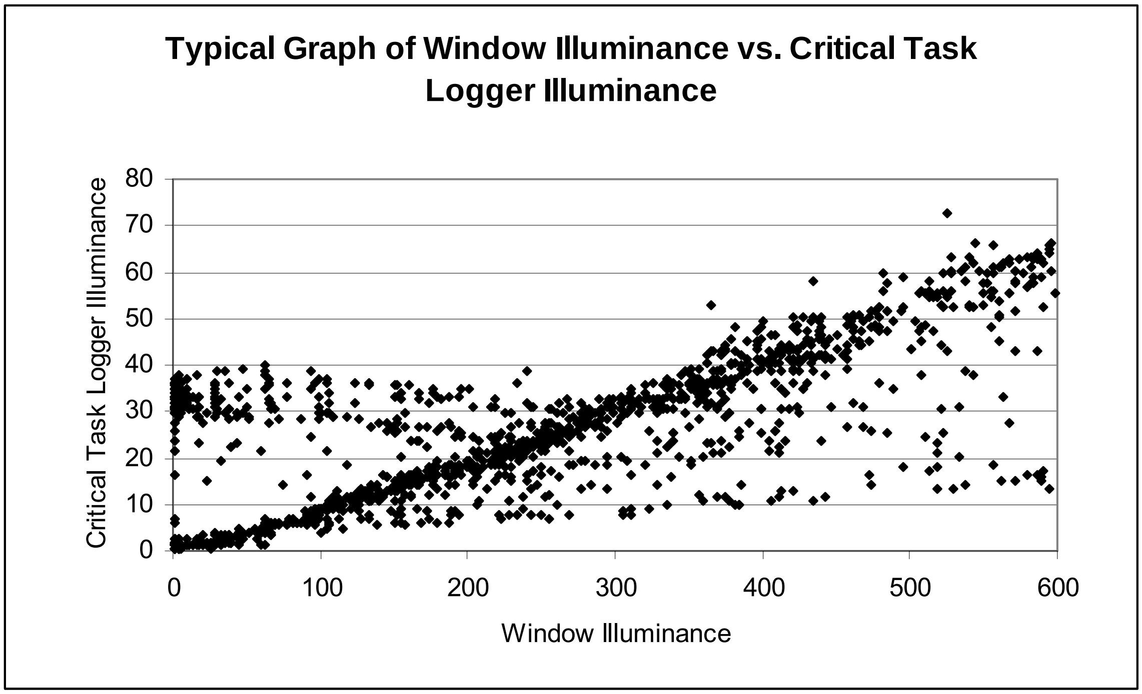

Figure 34 - Typical Graph of Window Illuminance vs. Critical Task Logger Illuminance

The final dataset for each logger was imported into a template that provided a standard format to record all the current data for each space. In addition to quality control, two types of data processing were carried out in the template. First, the sunrise and sunset times for each space and survey date were used to discard any “savings” that occurred before sunrise or after sunset, on the basis that these could not be ascribed to the photocontrol system. Second, for dimming circuits, a new dataset was generated to show when the luminaires were switched on (i.e. whenever the logged current was above a certain threshold). This allowed the savings for dimming systems to be calculated by subtracting the logged current from the maximum circuit current whenever the luminaire was switched on.

5.1 Monitored Energy Savings

Energy consumption and energy savings figures for each space were derived from the monitored current data. The method used for deriving the savings varied slightly depending on the lighting control algorithm, but wherever possible we calculated how much of the saving was attributable to the photocontrol system, and how much was attributable to occupants manually dimming or switching off the lighting in daylit areas, although it was not always possible to separate these two.

5.1.1 Switching Systems

Where possible, the non-controlled circuit was taken as a proxy for how the electric lighting would have been controlled by the occupants if a photocontrol system were not present. The amount of energy saved was calculated as the difference between the controlled and uncontrolled circuits during daytime hours, between sunrise and sunset (calculated by time of year and site geographical coordinates). Figure 35 shows an example of the monitored data from a space with two switching circuits – one controlled and one uncontrolled.

This method of calculating savings assumes that the photocontrolled lighting is manually switched according to the same schedule as lighting that is not controlled by the photocontrol system. This could create a systematic error if occupants are more or less likely to switch off lighting near windows during daytime hours.

In spaces with switching systems that did not have a non-controlled circuit we had no proxy for the occupancy of the space, so we used the site host's or occupants' best estimates of how likely the space is to be occupied at each hour of the day.

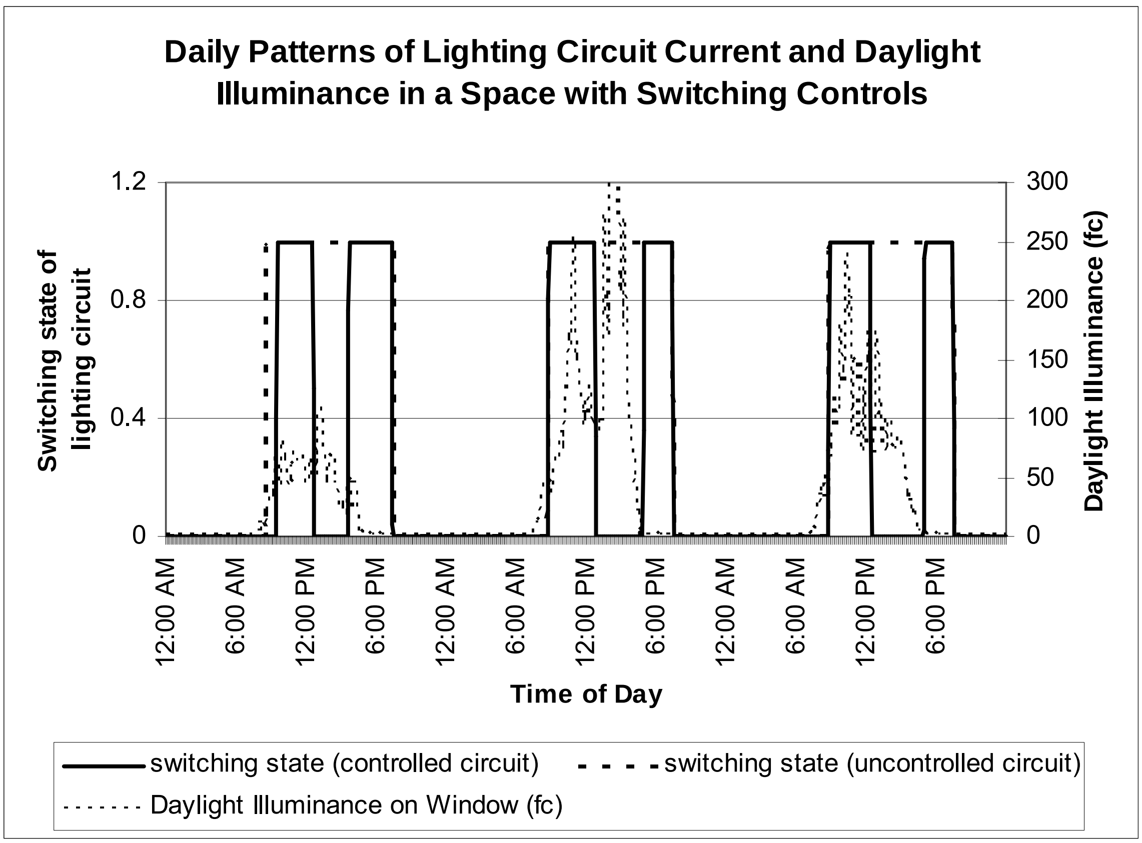

Figure 35 – Example of Monitored Data for a Switching Circuit

5.1.2 Dimming Systems

For dimming systems, we had two pieces of information: 1) how much power is being consumed by the circuit and 2) whether the occupants have switched the lighting on or off. We know the latter because none of the control systems in the survey switched the dimming ballasts off – they all remained at minimum output. Therefore if the circuit current is zero it means the occupants have switched the lighting off.

Figure 36 and Figure 37 show examples of monitored data from dimming circuits. The first circuit is saving modest amounts of energy and dimming the luminaires only to around 2/3 of their full load; the second is saving much more energy by dimming the luminaires to around 1/10 of their full load.

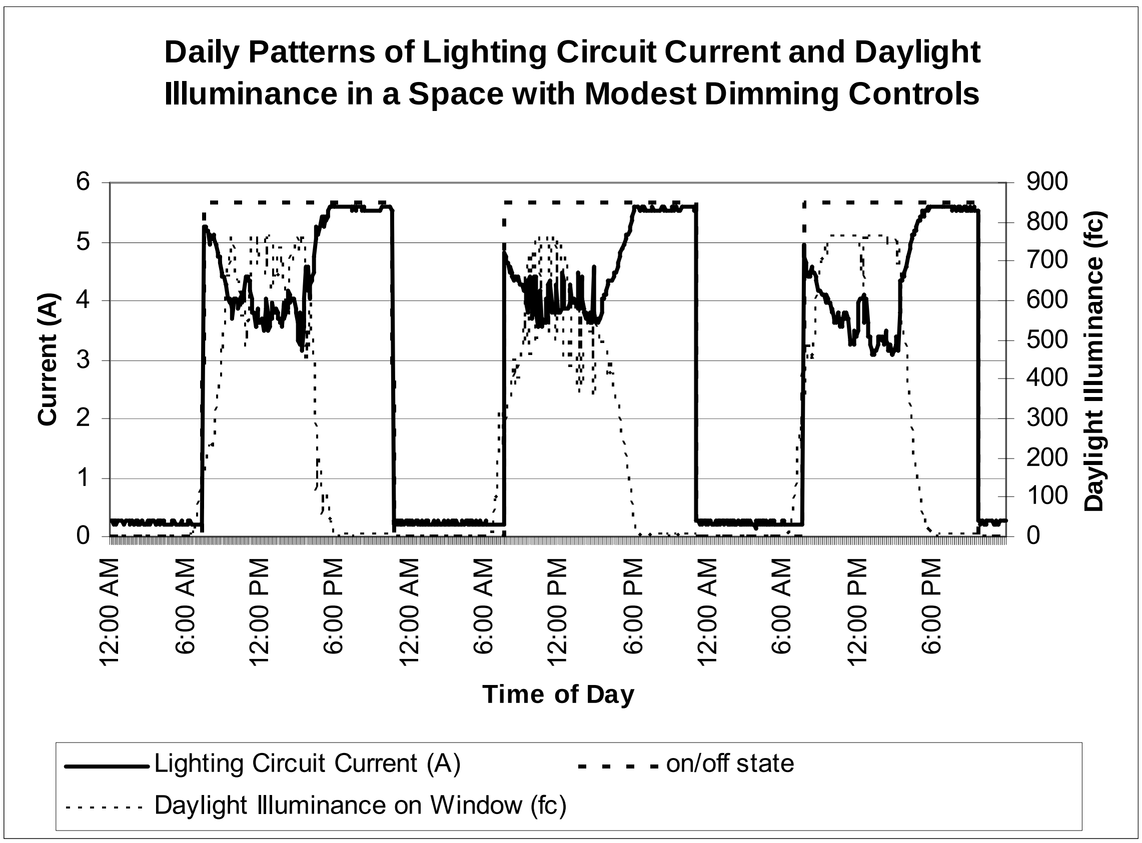

Figure 36 – Example of Monitored Data for a Dimming Circuit with Modest Setpoints

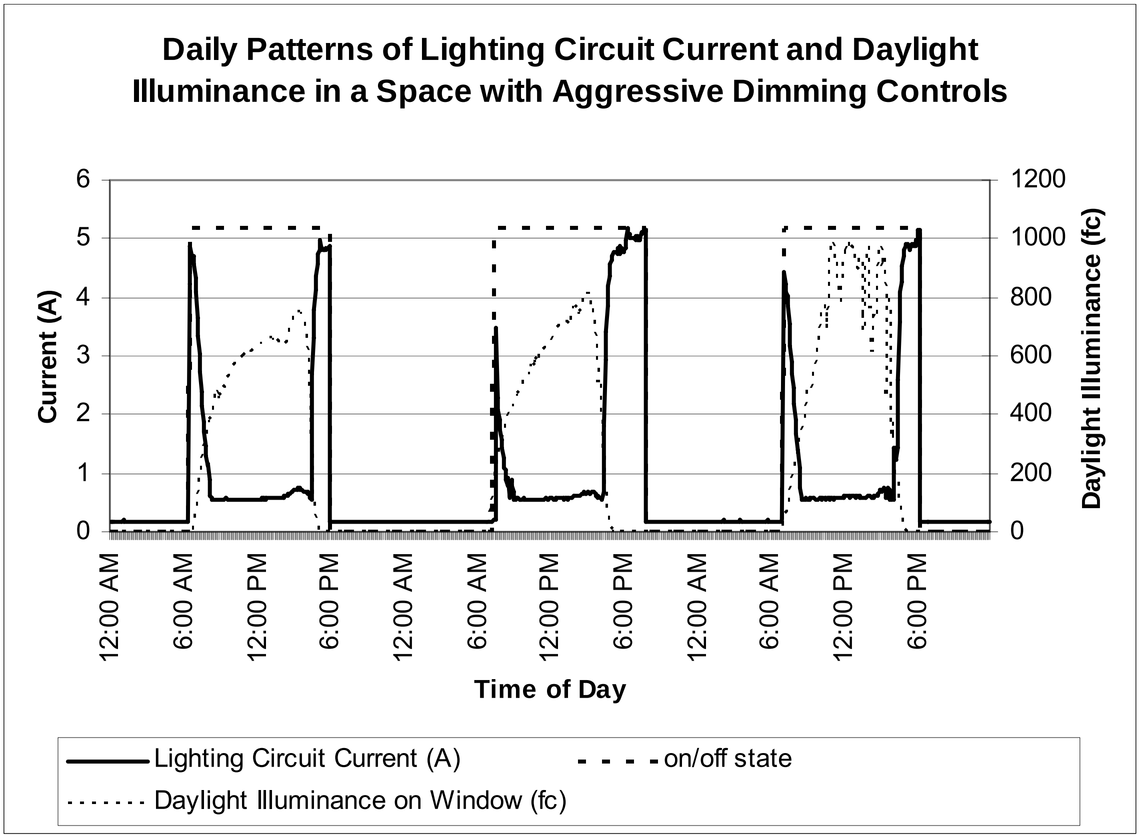

Figure 37 – Example of Monitored Data for a Dimming Circuit with Aggressive Setpoints

We calculated savings by comparing the monitored energy use with how much energy would have been used if the lamps had been at full output while on. This gives an accurate figure for how much energy was saved by the control system, with the exception of those few sites where the occupants had a manual dimming control (all of them schools).

5.2 DOE-2 Simulations of Energy Savings

We created a DOE-2 model of each surveyed space, with accurate space and window geometry, solar shading, photocontrolled and non-photocontrolled lighting loads, photosensor specifications, and utility rate schedules. DOE-2 requires a schedule of lighting use as one of its inputs, and this was derived from the occupancy patterns derived from the monitored data as described in the previous section.

Each DOE2 model included the entire surveyed space, to ensure that we were accurately reflecting the installed LPD of the whole space.

5.2.1 DOE-2 Modeling Decisions

The purpose of the DOE-2 model was to provide an idealized energy savings estimate from the photocontrol system in the space. The simulation program used for the analysis was eQUEST, which is based on the DOE2.2 whole building energy simulation engine. The tool is capable of detailed modeling of HVAC, ventilation, water heating, lighting and daylighting in the space. For the purpose of this study, we concentrated primarily on the lighting and daylighting modeling capabilities of the tool. As a result, we ended up making simplifying assumptions on the parameters that are not essential for lighting and daylighting analysis, while we did extensive analysis on factors that do affect daylighting and lighting. Following is a brief discussion of these variables:

Building Geometry

Accurately modeling of the building geometry is critical to a good model of the daylighting performance of the space, and the resultant daylighting controls performance. We modeled the building geometry as close to the surveyed space as possible including sloped roofs, window wall thickness, clerestories, exterior shading devices, etc. A couple of important limitations of the model is the inability of the DOE-2 tool to model multiple internal light reflections from light shelves, as well as complex geometries such as curved walls and ceilings. As a result, we did not model internal light shelves, and approximated curved ceilings to a sloped ceiling.

Building Materials

We modeled the average surface reflectances of walls, ceilings, floors and partitions as measured onsite, to best capture the light distribution in the space due to reflection from the envelope components.

We calculated the visible light transmittance of the windows based on onsite measurement of vertical illuminance on the inside and outside surfaces of the window.

T_{vis} = *(Internal Vertical Illuminance)/ (Exterior Vertical Illuminance)*

The DOE-2 model does not account for the presence of furniture in the space such as partitions, desks etc, which would affect the light distribution in the space. To account for the furniture and partitions, we developed a furniture factor that was used to modify the T_{vis} of the windows for the office and other space types where such furniture would be present.

T_{vis} *modified =* T_{vis} *x FF (Furniture Factor)*

Where

FF = (Illuminance reading at the task location in space)/ (Illuminance reading at an unobstructed location in space)

The unobstructed location was typically the top of partitions, or top of cabinets in the space.

We modeled blinds as blinds – blind type and blind % closed. The blind type is whether the blinds are observed on the day of the survey. There are two inputs to the DOE-2 model for vertical or horizontal, have light or dark color, and if they are opaque or translucent. The blind % closed was modeled by orientation to be the same as the conditions observed onsite.

HVAC Systems

The thermal performance of the space was not the primary concern in these models, and we did not have adequate information to generate an accurate thermal model of the space. We therefore let the DOE-2 tool use default envelope thermal characteristics such as R values.

We let the DOE-2 tool choose default HVAC systems for the space type modeled.

Lighting system

A number of separate variables were input for the DOE2 model for the lighting system, to both estimate total lighting power consumption and savings from photocontrols.

- Total Lighting Power Density in the space – This is the total installed lighting power in the space including the photocontrolled and non-photocontrolled luminaires in the space.
- Lighting Power controlled by photosensor – This is the percent of the total LPD in the space that is controlled by the photocontrol system.
- Lighting control strategy – This is the control algorithm used for lighting control by the photocontrol system. In the DOE-2 model, this is a choice between switching and dimming.
- Within the switching strategy, we input the number of control levels for a multi-level switching strategy.
- For dimming systems, we assumed that the ballasts dimmed the lamps to 10% of their full light output, while consuming 20% of their rated power. We assumed (in line with our survey findings) that dimming systems would *not* switch the lighting off after a certain period at minimum output, but would instead maintain the minimum output level indefinitely.
- Desired Illuminance level and critical task location – In DOE-2, the photocontrol system maintains a target level of illuminance at a particular point in the room. To determine this target point and the target illuminance we used one of two methods:
- For spaces in which we were able to place the critical task logger in the proper place (i.e. near the edge of the controlled area) we used the critical task logger location as the target point, and used the critical task logger data to determine the target illuminance (i.e. the illuminance from electric lighting alone).

- For all other spaces, we put the DOE-2 target point at the back edge of the photocontrolled area, and used the grid of illuminance measurements taken on site (see section 4.1.3) to estimate the electric lighting illuminance at the target point.
- Lighting Schedule – The lighting schedule is a critical component of the lighting system description and describes the overall lighting usage over the simulation period. We derived a lighting schedule for the non-photocontrolled circuit from the logger data template. Separate schedules were derived for Weekdays, Saturdays, Sundays and Holidays. These schedules are fractional schedules, and represent the fraction of the hour that the lighting would be ON during a given hour of the day without the operation of photocontrols.

Utility Rate Schedules

To account for the demand and energy impacts of the photocontrol system, we input a time-of-use rate schedule for small businesses. In the rate schedule, is built-in a definition of the summer peak period. Each utility defines the summer peak period differently, both in terms of the number of hours in a day, and the number of months in the peak period. For this analysis, the summer peak period is defined as between noon and 6 pm from May 1 to October 30th (this is the summer peak period defined by PG&E, which is the most inclusive period of the three utilities in our study).

5.2.2 DOE-2 Runs for Each Space

DOE-2 simulations use hourly weather data to generate an hour by hour simulation of the energy flows in the space and the energy consumption by HVAC, lighting and other equipment. The DOE-2 simulations yielded idealized estimates of energy consumption both with and without photocontrols, and gave outputs in terms of energy use intensity and full load hours. For each space, four DOE-2 models were run:

Monitored Period Runs

For an accurate simulation of daylighting and its impact on energy consumption during the monitored period, we used weather data from a nearby site that was coincident with our monitoring period for that site.[a]

We generated two models for the monitored period of analysis:

- Simulation model *without* photocontrols - monitored period
- Simulation model *with* photocontrols - monitored period

[a] Weather data was obtained from SCE and PG&E's own weather stations for California sites, except for the Bay Area, where data was obtained from the Bay Area Air and Water Resources Board through PG&E. For the NEEA sites, weather data was obtained from the University of Oregon Solar Radiation Monitoring Laboratory.

A simulated value for the lighting energy saved was calculated by subtracting the energy consumption *with* photocontrols from the energy consumption *without* photocontrols. This value was then compared to the savings calculated from the monitored data.

The primary output we obtain from these runs is the full load hours per day of controlled lighting energy consumption with and without photocontrols enabled. The difference between these two is the full load hours per day savings from photocontrols.

Full load hours/day = FLH/day

$$\mathrm{FLH/day} = \frac{\text{Monitored Period Controlled Lighting Consumption kWh}}{\text{Connected Lighting Load kW} \times \text{number of days in monitored period}}$$

Annual Period Runs

For the annual runs, we used the same two models generated for the monitored period analysis except the simulation encompassed the whole year and we used a year's worth of typical weather data. The "typical" year's weather data is provided by the National Renewable Energy Laboratory in the form of the TMY2 (typical meteorological year) data. For each 239 sites in the United States, weather data has been collected for approximately 30 years.[a] Thus the data is not for any given year but should result in energy consumption of buildings that would reflect long term (multi-year) averages.

Again, the output from two runs were compared to determine savings values:

- Simulation model *without* photocontrols – annual period
- Simulation model *with* photocontrols – annual period

This lighting energy savings and consumption was examined in two ways:

8. Full load hours/day = FLH/day

$$\mathrm{FLH/day} = \frac{\text{Controlled Lighting Consumption kWh/yr}}{\text{Controlled Lighting Connected Load kW} \times 365\ \text{day/yr}}$$

9. Energy Use Intensity (kWh/yr·sf) = EUI

$$\mathrm{EUI} = \frac{\text{Controlled Lighting Consumption kWh/yr}}{\text{Photocontrolled Area sf}}$$

Demand Savings for the Study Area are also reported. Unlike the rest of the energy results, which are for the lighting energy consumption only, the demand savings include all electrical loads simulated for the space, including air

[a] User 's Manual for the TMY2's, http://rredc.nrel.gov/solar/pubs/tmy2/overview.html#descrip

conditioning. Summer peak demand savings were calculated as the difference in the peak demand consumption of the annual model *with* photocontrols from the peak demand consumption of the annual model *without* photocontrols. . For this analysis, the peak demand is defined as the highest one hour's total electricity consumption between noon and 6 pm from May 1 to October 30th.

5.2.3 Derived Quantities from DOE-2 Models

The DOE-2 simulations were used to derive four key values that are used in the subsequent analysis—RSR, FLH, EUI and Demand Savings—each defined below:

- **Realized Savings Ratio** (RSR). This is an indication of how well the monitored performance of the photocontrol system matches DOE-2's prediction for the same time period. RSR quantifies monitored performance as a proportion of expected performance (as predicted by a DOE-2 simulation); it is a function both of how well the system is performing, and of how well the DOE-2 simulation is modeling reality. RSR is a dimensionless quantity, so has no unit of measurement.

  $$\text{RSR} = \frac{\text{Monitored (real) energy savings}}{\text{DOE - 2 ideal simulated energy savings over monitored period}}$$

  An RSR of one means that the system saved exactly as much energy during the monitored period as the DOE-2 model predicted. An RSR of less than one indicates that the site saving was less, while a RSR greater than one indicates that the site saving was greater than the DOE-2 prediction.

  The RSR value generated for each space was then used to adjust the annual DOE-2 output relative to the expected savings for that space as observed during the monitored period due to actual installation and operating conditions. The assumption is that on average, the actual savings of the control over the course of the year will be in the same proportion to the ideal DOE-2 simulation of savings as it was during the two week monitoring period.

- **Annual Realized Full Load Hour Per Day Saving** (FLH/day savings). This metric is a projected value for the energy saved by the control system over the course of a year, expressed as full load hours for the average day (including weekends and holidays).

  FLH Saving = RSR x DOE-2 Annual FLH/day Savings

  Since the units are *full load* hours per day, a control that saved two full load hours, might turn all the lighting off for two hours or turn half (or dim to half power) for four hours per day.

- **Annual Realized Energy Use Intensity Saving** (EUI saving). This is a slightly different way of expressing the same quantity (energy savings) as the FLH saving. For each space, FLH savings were multiplied by the installed lighting load for the controlled circuit in that space. EUI savings are quoted in kilowatt hours saved by the photocontrol system per square foot of photocontrolled area per year (kWh/sf·yr).

- **Realized Peak Demand Saving**. This is a projected value for how much demand would be saved for the hour with maximum demand consumption during the summer peak period. This metric includes both lighting energy and cooling energy impacts. The value is expressed at Watts reduced per square foot of photocontrolled area (W/sf). Note that it is not per square foot of building area.

  This metric stills falls a little short of a true demand impact because we are modeling individual spaces with default HVAC systems rather than an entire building with the actual system.

  Each utility defines the summer peak period differently, both in terms of the number of hours in a day, and the number of months in the peak period. For this analysis, the summer peak period is defined as between noon and 6 pm from May 1 to October 30th (This is the summer peak period defined by PG&E which is the most inclusive period of the three utilities).

  $$\text{Realized Peak Demand Saving} = \text{RSR} \times \text{DOE - 2 Peak Demand Saving}$$

5.2.4 DOE-2 Limitations

Like any modeling tool, DOE-2 has inherent limitations. We chose DOE-2 as our simulation engine because it provides annual energy analysis, and it is one of the most common tools used by utility programs and energy analysis consultants. While there are other simulation tools available that may do a better job of modeling daylight distribution for a given building design and solar condition, they do not easily generate annual energy impacts or whole building energy use.

In a future study it would be instructive to compare this DOE-2 analysis against other commonly used simulation tools. Such a comparison could generate a "correction" factor for the various predictive tools.

The accuracy of RSR values and the other quantities used in the analysis are affected by limitations in modeling weather, occupant behavior and the physical characteristics of the space. The most significant sources of potential error are described below.

Occupant Behavior

Some occupant behavior could not be monitored and could therefore not be accurately modeled in DOE-2. For instance, occupants' use of window blinds could not be monitored, and so we measured the position of transmittance of the blinds only once (during the on-site survey) and assumed that these conditions persisted throughout the monitoring period, and the year. Blind positions would significantly affect the amount of daylight reaching the interior, and therefore the performance of the system. However, evidence from many previous research studies (and most of our anecdotal evidence from sites) indicates that most occupants do not commonly change the position of their blinds. Thus, our simplifying assumption is that blind position is more likely to vary by occupant than by solar position.

Daylight Availability during the Monitored Period

The on-site surveys were conducted during the winter, so daylight levels during the monitored period were generally low. This means that the photocontrol systems would have been switching or dimming the luminaires less than in other seasons of the year. This reduction in the number of data points means that the values for RSR are subject to a higher degree of error than if they had been obtained in the summer. Also, if the efficiency of the system was very different during cloudy versus sunny weather, and our monitored observations were primarily for only one type of weather, we may have underestimated or overestimated the annual effects.

DOE-2 Modeling of Daylight Admission

Light shelves, blinds and other sources of reflected daylight are poorly modeled in DOE-2, because it uses a split-flux method to calculate interior daylight values, and does not accurately calculate inter-reflected light. Inter-reflected light is a particularly important source of interior daylight in sunny climates.

Weather Data

Weather stations were often tens of miles from the surveyed sites, so local weather at some sites may have varied significantly from the weather station sites. This is especially true in areas where weather is highly localized, such as the San Francisco Bay Area.

6. ON SITE SURVEY FINDINGS

The findings from our analysis are presented in a variety of formats. The following text in the report tries to summarize the significant findings, and provide possible explanations and interpretations.

The discussion is organized into four major groups:

- An overview of findings for the whole study population
- A discussion of the characteristics of *non-functional* (failed) systems
- An analysis of *functional* (successful) systems organized by four types of outcomes: RSR, FLH, EUI, and demand reduction
- An analysis of explanatory characteristics, such as control system type or window height by their success rates and various energy impacts

The size of our study population is generally large enough to support significant findings, for instance that a particular variable is indeed a reliable predictor of savings. However, the magnitude of those savings may vary with the introduction (or subtraction) of just a few more data points, and so we do not consider the magnitude of findings to be sufficiently robust for discussion. The following analysis therefore concentrates on the *direction* of effects (positive or negative), and especially on those characteristics that have consistent effects across a number of outcome variables.

In the appendix, tables provide numerical details on all the findings, including descriptive statistics on the study sample (e.g number of dimming vs. switching systems, the mean, minimum, maximum and standard deviation for each descriptive characteristic). The appendix also describes the magnitude and certainty of outcomes for each analysis run. These values are provided for the numerically curious, so that you may derive your own conclusions. However, any hypotheses or conclusions drawn form these findings should bear the following provisos in mind:

- There are a relatively small number of sites in our study sample (123 for all sites, 59 for functional sites, sometimes only 40 for comparison of detailed characteristics).
- This population was not a truly random sample, and therefore cannot be projected back to a larger known population.
- Many of the spaces are in the same building, and thus are not truly independent of each other.
- We were not able to explore potential interrelationships between the various explanatory characteristics considered.

6.1 Overview Findings for Full Study Population

Our final tally of spaces that could be included in the DOE-2 analysis was 123, out of 129 monitored spaces. Of these 123 sidelit spaces with installed photocontrol systems, 59 (48%) had functional photocontrol systems (defined as RSR[a]>0, i.e. the system is indeed saving energy). These functional systems had an average RSR of 0.53, meaning that their two-week monitored performance showed they were achieving 53% of the energy savings that would be predicted by a detailed DOE-2 model of that particular space, considering actual design details, observed occupancy schedules, and real local weather for that time period. The range in values went from trace amounts to an RSR of 2.2.

Using an annual DOE-2 analysis, corrected for the RSR calculated for each site, these 59 functional systems were predicted to be consuming 1.64 kWh/sf·yr in the daylit zone (electric lighting only), and saving 0.73 kWh/sf·yr explicitly due to the automatic operation of the photocontrol system, as compared to monitored operation of a nearby lighting system in the same or nearby space without photocontrols. They were predicted to have an annual average lighting energy consumption of 4.6 hours of equivalent full load per day, and save 2.2 full load hours per day due to the photocontrols. Thus, the photocontrols were responsible for saving 33% of the lighting energy of the controlled circuit.

The 59 functional systems were predicted to have an average demand reduction impact (lighting plus HVAC) of 0.4 W/sf of controlled area during the summer peak period, which is 38% of the installed lighting load in the controlled area.

It is important to note that these are observed field values for the functional systems as designed and operated. The average RSR=0.53 for functional systems suggests that with better system design and commissioning the group average RSR might approach 1.0 and thus the resulting energy savings could approximately double.

The 28 systems (23% of 123) that were identified as having good performance (RSR>0.5) contained all of the major space types. On average these systems save 1.1 kWh/sf·yr. This suggests that substantial savings from daylighting are possible in all space types if good daylighting and photocontrol practices are identified and pursued.

The idealized DOE-2 analysis of all the 123 sites as designed indicates that, if all the systems were performing optimally, they could be saving an average of 4.3 full load hours (FLH) of lighting energy per day, or 57% of the normal lighting energy use without photocontrols.

The most aggressively daylit site in our study with the maximum observed savings was saving 10.8 FLH per day, or 90% of all daylit hours in a year. This is

[a] RSR = Realized Savings Ratio, the ratio of the 2-week monitored energy use for the lighting circuits on an automatic photocontrol, compared to the energy use predicted by a DOE-2 model of that same space and circuit, using actual weather for the same 2-week period, and observed occupancy schedules and operation of the space.

clearly stellar performance, and demonstrates that the technical potential of daylighting is indeed achievable.

6.1.1 Comparison of Study Findings to Other Studies

	Sidelit Spaces			Comparison	
	All spaces	Functioning RSR>0	High Functioning RSR>0.5	Toplit spaces[a]	SBD 2002 Whole Building[b]
Number of spaces	123	59	28	33	40
Average RSR	0.25	0.53	0.82	0.98	NA
Energy Savings, kWh/sf·yr					
Per photocontrolled sf	0.4	0.7	1.1	1.2	Not available
Per whole bldg sf, when: Sidelighting = 25% bldg area Toplighting = 50% bldg area	0.09	0.2	0.3	0.6	4.7
Demand Savings, W/sf					
Per photocontrolled sf	0.2	0.4	0.6	Not available	Not available
Per whole bldg sf, when: Sidelighting = 25% bldg area	0.05	0.1	0.2	Not available	1.3

Figure 38: Energy and Demand Savings; for all spaces, functioning spaces, high function spaces and comparisons

Figure 38 summarizes the energy and demand savings found for our study population and compares those savings to other opportunities. First the savings that we found per square foot of controlled area are multiplied by an assumption for how large of an area the photocontrolled area might occupy in a typical building. A common assumption, if somewhat optimistic, is that 25% of a typical building's floor area could be daylit from sidelighting. Similarly, for toplighting, given the prevalence of one and two story buildings in this region, assuming that 50% of the floor area could be daylit from toplighting is reasonable. We used these assumptions to multiply the savings per square foot of controlled area, to generate savings per square foot of whole building area that could be compared to those achieved by the whole building approach used in California's statewide 2002 Savings By Design Program (SBD).

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[a] Heschong Mahone Group, *Photocontrol System Field Study*. Report submitted to Southern California Edison Company. 2002

[b] RLW Analytics, *Final Report, 2002 Building Efficiency Assessment Study: An evaluation of the Savings By Design Program.* Submitted to the California Investor-owned Utilities. July 2004. Available from CADMAC.org

The whole building approach in the Savings By Design Program worked with designers to maximize energy savings from all design opportunities and reported significantly higher savings than the parallel system approach which incented particular measures, such as high efficiency HVAC or lighting controls. Thus, the whole building energy savings represent a sort of maximum achievable savings that a program might aspire to. The SBD report does not include details of the types or proportions of measures included in the whole building approach, but they are very likely to include proper orientation and daylighting, along with other integrated design solutions. In addition, the evaluation of the SBD Program is based upon the energy savings relative to a building that is minimally code compliant, whereas the savings calculated in this sidelighting field study are relative to the actual building as built, but with no photocontrols. Since the lighting systems in this field study have lower lighting power densities than required in the California Title 24 building energy efficiency standards, if we used the same savings calculation methodology as the SBD report, the spaces in this study would be saving an even larger fraction of lighting energy.

From this comparison of the sidelighting savings to those achieved by the SBD whole building approach we can see that sidelighting, at it's best as represented by the RSR>0.5 population, compares quite favorably to toplighting systems in terms of savings per square foot of controlled area, with 1.1 kWh/sf·yr (sidelighting) versus 1.2 kWh/sf·yr (toplighting). As a whole building energy savings opportunity, toplighting starts looking more attractive if it is true that a larger percentage of the building floor are could be daylit with a toplighting strategy compared to sidelighting. Both these strategies suggest that daylighting with photocontrols might conservatively contribute roughly 5% to 15% of typical whole building energy savings (0.3 to 0.6 out of 4.7 kWh/sf·yr), or up to 25% if close to 100% of the building could be daylit (1.2 out of 4.7 kWh/sf·yr).

The Demand Savings analysis presents a similar picture. Unfortunately we do not have demand savings values from the toplighting study. The sidelighting values suggest that a high performing toplighting system could be expected to produce up to 50% of the demand reduction from a whole building energy efficiency program at 100% of floor area (0.6 out of 1.3 W/sf). or about 15% of whole building program demand reduction at 25% of floor area (0.2 out of 1.3 W/sf).

These values suggest that daylighting can provide an important contribution relative to whole building energy savings and demand savings potential from integrated design programs.

6.2 Analysis of Non-Functioning Systems

Non-functioning systems, for the purposes of this report, are defined as RSR=0. These photocontrol systems had been installed but were not functioning at the time of the survey, in that they were not automatically reducing the electric lighting energy use in response to the presence of daylight. For the sake of convenience, we often refer to these as "failed systems" implying that some part of the whole daylighting system—from building design, to installation, to occupant decisions, to hardware—resulted in a daylighting system that did not actually save any lighting energy. Similarly "successful system" is used to mean a functioning system, but not necessary a good or high performing system.

Of the spaces studied, 64, or 52%, were not saving any lighting energy. In addition, there were another five spaces that we surveyed, where we had been assured by reliable sources that photocontrols had been installed, but where we could not find any evidence of photocontrols. These five spaces were excluded from subsequent analysis, since our study was to analyze the performance of installed systems.

There are two types of analysis in this section; first, an analysis of which characteristics were more commonly associated with failed systems; and second, a discussion of the various reasons why systems failed to function.

6.2.1 Characteristics Predicting Failure

In this section, we look at what were the most common characteristics of systems that failed to function. The proportion of failed systems (RSR=0) with a certain characteristic was compared to the proportion that succeeded (RSR>0). The difference in this ratio was then tested for significance. For example, classrooms represented 14% of non-functioning systems but 42% of successful systems, and thus succeeded 28% more often than they failed, with a very high probability (p=0.0004) of this being a true finding.

Non-functioning systems seem to be strongly associated with space types and space characteristics, and lack of occupant training. The site hosts that we interviewed were somewhat reliable sources in being able to detect failure.

Metrics that characterize the uniformity of daylight illumination appear to be very useful in predicting failure. Similarly spaces with window designs and layouts that tend to produce more uniform daylight illumination distribution and higher levels of daylight illumination, such as north facing windows, high windows, multiple orientations, high visible light transmittance and spaces with no partitions were associated with higher success rates.

Some characteristics of the control system were also useful in predicting whether a system would be found functioning or not. Dimming systems were more likely to be working than switching systems, as were sensors looking down and systems with multiple control zones. However many of these findings reverse when we look at how well the system performed when it was working.

There were a variety of characteristics that very interestingly were *not* associated with higher failure or success rates. For instance, building age did not predict failure, nor did system age; in other words, older buildings or systems were not more likely to get fixed, nor were they more likely to have been disabled over time. The type of management (remote versus on-site) did not predict failure.

From this pattern of findings, we conclude that the likelihood that a system will be found functioning has a lot to do with both the types of occupancy and occupant behavior as well as the design of the daylight system.

Since we could analyze the entire population of 123 spaces for failure rates, but only the 59 functioning systems for performance metrics, the number of characteristics that were found significant in predicting whether a system would be functioning or not is much larger than in our analysis of which characteristics predicted better performance. The following list presents those characteristics of the space and the photocontrol system that had a significant effect on failure rate, presented in order of significance. These were then grouped into types of characteristics for a more interpretative discussion.

Highest probability, p<0.001:

- The more strongly the site host believes the system is working, the more likely it is to be working, p<0.00001

  On a scale of 1-7, where 1=not working at all and 7=working well, site hosts ranked failed systems 3.7 and working system 5.8.

- Spaces with only a single circuit on photocontrols were more likely to fail than spaces with multiple circuits, p=0.00001

  Single circuit controls represented 72% of the population. 87% of the failed population had single circuits, whereas only 56% of the working population had single circuits.

- Spaces with partitions are more likely to fail, p<0.00005

  Spaces with partitions failed 37% more often than they were working.

- Larger buildings, >50,000 ft^2, are more likely to fail, p=0.0002

  The largest buildings in the study failed 33% more often than they succeeded.

- Classroom spaces are more likely to succeed, p-0.0004, K-12 schools are more likely to succeed, p=0.001

  Classrooms were 28% less likely to fail.

- Buildings that were owner-occupied are less likely to fail, p=0.0008

  Buildings that were owner-occupied represented 80% of our sample. Owner-occupied buildings represented 68% of the failed systems, but 93% of the functioning systems.

- The more uniform the daylight level readings between the front and the back of the room, the less likely the system was to fail ==0.001

  This metric compares the average of three daylight illumination readings near the window (horizontal 3” from floor, 5‘ or less from window) versus the average of three at the back of the room.

- Spaces where the occupants were not trained in how to operate the system are more likely to fail, p=0.001

  Spaces with trained occupants had a 25% lower failure rate.

- Spaces in K-12 school buildings, which represented 30% of our sample, were more likely to succeed than other building types, p=0.001
- The shallower the control zone, the more likely the system was to fail, p=0.001

  Non-functioning systems averaged 18' for their control depth, ranging from 9' to 27'. Functioning systems averaged 24 feet, ranging from 12' to 35'. This finding deservers more detailed analysis to understand interactive effects with other characteristics, such as unilateral versus bilateral daylight distribution.

- Office buildings are more likely to fail than other building types studied, p=0.002, office spaces are also more likely to fail than other space types, p=0.007

  Office buildings (which also tended to be large buildings, see above) failed 28% more often than they succeeded.

- The more uniform the daylight in the space, as gauged by the standard deviation of a 3x3 grid of horizontal readings versus the average of those readings, the more likely the systems was to be working. P=0.002
- The more daylight entering the space, as gauged by the weighted average visible light transmittance of each window, including the blinds settings, the more likely the system was to be working, p=0.004

  Average net Tvis of non-functioning spaces was 0.30, while that of functioning spaces was 0.47.

- Spaces with direct luminaires are more likely to fail, p=0.009

  They failed 24% more often than they succeeded.

High probability p<0.10

- Open office spaces, with multiple occupants, were more likely to fail, p=0.01
- The higher the window head height, the less likely the system was to fail, p=0.01

  The average head height of systems that failed was 9.25', with a range of 7' to 12'. The average head height of systems that functioned was 11.75', with a range of 7' to 14.5'

- Switching systems were 18% more likely to fail than dimming systems, p=0.01
- Spaces with windows facing only one direction (unilateral daylighting) were 22% more likely to fail, p=0.015

- The less uniform the daylight illumination, as measured by the ratio of maximum versus minimum daylight reading in the space, the more likely the system was to fail, p=0.02

  Failed systems had an average ratio of max to min of 15.5, with a range of 1 to 35, while functioning systems had an average ratio of 8.5, with a range of 1 to 17.

- Library spaces had a high (14%) failure rate, p=0.02
- The higher the visible light transmittance of the glass, the more likely the system was to be working, p=0.03

  The average primary window Tvis of non-functioning spaces was 0.60 while that of functioning spaces was 0.70.

- The more satisfied the site host was with the functioning of the system, the more likely it was to be working, p=0.03

  On a scale of 1-7, where 1=totally dissatisfied and 7= completely satisfied, site hosts at non-functioning n sites averaged 4.6 (slightly satisfied) while those at functioning sites averaged 5.3 (slightly satisfied).

- Sensors which looked down had a lower (15%) failure rate, p=0.03, while sensors that looked out a window were more likely to fail, p=0.04

  Sensors that looked down constituted 72% of our sample.

- Spaces which only had view windows (less than 8' head height) tended to fail (16%), p=0.03

  24% of our sample had head heights less than 8'.

- The greater the ratio of the window head height to the depth of the control zone, the more likely the system was to fail.

  The ratio of the failed systems was 0.66, with a range of 0.32 to 1.0. The ratio of the successful systems was 0.54 with a range of 0.25 to 0.84

- The higher the ceiling height, the more likely the system was to be working, p=0.07

  Average ceiling height of failed systems was 11.25 while the average ceiling height of working systems was 12.75.

- Spaces with any north facing windows failed 15% less than spaces with other window orientations, p=0.09

Types of Spaces

Spaces with partitions are more likely to fail, presumably because the partitions block the distribution of daylight evenly in the space. Similarly, open offices (likely to have partitions) are more likely to fail, and classrooms (likely without partitions) more likely to succeed.

Large buildings and office buildings seem to increase the risk of failure. We believe this may have to do with the complexity of the buildings, the lack of a 'sense of ownership" Similarly, direct luminaires are associated with a higher failure rate. This may be because office spaces are more likely to use direct luminaires. Another rationale for the negative finding associated with direct luminaires is that the effect of the photocontrol is more noticeable and luminaires noticeably fully dimmed or turned off may be disconcerting to the occupant. Large buildings with office spaces are also more likely to have only view windows, i.e. less than 8' high, and lower ceiling heights, both of which also predicted failure.

For some reason there were a disproportionate number of libraries (12 out of 15) with failed systems. We did not investigate the particular characteristics of the 12 failed library spaces to try to understand why. However four spaces of the failures were in a single library.

Occupants Training and Satisfaction

Training of occupants clearly reduced the risk of failure of a system, and would seem to be a clear opportunity for program intervention. It may be that institutions, such as schools, are more likely to train occupants in the use of the lighting control system, while tenant occupied buildings, such as offices, are less likely.

It is also reassuring to note that if the site host (typically the facility manager) believed that the system was working than there was a very good chance that it was indeed working. Similarly, if the site host was satisfied with the performance of the system there was also a significant probability that the system was working.

Uniformity

Metrics that predicted more uniform daylight in the space all tended to predict a greater likelihood of success. In perhaps a related finding, spaces with partitions (that tend to cause local shadowing) were highly likely to fail. The ratio of daylight readings near the primary window versus those at the back of the space was also a powerful metric. The greater this ratio, the greater the likelihood of failure. Two other metrics of uniformity, the ratio of standard deviation of daylight readings relative to the average of those readings and the ratio of minimum to maximum readings, also predicted more likely failure as those ratios increased, although with less precision than the window versus back of room ratio.

Spaces with high windows (>8') were more likely to succeed. Spaces with windows facing only one direction, described as "unilateral daylighting" in the survey forms, also were more likely to fail. This would be expected as multi-lateral daylighting and/or high windows could have reduced spatial daylighting gradients and thus minimized areas of the controlled zone that are comparatively dark when the electric lighting output is reduced. Spaces with north facing windows tended to fail less often than other orientations. Again, this suggests that more uniform distribution of daylight, with less glare and sun penetration problems contributes to a higher success rate for photocontrol systems.

Interestingly, indirect luminaires, which tend provide more uniform electric illumination than direct luminaires, were also associated with a higher proportion of functioning systems. Indirect luminaires tend to be used in spaces with higher ceilings, which also predicted success, an the space types such as classrooms that were more successful, thus this finding is likely to be confounded by other relationships. However, this finding is consistent with the observation that most daylight experts believe that indirect lighting is more compatible with daylighting design than direct luminaires.

Daylight Quantity and Control Zone Geometry

The more daylight entering the space, as measured by the visible light transmittance of the primary window or the net visible light transmittance of all windows including the settings of their blinds, the more likely the system was to be working.

Similarly high window head height, higher ceiling, and deeper daylight zones all predicted greater likelihood of a functional system.

Interestingly, working systems had a lower ratio of window head height to control zone depth. In general the daylight control zone seems to average about twice the window head height; however this finding is likely confounded by our definition of control zone depth. For this analysis, the control zone depth was defined as the maximum distance from the back of the control zone to the "primary" window in the space. However, if the space had daylight entering from more than one wall, as in the 50% of spaces defined as multi-lateral, then this metric overestimates the control zone depth to all windows. Since we also found that multilateral spaces tend to perform better than unilaterally daylit spaces, the relationship of control zone depth to window geometry should be studied further.

Control System Characteristics

The failure rate of control system types are interesting, since they generally run counter to those characteristics that predict better performance when functional. Spaces with a single photocontrolled circuit failed significantly more often than those with a multiple controlled circuits. This failure might be explained by the over dimming or switching at the far end of the daylit zone, which might have been corrected if there were two levels of response possible (see section 6.2.2). A very high level of confidence is associated with this finding.

Switching systems failed more often than dimming systems, but saved significantly more energy when working. Similarly, sensors which looked up or out failed more often than those looking down (the vast majority of our sample were looking down), but also saved more energy when functional.

6.2.2 Diagnosis of Failure Modes

For all those sites that had RSRs of zero, the surveyor provided a “failure mode” that describes the physical reasons why the system was not functional, and, when possible, the “reason for failure” that describes our best understanding of the reason why the system ended up in this state.

Usually the site host provided this information; sometimes it was provided by occupants, and on a few occasions the surveyor had to investigate further to determine the reason. In every case, one “failure mode” and one “reason for failure” were sufficient to describe what had happened to make the system non-functional.

The first question that often comes to mind when considering failure modes, is: “Did the widget fail?” There are two possible types of failure: hardware that was initially flawed and simply incapable of working, and hardware that initially worked but then stopped working at some later point.

We did not find any evidence of the first type of failure, but it’s also unlikely that this type of failure would have correctly identified and reported to us by facility managers. If the system had simply never been made to work, it is difficult to know whether this was due to hardware failure, incorrect wiring, poor design, poor application, inadequate commissioning or a variety of other causes.

More significantly, we did not find any evidence of the second type of failure (failure in use). We believe that this type of failure did not occur in our sample, because in all cases where the system could be inspected, the mechanism of failure was known (for example a disconnected wire or a deliberate override). None of the site hosts reported that the system had simply “failed by itself”.

Figure 39 shows groups of failure modes as diagnosed by the surveyors and/or reported by the site host. The top shaded areas in the table show the four modes of failure where we had clear evidence that the system was intentionally disabled. These include set point too high, wire disconnected, sensor taped over, and whole system disabled. These represent 55% of the failed spaces, and 70% of those that we could conclusively diagnose. Thus, from this table we do have clear evidence that the occupants are dissatisfied with the performance of the system

Of the six spaces classified as “other”, two failed because the occupants kept the blinds permanently closed, and one space failed for each of the following four reasons: the system was never installed; the EMS and photocontrol system were not compatible; the photosensor was poorly oriented; and the space had insufficient daylight.

It is interesting that “whole system” disabled occurs only in open offices and “other space types”; i.e. likely larger areas with multiple occupants complaining. The high number of failures in open offices is consistent with the earlier finding that offices tend to fail, spaces with partitions tend to fail, and spaces without a single decision maker tend to fail.

Failure Mode	Private offices	Open offices	Classrooms	Other Space Type	**Total**
Setpoint adjusted to make system inoperative	1	7	6	3	17
Taped over	4	3			7
Wire to photosensor disconnected	1	2		1	4
Whole system disabled		4		3	7
Installed but has never worked		1		4	5
Not yet enabled by site maintenance staff		3		1	4
Other reason	1	1	1	3	6
Unknown	1	7	2	4	14
Totals	13	28	9	19	64

Figure 39 - Failure Modes of Non-Functional Systems

Reasons for Failure

The following discussion provides a little more insight into the table in Figure 39 by discussing the *reasons* for the various types of failures (when those reasons were communicated to the surveyor by the occupants or site host). These reasons are not shown in Figure 39. Among the "reasons for failure", as explained by the site host, were too-frequent switching (5 spaces) and over-dimming (5) emerge as the two most common. However, in most cases the reason for failure is not known. It is noteworthy that none of the systems was reported as having failed in use, i.e. "it stopped working by itself".

Occupants appear to play an important role in the disabling of systems; Figure 39 shows that the most common failure mode was that the setpoint of the photosensor had been deliberately adjusted to make the system inoperative (17 spaces), and in almost all cases this had been done by the site maintenance staff at the request of occupants. Most often (6) this was because the lighting was cycling on and off either too frequently or at inappropriate times. The reason was not known for the remaining nine spaces.

It was not possible, given time constraints, to investigate exactly why the photocontrol system was switching the luminaires too frequently or at inappropriate times. A previous study found that some switching control systems have an inadequate “deadband”, and that incorrect photosensor placement could also cause too-frequent switching[a].

Occupants were also responsible for four of the seven photosensors that had been taped over. The reason why the occupant had taped over the photosensor was known in only one of these cases, and that was due to over-dimming when the blinds were closed.

Of the seven systems that had been completely disabled by maintenance staff, five had been disabled at the request of occupants, and in four of these cases the reason for failure was over-dimming of the second or third row luminaires, i.e., the controlled zone was too deep, or should have had a multi-level rather than a single-level response.

Apart from occupant complaints, the other major reason for system failure (nine spaces) appears to be incomplete or improper installation. In one space the system had never been connected by the contractor; in four spaces it had been installed but had never worked; and in four spaces the site maintenance staff had not yet enabled the system.

In four spaces the wire to the photosensor had been disconnected; it is not known whether this was done by occupants, maintenance staff, or by electrical contractors. Given that it involved wires, it is a reasonable assumption this was the most likely the work of electrical contractors.

In three spaces the surveyor judged that there was inadequate daylight to ever make the controls work. In one of these the occupant always kept the blinds closed. In another darkly tinted glass reduced daylight penetration to a minimum. In the third, the photosensor faced the back of a deep room filled with library stacks. In this last case, a potential fix might have been to reposition the photosensor.

Number of Functional and Non-Functional Spaces at each Site

The sites in the survey where more than one space was studied tended to have either all-functional or all-non-functional spaces, rather than a mixture of the two. The number of sites that had a mixture of functional and non-functional spaces is significantly less than would have occurred by chance. Figure 40 shows that, even though the number of sites in each of the three categories is almost the same, this distribution differs significantly from what would have been predicted by chance alone based on a 50% probability that a space would be functional or not (a chi-squared test shows that $p<0.001$).

[a] Heschong Mahone Group, *Photocontrol System Field Study*. Report submitted to Southern California Edison Company. 2002

	All spaces at site are RSR=0	Mixture of RSR=0 and RSR>0	All spaces at site are RSR>0
Actual number of sites with more than one space surveyed	12	11	10
Expected number of sites due to chance alone	5.3	23.3	4.4

Figure 40 - Distribution of Multi-Space Sites According to the Number of Functional and Non-Functional Spaces

Whenever possible, the surveyors attempted to find a mixture of functional and non-functional spaces at each site, so ideally we would have found a mixture of functional and non-functional spaces at *every one* of the 33 multi-space sites. Figure 40 shows results for 33 sites; there were 48 sites in the survey but 15 of them had only a single space and so can't be categorized. The 11 sites at which a mixture of functionalities was found is less than the proportion of functional to non-functional sites in the overall sample, and thus did not artificially inflate the ratio to failures to functional systems in our analysis.

Discrepancies between Surveyor's Assessment of Functionality, and Monitored Data

Figure 41 shows that in 109 cases where the surveyor's initial judgment of whether the system was working was recorded, the surveyor was indeed correct 89% of the time. However, in ten cases (8%) the surveyor thought the system was working but the monitored data showed it actually wasn't savings any energy, while in four cases (3%) the surveyor thought the system was not working when it did actually save some energy.

		Realized Savings Ratio (RSR)	
	Working?	RSR=0 (no)	RSR>0 (yes)
Surveyor's assessment	no	54	**4**
	yes	**10**	55

Figure 41 - Discrepancies between Surveyor's Assessment of Functionality, and Monitored Data

6.3 Analysis by Better Energy Performance

For the functioning systems (RSR>0), we looked at energy impacts that could be attributed to the automatic operation of the photocontrol system in three ways: equivalent full load hour savings per day (FLH); energy savings (kWh/sf·yr); and demand savings (w/sf). The following presents an overview of each. In order to avoid undue repetition, the detailed discussion and interpretation by system characteristics is saved for section 6.4, Analysis by Characteristics.

The graphs (Figure 42 and Figure 43) below show the relationship of these two metrics to RSR and to each other. It is clear from these graphs that there is substantial variation among these three metrics. While energy savings tends to the most relevant to program managers, FLH savings may actually be a slightly better metric to judge the energy savings potential of the control system, because FLH is independent of the lighting power density installed in the space.

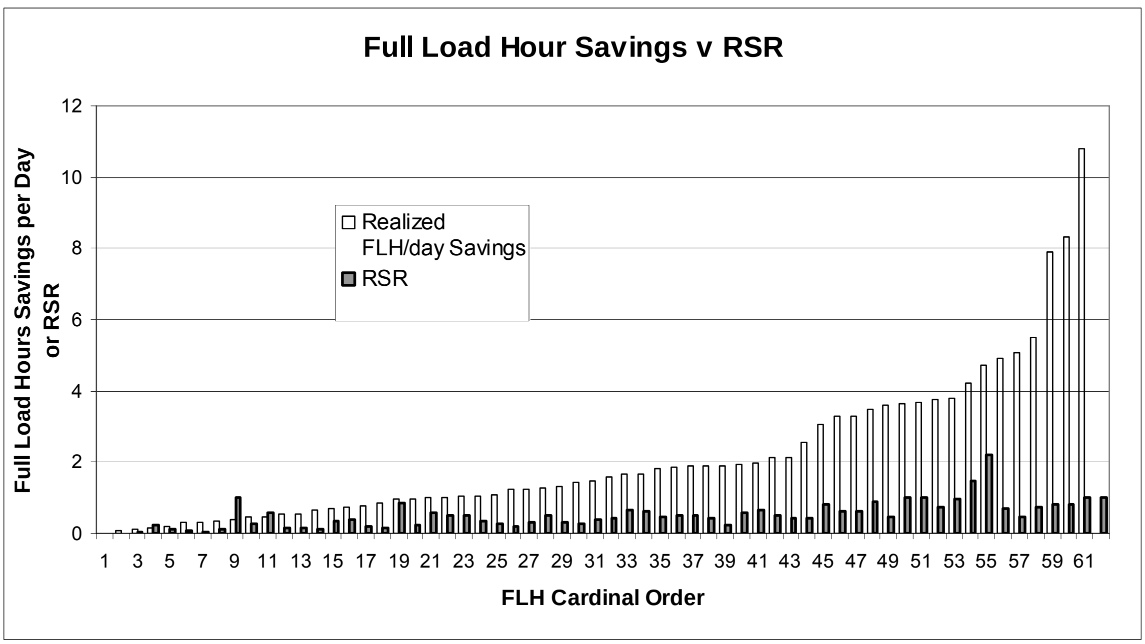

Figure 42: Full Load Hours v RSR

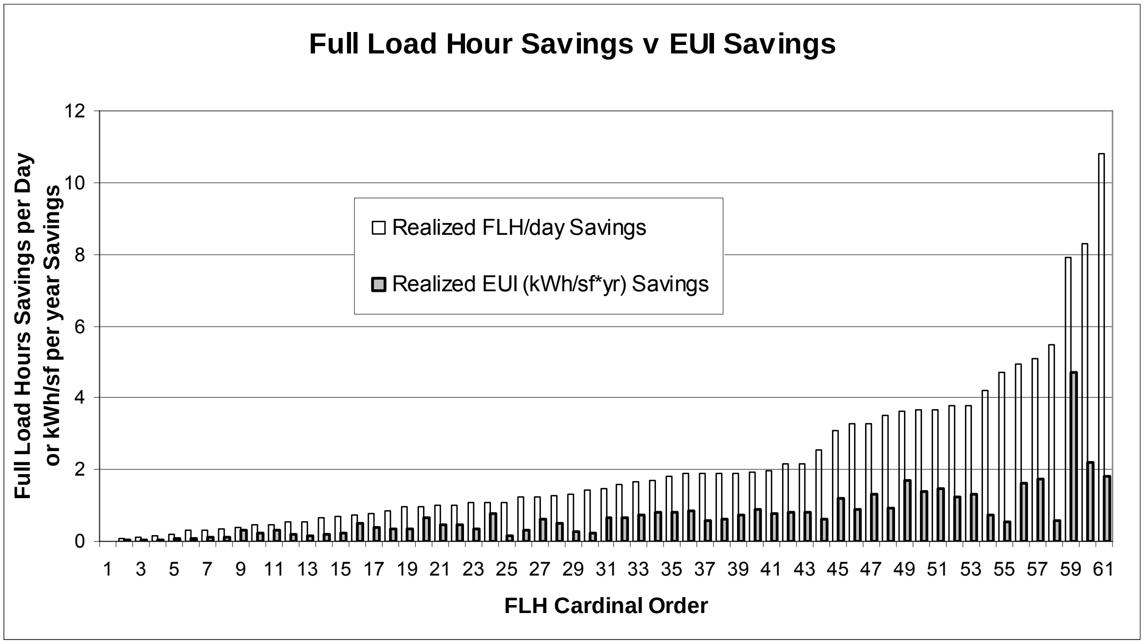

Figure 43: Full Load Hour Savings v EUI Savings

6.3.1 Characteristics Predicting FLH Savings

Overall, the daylit spaces had a net reduction in full load hour lighting energy use of 1.04 FLH savings in the photocontrolled area for all 123 sites, and 3.4 FLH for the 28 well-functioning spaces with RSR>0.5.

More characteristics that we considered are significantly associated with full hour reductions than other outcome metrics. Metrics which describe the amount of daylight available in the space and the specifications of the photocontrol system clearly are related to full load hour savings.

Highest probability, p<0.001

- Older systems save more hours, p=0.0004
- As the distance of photosensor to window decreases, more hours are saved, p=0.001
- Effective aperture, as the ratio of available daylight (net Tvis * glazing area) increases relative to the area of the control zone, more hours are saved, p=0.002

  Similarly, as the ratio of simple window area to control area increases, more hours are saved, p=0.006
- If the site host did not have records of settings or commissioning, FLH were higher, p=0.007

  This survey question was considered vague and likely to have been misinterpreted.

High probability p<0.1

- If there are no blinds or curtains in space, FLH ere higher, p=0.01
- Smaller buildings (<15,000 sf) save more hours, p=0.03
- As the head height of the window increase relative to depth of the daylight control zone, more hours are saved, p=0.04
- If there were no clerestories, FLH were higher, p=0.06
- If the system is switching instead of dimming, more hours are saved, p=0.06
- If the sensors are NOT looking down, FLH were higher p=0.08
- If the space is not an office or classroom (i.e. it was an "other" space type) p=0.08,
  If the space is not a classroom, p=0.08,
  If the building is not K-12 p=0.07,
  If the space in not a library, p=0.09,

6.3.2 Characteristics Predicting Energy Savings

Energy Savings, as described by kWh/sf*yr, had the second largest number of characteristics significantly associated with it. These characteristics are similar, but not identical, to those associated with full load hour savings. Again, metrics which describe the amount of daylight available in the space and control system specifications seem to be the most prevalent.

Overall, the daylit spaces had a net reduction in lighting energy use of 0.4 kWh/sf·yr in the photocontrolled area for all 123 sites, and 1.1 kWh/sf·yr for the 28 well-functioning spaces with RSR>0.5.

Below are those characteristics which significantly predicted greater energy savings per square foot of controlled area, in order of the significance of the findings.

Highest probability, p<0.001

- Effective aperture, as the ratio of available daylight (net Tvis * glazing area) increases relative to the area of the control zone, more energy is saved, p=0.00000002
- Greater window area to control area, p=0.0000002

  (but FLH for window area is only p=0.14)
- Older photocontrol systems are saving more energy, p=0.00008
- The greater the window head height to control depth, the greater the energy savings, p=0.0001
- If the space is library versus all other types, p=0.0004
- The shorter the distance of photo-sensor to nearest window, p=0.001

High probability p<0.1

- If site host did not have records of commissioning or settings, p=0.028 (Again, this survey question was considered vague and likely to have been misinterpreted).
- If window did not have blinds, p=0.029
- If system was switching instead of dimming, p=0.08
- If space did not have clerestory windows, p=0.09

6.3.3 Characteristics Predicting Demand Savings

Figure 44 shows the relationship between demand savings (W/sf) and energy savings (kWh/sf·yr) among the study sites. Again there is not an obvious relationship between the two outcomes. Demand reduction includes HVAC effects, and so heat loss and heat gain through the daylight windows becomes an important factor, along with the concurrence of heat loads with daylight availability as function of local climate conditions.

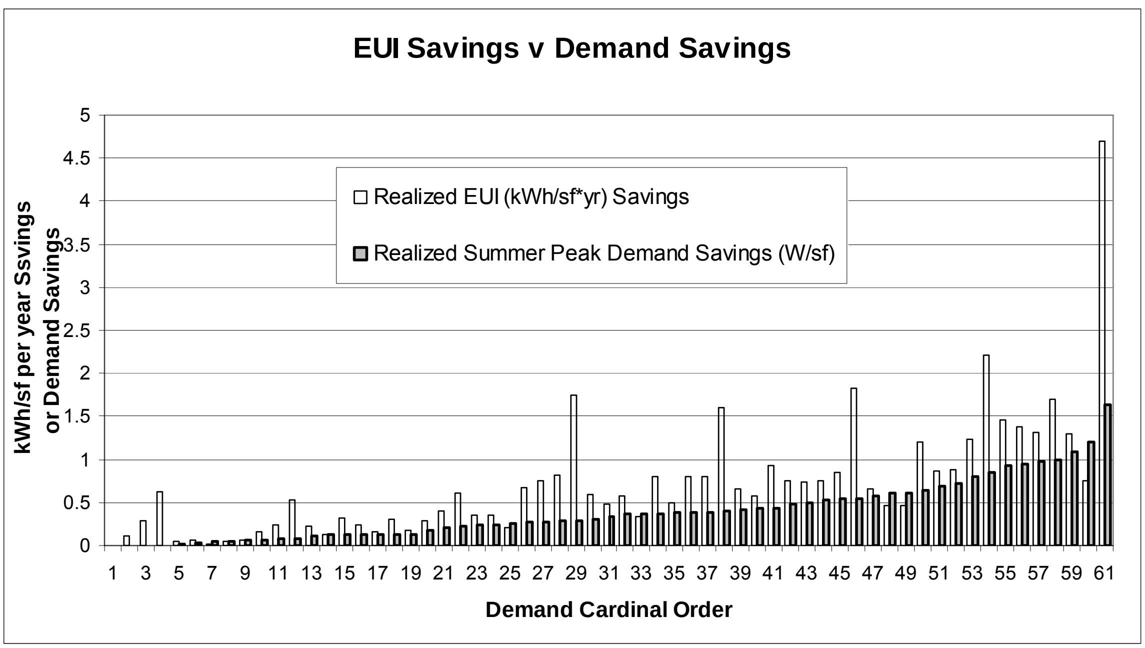

Figure 44: Demand Savings v Energy Savings

Overall, the daylit spaces had a net reduction in demand load of 0.2 W/sf in the photocontrolled area for all 123 spaces, and 0.6 W/sf for the 28 well-functioning spaces with RSR>0.5.

The following list shows the characteristics associated with greater demand savings, in the order of certainty that this is a true effect. Demand reduction had the fewest characteristics significantly associated with it of all outcomes considered.

Highest probability, p<0.001

- The bigger the effective aperture ratio, p=0.0015
- Libraries v all, p=0.005, libraries v other p=0.02

High probability p<0.1

- The shorter the distance of sensor to window, p=0.006
- The older the photo-control system, p=0.014
- The larger the window area to control area, p=0.016,
- If system was switching instead of dimming, p=0.03
- If remote management instead of local management, p=0.05
- Head height to control zone depth ratio, p=0.09
- If photo-sensor was not looking down, p=0.10

6.4 Summary Table of Findings

Figure 45, shown on the following page, is a table of summary findings, for all explanatory characteristics considered. The characteristics that were found significant in explaining the most number of outcomes are sorted at the top. The p-value for each significant finding is shown, when p<0.1, i.e. there is a greater than 90% probability that this is a valid finding. A p-value in **bold** indicates a positive effect. A p-value in (parentheses) indicates a negative effect. This table and tables with further detail on the values for each outcome and descriptive statistics for each variable are included in Appendix E.

TABLE OF SUMMARY FINDINGS

Category	Explanatory Variables	Count of Significant findings count p	RSR=0 vs. >0 Functional	For RSR>0 where p<0.10 RSR	FLH	EUI
Controls	If dimming v switching	5	**0.0118**	(0.0088)	(0.0598)	(0.0835)
Control zone	Ratio of window head ht to depth of control zone	4	(0.0427)		(0.0385)	(0.0001)
Control zone	Distance of photosensor to window (ft)	4		(0.0047)	(0.0010)	(0.0011)
Occupants	If library space v all others	4	(0.0207)		**0.0969**	**0.0004**
Fenestration Design	Ratio of (net Tvis * window area) to control area	3			**0.0021**	**0.0000**
Fenestration Design	Ratio of window area to control area	3			**0.0056**	**0.0000**
Controls	If photosensor is looking down	3	**0.0307**	(0.0309)	(0.0801)	
Space or bldg design	Number of years of PC operation	3			**0.0004**	**0.0001**
Window Type	If space has clerestory v no clerestory	2			(0.0553)	(0.0923)
Controls	If single daylight circuit v multiple circuits	2	(0.0000)	(0.0855)		
Window controls	If windows have blinds	2			(0.0133)	(0.0295)
Operator	If site host has records of PC settings	2			(0.0074)	(0.0282)
Occupants	If classroom space	2	**0.0005**		(0.0841)	
Space or bldg design	If small bldg (<15,000 sf) v all others	2		**0.0105**	**0.0284**	
Space or bldg design	K-12 school building	2	**0.0012**		(0.0669)	
Luminaires/illuminance	Illuminance ratio, horizontal min to max	2	(0.0163)			
Control zone	Depth of control zone (ft)	1	**0.0015**			
Window Type	If daylight comes from only one direction	1	(0.0150)			
Window Type	If space has only north facing windows	1	**0.0937**			
Fenestration Design	Net Tvis of windows w blinds	1	**0.0039**			
Fenestration Design	Window head height (ft)	1	**0.0110**			
Fenestration Design	If space has high windows (>8') v low only	1	**0.0325**			
Operator	If building has off-site management	1				
Operator	If occupants were trained about PC system	1	**0.0009**			
Occupants	If "other" type space	1			**0.0868**	
Occupants	If office space	1	**0.0000**			
Occupants	If open office v all others	1	(0.0107)			
Occupants	If owner occupied building	1	**0.0008**			
Space or bldg design	If large bldg (>50,000 sf) v all others	1	(0.0002)			
Space or bldg design	If office bldg	1	(0.0019)			
Space or bldg design	If space has partitions	1	(0.0000)			
Luminaires/illuminance	If luminaires use direct light distribution	1	(0.0088)			
Fenestration Design	Tvis of glass	1	**0.0258**			
Operator	If site host believes system is working (1-7)	1	**0.0000**			
Operator	If site host is satisfied w system (1-7)	1	**0.0297**			
Space or bldg design	Weighted reflectance of surfaces	1	(0.0623)			
Space or bldg design	Ceiling height in room	1	**0.0654**			
Luminaires/illuminance	Illuminance ratio, from front to back of room	1	(0.0008)			
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average	1	(0.0020)			
Space or bldg design	Room size (sf)	0				
Control zone	Size of controlled load (Watts)	0				
Control zone	Area of daylight control zone (sf)	0				
Luminaires/illuminance	Illuminance ratio, vertical min to max	0				
Occupants	If private office space v all others	0				
Space or bldg design	Number of years building has been occupied	0				
Space or bldg design	If office bldg or K-12 school	0				

Notes: Table sorted by count of significant findings per explanatory variable
Values in bold indicate a positive influence of the explanatory variable on the outcome variable (RSR, FLH, EUI, Demand)
Values in paranthesis indicate a negative influence of the explanatory variable on the outcome variable (RSR, FLH, EUI, Demand)

Figure 45: Summary Table of Significant Characteristics

6.5 Analysis by Characteristics

The following discussion analyzes the impact of various building and system characteristics on the performance of the photocontrol system. The discussion is grouped by type of characteristics, rather than by outcome.

We performed all of the analysis to date in simple bi-lateral analysis, looking at the relationship of one characteristic at a time. While this approach results in simple answers, it does not account for interactions among the various characteristics. While it should be possible to study some of these interrelationships using a multi-variate regression analysis, in general our populations were too small to support this level of analysis, and we have not done so. Thus, while we might hypothesize in the text about inter-relationships, those suppositions are not substantiated with more detailed analysis.

6.5.1 By Manufacturer

The surveyors collected manufacturer information whenever possible, noting manufacturer, model and number, and control settings when possible. In every space where we could make these observations, the entire system was from a single manufacturer, i.e. we found no systems where components from several manufacturers were mixed. The manufacturer was not identified in survey forms in 31 spaces, or 25% of the sites. In the other 75% of the sites, we observed 10 different manufacturers represented.

Eight of the manufacturers were each found at only one or two buildings each. One manufacturer was found at 42% of the 50 buildings studied, another at 22% of the buildings. These were equally distributed between both functioning (RSR>0) and non-functioning (RSR=0) sites. Likewise, when the spaces were sorted by better energy performance (RSR>0) one manufacturer did not dominate either end of the spectrum.

Manufacturer	RSR=0		RSR>0	
	# spaces	# bldgs	# spaces	# bldgs
A	18	10	17	11
B	3	1	2	1
C	4	1	1	1
D	7	6	9	5
E	7	2		
F	7	2		
G	1	1		
H	4	1		
I			1	1
J			10	2
Unidentified	12		19	
Number of mfgs	8		6	
Number of spaces	63		59	

Figure 46 - Functioning and Non-functioning Sites by Manufacturers

Figure 46 shows that the distribution of manufacturers across both functioning and non-functioning sites is quite evenly distributed, especially considering the small sample for most of them. Generally any given building had only one photocontrol manufacturer represented, although in a few cases this could not be confirmed. In conclusion, manufacturer choice was not a predictor of system success or failure.

6.5.2 Orientation and Window Characteristics

Orientation

There was a wide distribution of window orientations in the study sample. This was partly due to our methodology of selecting spaces with more than one orientation when there was more than one space available to survey per building site.

North only	South only	East only	West only	Off axis	Combination
15%	16%	10%	11%	8%	40%

Figure 47 - Orientation of daylight view windows

Spaces with windows facing only north were less likely to fail. Other than that one finding, orientation of windows in the space was not significantly associated with better or worse performance.

Unilateral versus multiple orientations

50% of the spaces were judged by the surveyors to have a “unilateral daylight strategy”, with the windows providing the primary daylight facing in only one direction. The other 50% had useful daylight windows facing in more than one direction, i.e. multilateral daylighting. (These numbers are slightly different than those shown in Figure 47 since they account for clerestories, and other variations in window geometries.) By far the most common pattern was north and south, especially for classrooms, although we also had a substantial number of spaces with corner aspects.

When the system was multilateral, i.e. when daylight came from more than one direction, the system was more likely to be found functioning.

Blinds

The majority of spaces surveyed had blinds (83%). Surveyors noted the blind position on the day of the survey and this was used as a static setting for the yearly simulation model.

The lack of blinds in a space predicted both more FLH savings and more energy savings. In general, the spaces without blinds tended to face north, be in large open spaces, and/or at colleges.

Window Head Height

The higher the window head height the more like a system was to be found working, but window head height by itself did not predict better performance. When we divided the spaces into two groups—those with high windows reaching more than 8' above the floor, and those without high windows—those with high windows were more likely to succeed. However, when we analyzed the spaces by whether or not they had a clerestory window, those with clerestory windows had lower full load hours and lower energy savings. There seemed to be some contradictions in the data, and indeed upon closer examination we discovered that there were quite a number of spaces with clerestories or very high windows that were functioning but had very poor performance. We wondered if there was a negative correlation between window head height and visible light transmittance (Tvis) of the windows that might be responsible for this unexpected pattern.

There is a slight positive relationship between windows with higher head heights having higher visible light transmission. This relationship actually strengthens even more when we consider net Tvis, or the effect of blind position on visible light transmission. This suggests that architects who are designing spaces with high windows for daylighting are also tending to use higher transmission glass, although this relationship is not a strong as one might anticipate. Figure 48 plots this relationship as a scatter plot, with a straight line of best fit added. While the trend line is clearly positive, the R^2 is only 0.04. More interesting is the degree of scatter in the data. Figure 48 clearly shows that the majority of the systems surveyed included window head heights about 9' above finished floor. The range of net Tvis conditions, on the other hand, varied considerably.

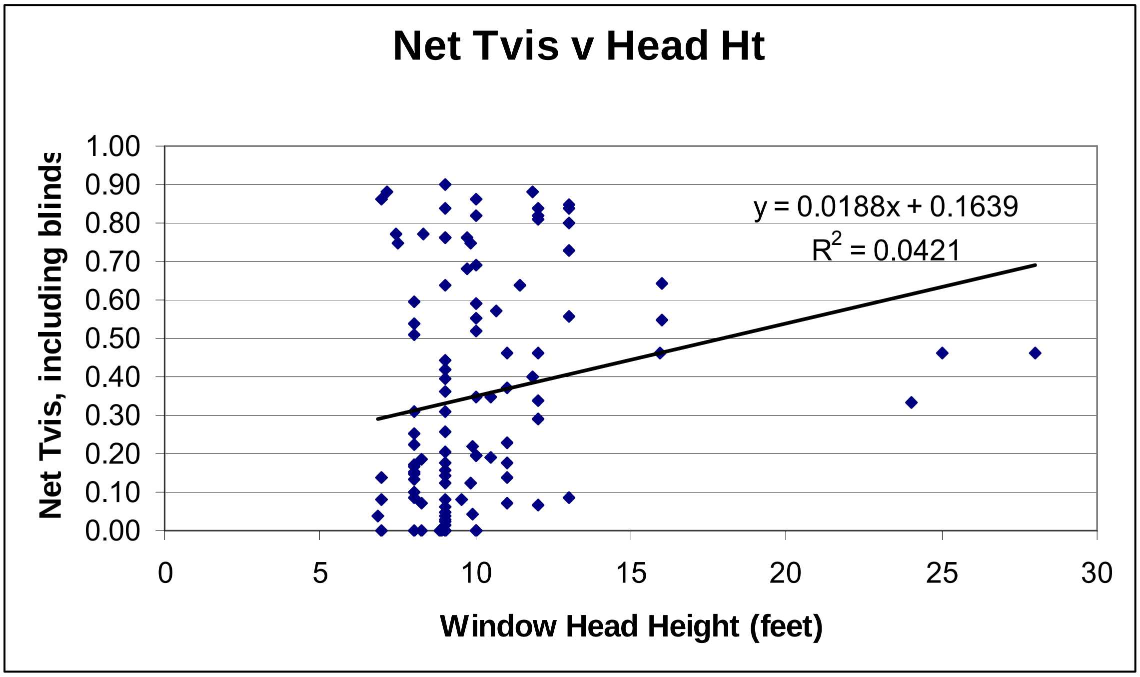

Figure 48 - Net Visible Light Transmittance of Window relative to Window Head Height

Visible Light Transmission

The higher the measured visible light transmission (Tvis) of the primary window in the space the more likely the system was to be working. We created a second metric, “net Tvis,” which averaged the Tvis of all glazing in the space, along with the effective transmission of the window blinds given their settings observed on the day of the survey. This metric also predicted less failures, but neither predicted better performance among those systems that were working.

Window Characteristics Summary

Some obvious window characteristics were associated with lower failure rates: north facing windows, multi-orientation, a.k.a. “light from two sides”; windows head heights above 8’, glazing with higher Tvis. However, these characteristics did not predict better performance. It is very interesting then, that when these window characteristics were considered in relationship to the size and/or depth of the control zone, they did become powerful predictors of performance, as discussed below. This suggests that it is the relationship of window characteristics to control zone geometry that may be the key issue in understanding performance. This is discussed further in the next section.

6.5.3 Room and Daylight Zone Geometry

Ceiling Height

Spaces with higher ceilings were associated with lower failure rates.

Size of Daylight Space (sf)

The size of the daylit space (as opposed to the size of our survey area or the size of the daylit zone) was not significant in predicting any aspect of system performance.

Size of Controlled Load (kW)

The size of the controlled load in watts was not significant in predicting any aspect of system performance.

Depth of Controlled Zone (lf)

Spaces that were functioning tended to have deeper control zones than spaces that were not functioning. We doubt that this finding is independent of all the other characteristics of the daylit space. As explained earlier, this finding is confounded by the definition of the depth of the control zone, which does not account for multilateral daylight sources. It may be that spaces with deep control zones were more aggressively daylit than spaces with shallow zones, or less likely to be in the kinds of spaces that tended to fail, such as offices.

Size of Control Zone (sf)

The size of the controlled zone in square feet was not significant in predicting any aspect of system performance.

Ratio of Window Head Height to Control Zone Depth

The spaces in our study had a ratio of window head height to control zone depth ranging from close to zero to two. The bigger this ratio, i.e. higher windows relative to shallower control zones, the more likely the system was not working. But for those systems that were working, the greater the full load hour savings, energy savings and demand savings per square foot of controlled area. However, when this metric is analyzed per linear foot of façade, the value becomes negative, i.e. a higher proportion of window height to control zone depth results in less energy savings and demand savings overall, per linear foot of façade. This suggests that there may be an optimum ratio of window head height to control zone depth. As per the discussion of Control Zone Depth, above, this finding should be analyzed relative to unilateral versus multilateral spaces, which may be confounding the results.

Ratio of Window Area to Control Area

This metric predicts better full load hour savings, energy savings and demand savings. This is the most significant predictor of better performance especially when adjusted for net visible light transmittance through the windows (see below). Given that these metrics predict better performance per square foot of control zone, but not per linear foot of façade, there is probably an optimum balance between more daylight versus a larger control zone that should be explored.

*Ratio of (Net Tvis * Window Area) to Control Area*

This metric, which in includes the visible light transmittance as a function of window glazing and blind position, is even more precise than the metric above (window area/control area) in predicting better full load hour savings, energy savings and demand savings. It suggests that occupants have made rational decisions in setting their blind positions that help to improve the daylight performance of the space.

However, both of these metrics loose their significance when analyzed per linear foot of façade. In other words, while more daylight per unit of control zone floor area improves the performance of the controls per square foot of control zone, it does not improve performance per linear feet of façade. This suggests that there may be an optimum ratio of daylight aperture to control zone depth.

Room and Daylight Zone Geometry Summary

Simple metrics like higher windows, higher ceilings or higher Tvis of window glass are associated with photocontrol systems that are more likely to be functioning, but not with better performance.

6.5.4 Control Characteristics and Sensor Placement

Dimming versus Switching

Dimming controls formed a majority (67%) of the study population. Dimming versus switching was significant for all five outcome metrics that we looked at (failure rates, RSR, FLH, EUI, Demand savings)—one of the few variables to do so.

Dimming systems have a significantly lower failure rate than switching controls. It would seem that occupants are less likely to object to the performance of a dimming system in a sidelit space, so it has a greater chance for survival.

However, dimming systems performed worse than switching systems in saving energy. They had lower RSRs, FLH savings, energy savings and demand savings. They also had lower energy savings per linear foot of façade, although these findings were not quite significant. In other words, it wasn't just that the dimming systems were saving less per square foot of controlled area; they were also saving less total energy per linear foot of façade.

When the two effects are combined—higher failure rates but better performance—the net energy savings of switching systems across the whole population are only slightly better than dimming. Accounting for both effects, the whole population of dimming systems was achieving an average savings of 1.05 FLH and 0.33 kWh/sf·yr, while switching systems were saving 1.12 FLH (6% more) and 0.37 kWh/sf·yr (11% more). These values, however, are very likely to change with a different study sample. Thus, in comparing dimming to switching systems program managers should consider whether their interest is in avoiding failures, or promoting greater energy savings in functioning systems, or considering the likely net effect across all systems.

This paradox in performance might be explained by the following “fix it or break it” theory. Dimming systems can be continuously adjusted so they are below the threshold of anyone’s noticing their performance. This is a two edged sword, both reducing a tendency for complete disabling, but also likely reducing overall performance for functional systems. We found cases of both dimming systems that were so subtle in their response to daylight that no one knew they were working, and others where the site host happily thought they were working but where there was no electrical response. Switching systems, in comparison, are more easily noticed when they take action or fail to take action. Occupant response to poorly performing switching controls can be characterized as a binary choice of “fix it or break it.” When occupants “fix” the switching controls so they are performing appropriately, higher RSR’s are likely to be obtained relative to dimming. However, when the occupants “break” the controls (via overrides, covering the sensor, etc.) the switching controls are most likely to be disabled completely.

Single Circuit versus Multiple Circuits

Spaces with single daylight circuits represented 72% of our sample, and spaces with multiple daylight controlled circuits represented 28%. Spaces with single circuits failed more often than multiple circuits, but also had significantly better RSRs and Full Load Hour Savings (but not quite significant for energy or demand savings, and absolutely not significant by linear foot of façade.) . This suggests that while the more subtle system (multi-level) might draw fewer complaints that would result in disabling, the simpler system performs better in terms of energy savings.

When the two effects are combined—higher failure rates but better performance—the net energy savings of single circuit systems across the whole population is actually worse than multi-circuit systems. As a population, single circuit systems were saving 1.01 FLH and 0.32 kWh/sf·yr, while multi-circuit systems were saving 1.12 FLH (10% more) and 0.44 kWh/sf·yr (28% more). These values, however, are very likely to change with a different study sample. Again, in comparing these two system types, program managers should consider whether their interest is in avoiding failures, or promoting greater energy savings in functioning systems, or considering the likely net effect across all systems.

Single Level Controls versus Multi-level Controls

We attempted to analyze the difference between single step switching controls versus multiple level switching controls providing multiple levels of response to the presence of daylight. As we had very few example of multiple level switching controls, the data was unable to support this analysis.

Sensor Orientation

Sensors looking down represented 72% (87 spaces) of the study population. Other sensor orientations included looking out a window (27), looking up to the ceiling or a light well (2), looking sideways (2) and located outside the building (3) Sensors looking down failed less often then other sensor orientations, but when functional, saved significantly less energy.

Again, the net effect of these contradictory findings is that across the whole study population the energy savings were indistinguishable between the two orientations when the impact of both failure rates and better performance are considered. Both orientations saved 0.35 kWh/sf·yr and differed by only 0.03 FLH. These values, however, are very likely to change with a different study sample.

Sensor Proximity to Window

Sensor location relative to the windows varied from zero (located outside the space) to 23 feet from the window. Sensors in both spaces that failed or succeed had very similar average distances to the window (9.7' v 9.3') and so we did not find that sensor distance predicted success or failure. However, sensors closer to the window were significantly more likely to save energy. The closer a sensor was to the window the better its RSR, FLU and EUI savings.

Control Characteristics and Sensor Placement Summary

The findings of this analysis suggest that while certain control system characteristics reduce the risk of failure, the opposite characteristic is often associated with better performance, and the net impact between these contradictory findings may be a wash.

Dimming systems and multi-level systems are both less likely to fail, suggesting that more subtle control results in fewer occupant complaints resulting in disabling the system. But switching systems and single circuit systems are likely to save more energy when they are working. It is unknown whether these findings are confounded by other characteristics of where designers choose to use one type of system over another.

Sensors looking out a window, and mounted closer to a window perform significantly better than those looking down and those further from the windows. This is a pretty good description of a sensor in a sidelit space acting as much like an open loop sensor as possible.

6.5.5 Space and Building Type

Occupancy Type

Offices represented 45% of our sample spaces, (11% private, 33% open offices), classrooms represented 28% of the sample, and "other space type the remainder. Most of other space types were libraries. Interesting the space types that predicted fewer failed systems, also tended to predict better performance in the those systems that were functioning.

We saw that classrooms and spaces in K-12 school buildings were significantly more likely to be functional, while office spaces, especially open office spaces, and any space in an office building was more likely to fail. However, classrooms saved significantly less energy than other space types when they were working.

Libraries were also more likely to be non-functional than functional, but the few library spaces that were working outperformed most other spaces.

Partitions

Spaces with partitions represented 44% of our sample, and were significantly more likely to fail than spaces without partitions.

Owner-occupied buildings

Owner-occupied buildings represented 80% of our study population. That in itself is very interesting, since we did not seek out owner-occupied buildings in our site selection. It suggests that owner-occupied buildings are most likely to be early adopters of daylighting technologies.

Owner-occupied buildings represented a significantly larger percentage of the successful population (93%) than the failed population (68%). Indeed, 53 out of 59 functional spaces were owner-occupied.

Building Size

Larger buildings (>50,000 sf) constituted 51% of our sample, and were significantly more likely to fail than smaller buildings.

Space Size

Space size did not predict failure rates or better performance.

System Age

The year the photocontrol system was installed predicted better FLH, energy savings and demand savings: the older the system, the better the performance. We believe that there may be a selection bias, in that we were more likely to be told about the more successful systems older systems, whereas poorly functioning or failed systems may be more likely to be forgotten over time. However, system age did not predict greater rates of failure or success, as one would expect if we were never told about failed older systems.

Building Age

Building age (years since original occupancy) did not predict any outcomes.

Building Type Summary

Most of our findings point to a nexus where office spaces with partitions are poor candidates for daylighting controls. Owner-occupied buildings clearly have an advantage over tenant occupied buildings, at least in this stage of the development of daylighting technology. And school buildings, even though their energy savings are lower, seem to be a reliable location for functioning photocontrols.

6.5.6 Building Operation

Training

If some one at the site was trained in the system, then the system was more likely to be functional. However, for those functional systems, training did not predict better performance. This seems logical, in that trained occupants are probably less likely to complain and ask that a system be disabled, whereas training the occupants has little to do with tuning a system for better performance.

Record keeping and/or commissioning

If the site host reported that there were records reporting on system adjustments or commissioning, it was not more likely to fail or succeed. If it was functioning, however, then having such records actually predicted lower energy savings compared to those systems which had no records. No site host was able to produce these records for us, and so we could not verify their contents. There also seemed to be considerable confusion about the meaning of the word “commissioning” relative to daylight controls. We found it impossible on site to verify in our surveys if a system had ever been commissioned, by either an internal or external agent. It seems that memories of such events (and/or their records) are far too fleeting to be preserved over the life of a system.

Host satisfaction

A belief by our site host that the system was working was a strong predictor that it was indeed working. Similarly, though less strongly, if the site host was satisfied with the performance of the system, then it was more likely to be working.

A site host’s belief that the system was working had no relationship to how much energy it was saving ($p=0.94$). If the site host was more satisfied with the system it had a slight relationship to better observed energy savings ($p=0.14$). Basically, while the site hosts were reliable in predicting functionality, they were not reliable in predicting the level of energy savings.

Remote versus local management

Those sites that had some one managing it remotely, such as at a district or headquarters office, were more likely to have better demand savings than those with someone managing the system on-site. However, since this finding did not also hold true for energy savings, we find it less than compelling.

6.5.7 Illuminance Data

Metrics of daylight illuminance uniformity were useful in predicting the likelihood that a system would be functioning, but not how much energy it would be saving. In order of their significance, the following three metrics proved significant in predicting if a system was working: ,

- Daylight dropoff: Ratio of averaged readings by the (primary) window to readings at the back of the study space.
- Normalized range: Ratio of the standard deviation of the horizontal readings to the average of all horizontal readings.
- Horizontal ratio: Ratio of the maximum to the minimum of all the horizontal readings, taken on a 9 point 3x3 grid around the room.

This is consistent with the hypothesis that more uniform daylight illumination would result in better user acceptance[a]..

We also considered three other illumination metrics, described below, that were not significant. We actually expected the vertical ratio of maximum to minimum vertical readings to be more representative of the space daylighting quality, since the vertical reading integrates the luminance of many surfaces within its view. These readings were taken on the four vertical faces of a hypothetical cube in the center of the space, 4' above the floor. We also attempted to compare readings at the critical task, as defined by the surveyor, to various averages. However, we found it very difficult to apply a consistent standard to defining a critical task in the study spaces. Similarly we had difficulty placing monitoring equipment at a critical task in many spaces. So while "critical task" is a useful design and simulation concept, we found it difficult to apply in the field.

From this experience, our recommendation for further field measurements would be to stay with a grid of horizontal readings for analysis of daylight distribution in the space, as those best correlated with system performance. Our data was, of course, compromised by being highly variable. It was taken opportunistically, at the time of the survey, which meant at different time of the day, different weather conditions, and in only approximately similar positions, as best judged by the surveyor on site. A better approach to field measurement of daylight illuminance uniformity would probably use data collected over time, to account for the dynamic distribution of daylight in the space as a function of time of day, climate, and occupant operation of the blinds.

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[a] This result is also supported by a previous study that showed that smaller differences in vertical illuminance were preferred by occupants of a library: Parpairi, Baker, Steemers, Compagnon, *The Luminance Differences Index: a new indicator of user preferences in daylit spaces*. Lighting Res. Technol. 34(1). 2002. pp.53-68

7. LESSONS LEARNED AND NEXT STEPS

This study provides a snapshot of the current status of photocontrol applications in sidelit spaces. It is a first step in helping program managers and designers focus their efforts on sidelit photocontrol projects that are most likely to result in energy savings. We report on the magnitude of energy savings that can be expected under current market conditions. This reports identifies the application types, such as classrooms or owner-occupied buildings, that are more likely to be successful than other applications, such as spaces with partitions or where daylight enters from only one direction.

These energy savings are expected to improve as the available technology and industry-wide understanding of photocontrol systems improves. The next question is: can anything be done to accelerate that process? The following discussion relates some HMG observations resulting from of our experience on this project, and some editorial comments about where we see the greatest need for improvement in the daylighting industry.

7.1 Sidelit Systems are Complex

Finding, describing, monitoring, simulating and analyzing sidelit systems proved to be an order of magnitude more complex than what we found with toplighting in our previous study. Since almost all commercial buildings have some view windows, the distinction between an ordinary space with view windows and one that is intentionally daylit can be difficult to describe. The architectural characteristics and the daylight distribution in sidelit spaces also tend to be much more varied than in toplit spaces. Currently, there is no consensus on what elements are necessary for good daylight design, how to describe good daylight design, or how to measure its performance. As a consequence, a great deal of information needed to be collected to describe all potentially significant characteristics and to evaluate the performance of the sidelit spaces. It is hoped that one of the contributions of this study will be to help narrow the range of important characteristics that need to be considered and systematize the collection of on-site data. Ultimately, daylight performance metrics and on-site diagnostic methods should merge towards a simple, unified set of tools and descriptors.

The inherent complexity of sidelit daylighting is both its strength and its weakness. On the one hand, daylight introduced from the side is, and will likely continue to be, the most common approach to introducing daylight into a space, since windows serve so many different types of useful functions from an architectural and occupant comfort point of view. On the other hand, because of these varied functions, achieving an optimum balance for all the requirements is inherently complex and requires carefully integrated design for any sidelit system. The list of issues that need to be properly addressed includes:

- architectural massing and orientation
- window sizing, shading and glazing specifications
- interior layout, room surfaces and furniture selection
- luminaire selection, layout and circuiting
- control strategy, sensor placement; and control settings;
- correct installation, commissioning and record keeping
- occupant training and behavior

These issues are the responsibility of a wide range of professions, who all need to coordinate with each other to achieve optimum daylighting performance. As a consequence, successful daylighting programs cannot rely on just promoting better widgets, but instead must focus on improved communication across all the pertinent construction professions.

7.2 Photocontrols in Sidelit Spaces Are Still an Emerging Market

Even though there have been sidelit daylighting control installations for over twenty years, the market has not matured. It has remained a very tiny niche market, with very little experience sharing among participants. Meanwhile, the available technologies for control systems are changing rapidly, and the number of installations also promises to increase very rapidly. Rapid technology development and market expansion will increase the need for information on how to achieve successful systems. New daylight products—sensors, controllers, advanced blinds, advanced glazings, daylight distribution systems—are being developed world wide, and will offer new opportunities for innovative daylight designs. However, without feedback on how well these innovative designs work in real installations, the daylight industry as a whole is unlikely to evolve as rapidly as the products. More careful demonstration projects, and more experience sharing are needed to help clarify best practices in this emerging field.

Consistent with its status as an emerging market, we clearly found that sidelit photocontrols systems were most likely to be successful in an owner-occupied building, where performance criteria, careful specification, construction supervision and operator training are more likely to be in place. This implies that, during this transitional period, promotional programs should selectively target owner-occupied buildings for this technology, and that mandatory requirements for the installation of photocontrols in all sidelit spaces regardless of size or characteristics, such as in the Seattle City Energy Code, may be premature.

7.3 Sidelit Spaces with Photocontrols Can Save Significant Energy

In spite of the number of non-functional or poorly functioning systems that we found, some systems were performing very well and are making significant contributions to the energy efficiency of their buildings. Given this evidence, there is good reason to believe that successful systems, that reliably and persistently save energy and reduce peak demand impacts, could be commonly achievable.

The top quartile of automatic photocontrol systems that we studied (28 spaces) were saving an average of 3.4 Full Load Hours of lighting energy per day, which translates into 1.1 kWh/sf·yr of lighting energy savings. They were also averaging 0.6 W/sf of whole building peak electrical demand reduction for each square foot of space with automatic photocontrols. This top quartile was saving 82% (RSR=0.82) of the energy predicted by a DOE-2 simulation of the space. The very best performing individual systems were saving 2 to 4 times these values.

In addition, we found that the installed lighting power densities in the daylit controlled areas were 20% lower than in adjacent spaces. This is an additional savings attributable to daylit space not included in our analysis of contribution of the control systems.

Thus, achievable energy savings from sidelit daylighting systems are substantial. The magnitude of the technical potential of sidelighting (RSR=0.82) relative to current market conditions (RSR= 0.25) makes it an important goal for research support and program development.

7.4 We Need Simpler Control System Design and Industry Communications

Photocontrol systems are perceived by building operators as too complex and difficult to adjust properly. From our phone interviews, complaints about the complexity of photocontrol systems and/or the difficulty in calibrating them continue to be at the top of the list. Disabling systems in response to occupant dissatisfaction with the performance of the systems seems to be the prime reason why systems were found to be not functioning at the time of our site surveys. Rather than being able to adjust or “fix” a system, building operators seem more inclined to just “break” the system when it is found to be performing unsatisfactorily.

In a similar vein, system installers seem to be prone to making relatively simple installation mistakes. Wires are connected to the wrong circuit. Bridge connectors or jumpers are missing. Photo sensors are located in the wrong spot. These types of mistakes are common throughout the controls industry, especially with newer technologies. An installation problem is often perpetuated once such an initial mistake is made, since few installers or operators have the diagnostic tools to verify the system is performing correctly; or, if they can observe a malfunction, they are not likely to know how to pinpoint the mistake and fix it. The problem is then likely to be perpetuated, since the people providing the installation instructions (i.e. specifying engineers and manufacturers) rarely learn that their instructions were not sufficiently clear or detailed.

Thus, the whole organizational system for the design, specification and installation of sidelit photocontrols seems to suffer from a lack of simplicity, clarity, understanding and learning on the part of the participants. This lack of clear information flow is a common feature of new, evolving technologies where there is not a sufficient market to support investment in better product literature, simpler components with intuitive adjustments, and simple diagnostic tests. One can suppose that the problem will eventually resolve itself as the market grows and the technology matures. Alternatively, there could also be an appropriate role for interested outside parties, such as utility program managers or government agencies or NGOs, to help facilitate clearer communications and better feedback within the industry.

7.5 The Occupant Interface Needs Improvement

A number of our findings suggest that occupant decisions have a significant impact on the energy savings that result from photocontrols. Occupants' complaints seem to be the main reason photocontrols are disabled. Photocontrols save more energy in spaces where occupants have been trained in their operation. Manually operated window blinds were found in 83% of our study's sidelit spaces, and the blind settings chosen by occupants are clearly a significant factor in how much energy a given space saves.

All of this suggests that it is important to have a better understanding of how occupants are likely to operate a daylit space, and how to help them make choices that will result in greater energy savings. Logically, occupants tend to take actions that improve their personal comfort. Building managers tend to take actions that reduce occupant complaints. Both observations suggest that creating daylit spaces that ensure and enable occupant comfort will result in greater energy savings from photocontrols.

Daylight Design: Daylight designs that can provide fairly uniform daylight distribution into the space, while preventing visual discomfort from all forms of glare, and thermal discomfort from sun penetration or excessively cold or hot radiant surfaces, are likely to save more energy. The solution here is partly a question of architectural design, and partly one of better window products that address all these issues.

Occupant Education: Lighting systems that respond automatically to daylight levels are still strange and mysterious to most occupants. Outreach programs that help occupants understand how photocontrols are expected to work, just as the population has slowly come to understand and accept lighting systems attached to occupancy sensors, are likely to help improve savings. These programs might be specific to a given building, or a more general purpose campaign aimed at the working population. Flex Your Power is an example of a program that might convey this message in California.

User Interface: Daylight systems—including windows, window blinds, switches and dimmers—that provide a better, more intuitive, more informative, more convenient user-interface are also likely to help occupants make better choices. Proper installation and commissioning become less important if the occupants themselves can easily correct a poorly functioning system. If the occupant can make slight adjustments, they are less likely to simply "break" the system in order to get relief. And if the user-interface provides some feedback to the occupant, similar to the way a thermostat displays the current air temperature in a space, then there is more useful information with which the occupant can make informed choices. For example, a simple display for a photocontrol system might be: "*Your automatic lighting system saved 6 hours of energy yesterday*."

7.6 We Need Better Diagnostic Tools and Performance Metrics

As mentioned in the first of these "Lessons Learned" points, sidelighting systems are an order of magnitude more complex than toplighting systems. It follows then, that the tools used to monitor and metrics used to describe the performance of those systems are also going to be more complex. Complex, however, does not need to mean difficult to use or confusing. Complex means that the diagnostic tools and performance metrics need to account for the many factors that influence performance. A tool or a metric can be very sophisticated and yet still be simple to use and give appropriate guidance on how well a system is performing. For example, instantaneous and average miles per gallon readings in cars provide drivers with useful information to modify their behavior to achieve greater energy savings, or to purchase a better performing car.

As researchers who have performed numerous on-site evaluations of daylighting systems, we at HMG are supremely aware of the limitations of the tools currently available to describe and evaluate daylight systems. Below, we briefly describe the range of needs for tools and metrics that will improve communication within the industry. The discussion is generic, rather than specific, since specifics about each item could fill another report.

Any design process should begin with an understanding of two criteria: how the system should perform (performance criteria), and under what conditions (design conditions).

- **Performance criteria**. We need to be able to clearly describe and quantify the performance criteria that daylighting systems should meet. This includes addressing adequate illumination (over time and space), visual comfort and glare control, and energy savings over time. Energy criteria will inevitably evolve over time, based on current technical capability and economic conditions. The IESNA currently provides the most widely accepted illuminance criteria, but these were developed largely for static electric illumination rather than dynamic daylight illumination.

- **Design conditions**. We need to be able to agree on the worst case conditions under which the system should be able to maintain the performance criteria. This means the range of sun angles and sky conditions under which comfort and energy performance are maintained. Common practice is currently to use the Daylight Factor, a static criterion developed in Britain for use under cloudy northern skies, or illumination levels achieved at noon at the solar equinox and solstices. Neither approach addresses the very low sun angles that are most often responsible for glare, or the dynamic range of daylight conditions that a space will experience with a day or season.

  Codes, standards and voluntary programs all need to reference commonly understood performance criteria that will be satisfied under set design criteria. These standards should then provide the correct guidance to designers on what they are expected to achieve. Overly simplified criteria can result in poorly performing designs.

- **Engineering analysis**. We need to have user-friendly tools that allow analysis of whether the design can maintain the performance criteria under design conditions. Tools can include rules-of-thumb, simple calculations or charts, and highly sophisticated dynamic computer simulations. Most tools currently in use were developed for other purposes, and are not optimized for daylighting analysis. The engineering analysis needs to have outputs that answer the question: are the performance criteria being sufficiently met?

- **Specification language**. We need clear terms and metrics that enable clear and accurate communication between designers, manufacturers, suppliers, installers and operators. Engineers need to know if a product will meet their criteria and how to select from among competing products. Manufacturers need to know what engineering criteria need to be met, and how to communicate how their products will achieve those goals. Suppliers, installers and operators need to know if the correct products are being delivered, and that they are properly installed. Instructions for all the above should be clear and easy to follow.

- **Performance verification**. Once a system is in place, there needs to be a simple way to verify that it is installed and performing correctly. Construction supervisors need an easy way to check for sloppy work. Building owners need acceptance criteria for confirmation that the system is operating as intended. Investors need validation that the system is saving energy as promised. Surveyors need a quick way to observe and describe performance. All these verification actions need simple tools for measuring performance and metrics for reporting. The challenge is that a one-time set of measurements needs to accurately predict satisfactory performance under the full range of daily and seasonal conditions.

- **Adjustment**. Finally, no building condition is static. This is especially true for daylighting. Trees grow. New buildings are put up next door. Furniture layouts and carpet colors change. New owners move in. We need systems that enable simple and intuitive adjustments over time, so that systems can made to work satisfactorily under a variety of conditions. Once the system is readjusted, performance needs to be verified again.

In an ideal world, one set of diagnostic tools and metrics could serve all these needs. There would be an obvious feedback loop between design criteria and verification tools. For example, there is currently disagreement over whether existing glare indices are meaningful, and few people have tested these criteria in the field because, in the past, they have been difficult to measure. The advent of the illuminance mapping camera offers a quick diagnostic tool that might solve this problem, by creating an easy and quick way to calculate complex glare metrics within a space, and relate them directly to design simulations.

A mature industry will tend to evolve ever simpler tools that will solve multiple needs. Typically this process either takes years of volunteer committee work, or intensive industry investment in collaborative standards development. But the daylighting industry suffers from both a lack of funds and manpower, and so that process is likely to be very slow without outside support. Thus, we believe that the nascent daylighting industry needs help to increase its internal dialog and consensus building process, with a goal to develop simple but sophisticated tools and metrics that will serve all of its needs.

APPENDIX A

PHOTOCONTROLS ADVISORY BOARD (PAB) MEMBERS

Market Role	Company	Name
Client	SCE	Henry Lau (for J Melnyck and G Ander
Client	PG&E	Steve Blanc
Client	NEEA	David Cohan
Manufacturer	The Watt Stopper	Doug Paton
Manufacturer	Lighting Controls and Design	David Wilson
Manufacturer	Lutron	Jim Yorgey
EE program/architect	Pacific Energy Center	Bill Burke
EE program/architect	Seattle Daylighting Lab	Joel Loveland
EE program/architect	Lighting Design Lab	Michael Lane
Lighting designer	Clanton Engineering	Nancy Clanton
Lighting rep	Harry Stern	Stuart Pieloch
Commissioning agent	Keithly Welsh	Holly Townes
Installation contractor	Vista Lighting	Bob Seraphin
Academic	Penn State University	Rick Mistrick
Academic	Lawrence Berkeley National Laboratory	Eleanor Lee

APPENDIX B

TELEPHONE SURVEY INSTRUMENT

Qualifying Questions

1. Can you confirm the address for your facility? Is it <<address>>
   - ❑ Yes [Skip to Q3]
   - ❑ No
2. Please update our address information

   Address: ____________________

   Contact name: ____________________

   Contact number: ____________________
3. What occupancy best describes your building type?
   - ❑ K-12 School
   - ❑ College classrooms
   - ❑ Office
   - ❑ Medical/clinical
   - ❑ Library
   - ❑ Community center
   - ❑ Gymnasium
   - ❑ Grocery store
   - ❑ Restaurant
   - ❑ Retail or wholesale store
   - ❑ Hotel/motel
   - ❑ Theater
   - ❑ Fire/police/jail
   - ❑ Religious
   - ❑ General commercial or industrial work
   - ❑ Storage
   - ❑ Other describe ____________________
4. Approximately how big is this facility?
   - ❑ Square footage ____________________
   - ❑ Or, other description ____________________
5. How many floors in this facility?
   - ❑ Number of floors ____________________
   - ❑ Or, description ____________________
6. When was the facility fully occupied?
   - ❑ Not yet occupied
   - ❑ Not yet fully occupied
   - ❑ Occupied since month, year ____________________

- ❑ Or, Number of years ____________________

7. Are you the best person to talk to regarding the operation and maintenance of the lighting and daylighting systems in your facility?
   - ❑ Yes
   - ❑ No
8. If no, Can you transfer me to [or refer me to] the person who is?

   Name: ____________________
   Phone: ____________________
   Position/title: ____________________

   [Thank them for their time and end call.]

   There are about 20 more questions in this interview. [If necessary, add "We would like to send a $25 gift certificate to [xx] to you for completing this interview]

   We consider a daylit area to be a space, or a part of a room, which you could conceivably continue to use even if the electric lights were turned off during the day.
9. Does this building have any such daylit areas?
   - ❑ Yes
   - ❑ Uncertain
   - ❑ No
10. If yes, how does the daylight enter the building? **(check all that apply)**
    - ❑ View windows
    - ❑ High windows (clerestories)
    - ❑ Skylights
    - ❑ Roof monitors
    - ❑ Atria, or covered courtyard
    - ❑ Other, describe: ____________________

    An automatic photocontrol system turns the electric lights OFF, or dims them, when there is significant amount of daylight in the space.

Photocontrol System Questions

11. Does this building have one **(or more)** of these automatic photocontrol systems? Please put your response on a scale of 1-7, where:

    - ❑ 7 Yes, I'm absolutely certain it does.
    - ❑ 6 Yes, I believe it does, but not 100% certain
    - ❑ 5 Uncertain, but it is possible
    - ❑ 4 Uncertain, I really don't know
    - ❑ 3 Uncertain, but probably not
    - ❑ 2 No, I don't believe it does, but not 100% certain
    - ❑ 1 No, I'm absolutely certain the building does not have a PC system

12. Could you describe the different types of rooms or spaces in the building that you would consider to be daylit? For instance, does the building have:

    [Let them describe up to six different types of spaces. Space names should be offered by respondent, if not surveyor can prompt from list]

Space type	How many Windows ?	How Many Skylights ?	Photo-controls?	Orient-ations (all that apply)	# space s of this type	Approx size of this type of space	*Or*, # people per space
i.e. office, kitchen dining area	0 = none 1 – few 2 – med 3 = lots	0 = none 1 = few 2 = med 3 = lots	0 = no 1=maybe 2=probably 3=certain	N S E W other		Square footage	

Further comments on spaces: ________________________________

[If the building clearly does not have any daylight or photocontrols, ask them if they have any other facilities that might qualify as daylit [Go to Q32] If not, thank them for their time and end call.]

13. Please describe if there is anything that is unsatisfactory about the daylight design of the building:

    [Let respondents volunteer own descriptions, categorize answers if obvious. [Check all that apply]

- ❑ Too much sunlight
- ❑ Too much glare
- ❑ Too hot
- ❑ Too cold
- ❑ Not enough light
- ❑ Too much contrast between bright and dark areas
- ❑ Dissatisfaction with control of blinds or curtains.
- ❑ Other, describe ________________________________

Photocontrol System Questions

14. Is the automatic photocontrol system in your building currently working?

    [i.e is the amount of electric lighting reduced when there is sufficient daylight present?]

    Please put your response on a scale of 1-7, where:

    - ❑ 7 Yes, it works extremely well.
    - ❑ 6 Yes, it works reasonably well
    - ❑ 5 Uncertain, but it may be working somewhat
    - ❑ 4 Uncertain, I really don't know
    - ❑ 3 Uncertain, but it's probably not working
    - ❑ 2 No, it is not working very well
    - ❑ 1 No, it absolutely is not working at all

15. How long has it been in this condition?

    - ❑ Ever since initial occupancy
    - ❑ Ever since years, months ________________________
    - ❑ I don't know

16. What percentage of lighting energy used by the controlled lights do you think the photocontrol system saves?

    [Does daylighting reduce the lighting?]

    - ❑ 7 91-100% reduction in lighting energy use
    - ❑ 6 76-90%
    - ❑ 5 50-75%
    - ❑ 4 25-49%
    - ❑ 3 10-25%
    - ❑ 2 1-10%
    - ❑ 1 0% reduction in lighting energy use
    - ❑ 0 I cannot judge

- ❑ and/or describe: ______________________

17. How satisfied are you with the current operation of the photocontrol system?

- ❑ 7 Completely satisfied
- ❑ 6 Satisfied
- ❑ 5 Somewhat satisfied
- ❑ 4 Neither satisfied or dissatisfied
- ❑ 3 Somewhat dissatisfied
- ❑ 2 Dissatisfied
- ❑ 1 Completely dissatisfied
- ❑ 0 I cannot judge

18. Please describe anything that is unsatisfactory about the control system's operation:

____
____
____

19. What type of lamps are controlled by the photocontrol system?**(check all that apply)**

- ❑ Fluorescent (full size)
- ❑ Compact fluorescent
- ❑ Metal Halide
- ❑ High Pressure Sodium
- ❑ Incandescent/Halogen
- ❑ Other, describe: ______________________
- ❑ Don't know

20. Can you estimate the percentage of the electric lights in the building that are controlled by an automatic photocontrol system?

- ❑ 7 91-100% of all lights in the building on photosensor control
- ❑ 6 76-90%
- ❑ 5 50-75%
- ❑ 4 25-49%
- ❑ 3 10-25%
- ❑ 2 1-10%
- ❑ 1 0% of all lights in the building on photosensor control
- ❑ 0 I cannot judge
- ❑ and/or describe ______________________

21. How are the lights controlled? **(check all that apply)**

- ❑ Dimming
- ❑ Switching
- ❑ Other. Describe: ______________________________

22. What is the brand name (or manufacturer) of the photocontrol system?

____

Additional Questions

23. Do you know where the photosensors are located? (Photosensors are the sensing devices that detect how much daylight is in the space)

- ❑ Yes
- ❑ Uncertain
- ❑ No

24. If yes, where are they located? **(check all that apply)**

- ❑ On the fixtures
- ❑ On the ceiling
- ❑ On a wall
- ❑ In a skylight
- ❑ On the roof, or somewhere outside
- ❑ Other: ______________________________
- ❑ Don't know:
- ❑ It varies by space type.

25. In addition to the photocontrols, are there other types of lighting controls in the **daylit** portions of your building? (check all that apply)

If occupancy sensors are not mention, ask – Do you have any occupancy sensors in the building? (Occupancy sensors automatically turn off the lights when there is no motion in a space.)

- ❑ Manual On/Off Switching, by the occupants
- ❑ Manual On/Off Switching, by the building manager
- ❑ Manual Dimming, by the occupants
- ❑ Manual Dimming, by the building manager
- ❑ Automatic occupancy sensors
- ❑ Automatic time sweeps, or time of day switches
- ❑ Building-wide energy management system (EMS)
- ❑ Individually addressable fixtures or DALI
- ❑ Programmable scene controls
- ❑ Demand response (peak demand reduction)

- ❑ Other, describe: ______________________________

Additional Questions

26. Did this building participate in any program promoting energy efficiency, such as: **(check all that apply)**

    - ❑ Help from local utility program
    - ❑ Savings by Design
    - ❑ Better Bricks
    - ❑ Daylighting Lab consulting
    - ❑ Seattle Lighting Design Lab consulting
    - ❑ LEED
    - ❑ CHPS (Coalition for High Performance Schools)
    - ❑ Other, describe: ______________________________

27. Who currently manages the energy performance of the building? **(check all that apply)**

    - ❑ This respondent
    - ❑ The maintenance staff
    - ❑ An on-site facility manager
    - ❑ A corporate level energy manager
    - ❑ An outside contractor
    - ❑ An ESCO company
    - ❑ Don't know
    - ❑ Other, Specify: ______________________________

28. Was anyone specifically trained in the operation of the photocontrol system?

    - ❑ Yes
    - ❑ Uncertain
    - ❑ No

29. If yes, who was trained? **(check all that apply)**

    - ❑ This respondent
    - ❑ Another building manager
    - ❑ Some of the maintenance staff
    - ❑ All the maintenance staff
    - ❑ Some of the occupants
    - ❑ All of the occupants
    - ❑ Don't know
    - ❑ Other, Specify: ______________________________

30. If yes, who did the training? **(check all that apply)**

- ❑ This respondent
- ❑ Another company manager
- ❑ The electrical contractor or installer
- ❑ The architect or design engineer
- ❑ A commissioning agent
- ❑ The controls manufacturer
- ❑ Don't know
- ❑ Other, Specify: ____________________

31. If you needed to re-adjust the photocontrol system in the future, who would do this? **(check all that apply)**

- ❑ The occupant(s)
- ❑ The respondent
- ❑ Other facility staff
- ❑ The electric contractor or installer
- ❑ A commissioning agent
- ❑ The architect or design engineer
- ❑ A utility company representative
- ❑ The manufacturer
- ❑ Don't know
- ❑ Other, Specify: ____________________

Additional Buildings

32. Do you have any other facility that is daylit?

- ❑ No
- ❑ Yes

33. If yes, are you the same contact for that facility?

- ❑ Yes
  If possible, conduct another interview for the second site after this interview is over. If time does not permit, set up a separate time if needed.
- ❑ No
- ❑ If No, what is the name, address and contact information for the other facility?

Facility Name: ____________________
Address: ____________________
Contact Name: ____________________

Position/title: ____________________
Phone: ____________________

On-site Scheduling

34. Are you the best person to talk to schedule the site visit?

- ❑ Yes… What would be a good time for our site visit?

Date: ____________________

Time: ____________________

- ❑ No…Who can we contact to get authorization to visit the site?

Name: ____________________
Phone: ____________________
Position/title: ____________________

35. As part of the survey, we would have an electrician install a current logger. This takes a few minutes and does NOT require that any power be turned off. We would pay your electrician or bring our own electrician. We would prefer to use your company's electrician.

- ❑ Yes
- ❑ No

36. Electrician Contact Info

Name/Company: ____________________
Phone: ____________________
Address: ____________________
Rate: ____________________

End

These are all of our questions. Thank you for your time. [As a thank you, we have a $25 gift certificate that we can send to you for your participation in this survey. Ask where the $25 gift certificate should be sent.]

Surveyor Rating

37. How technically confident was the respondent in answering the questions?

- ❑ 7 Extremely confident
- ❑ 6 Confident
- ❑ 5 Somewhat confident
- ❑ 4 Can't tell

- ❑ 3 Somewhat unconfident
- ❑ 2 Not confident
- ❑ 1 Extremely unconfident

38. How confident are you that this building has photocontrols?

- ❑ 7 100% certain there are (or once were) photocontrols
- ❑ 6 Very likely
- ❑ 5 Somewhat likely
- ❑ 4 Can't tell
- ❑ 3 Somewhat unlikely
- ❑ 2 Very unlikely
- ❑ 1 100% certain there are <u>NO</u> photocontols

39. How receptive was the respondent to a site visit?

- ❑ 7 Extremely receptive
- ❑ 6 Receptive
- ❑ 5 Somewhat receptive
- ❑ 4 Can't tell
- ❑ 3 Somewhat un-receptive
- ❑ 2 Not receptive
- ❑ 1 Extremely un-receptive

APPENDIX C

TELEPHONE SURVEY: ANSWERS TO OPEN-ENDED QUESTIONS

Q3. What Occupancy Best Describes Your Building Type?

Categorized answers: school, office

- 1/2 office, 1/2 central kitchen
- warehouse
- museum
- neighborhood service center
- research facility pub. health sciences
- campus day care
- lab and classrooms
- 2/3 residence, 1/3 nursing floor
- student/Community Center
- university child care program a service program
- classrooms and welding lab and jewelry lab
- office, lab, library
- children’s museum
- warehouse and offices
- and residential
- 1/3 office 2/3 conference rooms
- light industrial and technology complex
- classroom labs offices
- mixed use, public space on ground floor, small retail
- admin government
- shared college and public
- mixed use, public space on ground floor, small retail
- gym, classrooms, home economics dept. computer lab, dental facility
- nature center 1/3 office, 1/3 public space, 1/3 classroom
- lib, classrooms, game room,
- shop space, bays that are removed, office space is half of that
- multi family residential
- juvenile detention facility
- Boys and Girls Club of south bay, and office for council, computer lab
- classrooms, admin offices, multi use building
- office and industrial style work floor
- lecture rooms, some art labs
- old automobile repair shop everyone's on a cement floor, ceilings are all two storied high a few have mezzanines
- cafeteria
- childcare
- complex of three named one two and three, lecture and faculty, lab, student resource center, open library
- retail
- research lab
- college library
- light manufacturing
- warehouse
- mixed use office
- multi purpose rooms
- office / lab downstairs
- warehouse
- distribution center
- labs
- restaurant, store, gym, pool,
- science labs presentation rooms
- showroom

Q10. Please Describe the Daylight Features of the Building

Categorized answers: windows, skylights, roof monitors, atria

- lightshelves
- 200 feet of light shelves
- light wells are built up more and have louvers in them.
- rotunda on north east end
- light shelves extend three feet into interior, translucent with frit silk screened onto

- back part of two suites, roll up doors in back filled in with storefront glazing, vision glass, goes up to about 16'
- clerestory light wells
- curved roof with west facing high windows, perpendicular with gound
- clerestory light wells
- reflectors on the outside
- lobby area, two stories of glass facing north, faces north onto a turf area so ground floor is one level below street level
- reflective white ceilings
- special rafter system where sky light bounces through
- reflectors that bounce light into building
- cubicles on exterior
- light shelves

Q13. Please describe if there is anything that is unsatisfactory about the daylight design of the building

- too much sunlight and glare
- individual differences some love some don't
- interior cubicles lack natural light
- computer screen are affected by light no matter where it comes in , so severe they had to put cardboard on windows until blinds could be made
- provided window covering to reduce glare
- east side too hot since school in morning radiant heat resulting from the sun,
- café (part of great hall) absolutely terrible and sunny for 30 minutes as sun comes up, no shades
- a few shades to cut down on glare
- people on south side get too much sunlight occupants had high degree of input and asked for a lighter tint on windows
- too much heat on south side
- not enough outside light
- computer screens too much light certain times of year through clerestories
- large west window is way too hot, we've put motorized shades over them, that sunlight could be bad for books, so in certain spaces its problematic
- too hot in some areas
- the library is located on coast one mile from ocean, fairly cloudy. Even though it has a lot of windows, it is not enough to provide enough light
- not enough light
- glare on the computers most shut blinds
- too hot in corner offices they had to put awnings on them
- employees would rather have windows on work room floor on but not part of design
- real bright in reading room from skylight
- dissatisfaction with control of curtains or blinds
- glare on pc at certain times of day
- in the beginning, we arranged cubicles close to inner edge of atrium, they were getting way too much light, pushed people into building, eventually moved everyone in more and made a walkway. This cut down on complaints of too much glare and light
- at first teachers felt they didn't have enough light when it was set up to operate on 40-45 footcandles so people had to adjust
- overall pretty good because we have shade, but front entry no shades, pretty bright
- once we have gotten shades right, no complaints without shades unbearable
- we had to work with daylighting initially to make sure that it met everyone’s needs, but now is working very well
- during certain times of the year too much light, but blinds were installed.
- too much sun on the morning on east side, we put blinds up
- if we could get more natural light in ware house, but we maxed out
- just relative to corner televisions
- places with vertical windows, too much glare. Big bldg across street so only certain times of year and day when we get direct sun, at those times glare is a problem
- water leaks, some areas with glare
- it gets dim on cloudy days
- photo sensitivity of occupants

- have since installed Mechoshades
- sun is low in sky now, south side early morning east sun glares computer monitors, has two inch mini blinds, but doesn't like to shut them. North side complained of glare, and then they installed blinds.

Q18. Please Describe Anything That Is Unsatisfactory About the Control System's Operation

- dimming is stepped not continuous and the steps are annoying to those trying to work
- cloudy days it doesn't bring the lights on soon enough, dims it so much people can't see
- There are five different settings for controlling this dimming operation, how quickly it dims, percentage of lighting output, a lot of adjustments, that all has to be done very carefully, you get one shot, and then if you do something wrong you have to pay someone to go change each sensor, don't leave it up to the contractor. Making a mock up of office is really important
- naps to be dark, faculty need more training,
- people overriding, ignoring expensive system
- problems with ballasts and settings of lights ballasts seem to go out frequently
- we have some trouble with the shades, not made to support the weight that they support, in a half locked position all the time. Two jumped off of the wall
- takes maintenance labor to maintain and to keep it tuned and dialed as opposed to a system that is on all the time, expensive to maintain
- Didn't do it aggressively enough, some spaces where we should have installed and did not
- T5 had a difficult time getting services and the bulbs are $$$,
- just have to familiarize yourself with it if you need any overriding etc.
- very hard to service lights; hung up diagonally across cubicles so it is hard to get a ladder to them
- some tuning and ballast failure issues, have been corrected since, been adjusting since they are new tenants
- it works extremely well, but it is difficult to change (calibrate) a guy who knows the system can do so in 30 seconds but for me it takes a lot of time.
- know that there are people who have difficulties, some of the office spaces get too dark, just a calibration thing, but doesn't seem to get calibrated and people get head aches.
- as far as I know it works okay, but I have noticed that where the sensors are placed is a little questionable
- It is too sensitive, cloudy days it goes up and down too much as clouds pass by, some teachers will close the sky lights and they get left shut and then the lights stay on all the time
- Wattstopper has come out a few times to recalibrate
- analog pc; fail in the on position, failure mode is on, wired into overall building system
- we're still adjusting also if one of the lights goes out it is really hard to get a replacement
- we haven't had any difficulties, we’re just used to brighter light
- teachers are dissatisfied, so you don't know if it’s a controls problem, or it was explained badly so teachers don't know what is going on
- cannot turn lights on for writing or reading on rare overcast days, then we have to close blinds completely, lighting at night probably an engineering mistake
- Lutron dimmers, got hot, were always using energy just having them online they had their own air conditioning system, so when we got rid of them we ended up using less energy. Magnetic dimming ballasts were annoying, we got electronic
- school districts are short of maintenance people and people to take care of stuff. A lot of light is uplight that gets degraded because of dust
- original design was a problem, but now its good

- adjustment weren't made, we need to pay somebody to double check that it is working in its original design
- not all pc's fault, when they designed cubicles they are too tall, makes it difficult for pc's to work, pc's were designed for 5' cubicles and they put 7' cubicles
- we've had some problems making adjustments, awkward to make adjustments and difficult to understand how to make adjustments. Most of problems were in training of facilities people
- complexity for the users, they see lights going off and they think they are burnt out and then they call maintenance, they can't find switch,
- high maintenance, $$$ ballasts, concept is good, but for what you save not worthwhile
- one area where it needs to be rewired, can never shut lights off.
- complaints about people when lights go out cause they can't override the switch, just have to wait
- system works perfectly, just needs to be calibrated.
- having trouble getting it commissioned, not working the way it should, cloudy days biggest problem; one teacher actually claims that her lights turned off at 4pm
- it's all connected together, so sometimes the lights will go out and the teachers have to wave or stand up. No problems with sensors that sense daylight
- the dimming system on vertical windows not working very actively. I think sensor type and location in vertical window area may not ever have been properly calibrated.
- its not bright enough when the lights are on, they are literally wired wrong.
- working too well and created darker conditions than people wanted
- too few stages
- stay on too long we are working on it
- miswired maybe, some rows dim fine, either a 1 or a 7 depending on what row you are referring to; built by the CBs military guys and they are not known for doing a good job, things aren't straight

Q23. Where Are The Photosensors Located?

Categorized answers: fixtures, ceiling, wall, skylight, roof

- on the switch
- above light shelf pointed towards window
- open truss ceiling, bottom of open truss
- on ceiling joist
- dropped down 4 inches
- window sill of high window
- suspended from architectural i-beams at level of the fixtures
- probably on the roof
- adjacent to clerestories
- the sensor is in another building facing north
- ceiling is mesh metal fabric and they are in between that and skylights
- on the top of a 72 foot chilled water thermal storage tank on campus.
- suspended from the ceiling between or not directly under the skylights
- hanging
- adjacent to the row of fixtures in the middle of the row, one sensor per row

Q27. Who Manages The Energy Performance Of The Building?

Categorized answers: this respondent, maintenance staff, on site facilities manager, corporate level energy manager, outside contractor, ESCO

- kitchen manager, director of food services
- put so much time into it initially we just let it run now, someone in accounts payable pays the bills
- metered so no way to tell individual buildings
- energy efficiency director
- turned over to University of Washington

- many people have different levels of involvement
- schools in Oregon have had a huge funding problem, no money to do that now
- we do data collection, the students
- property manager
- no bldg manager, small office
- city libraries
- operations manager, utility bills go to billing department
- district energy manager / custodian
- County energy manager
- business management
- district office
- the city
- city
- El Segundo School District
- the city
- SJSU Facilities Development and Operations (FDO)
- the landlord
- someone at district
- technician for heating vent air conditioning
- maintenance supervisor
- Dept of general services /building manager
- district
- ACUTELY aware of energy use
- Thomas Prop Mngt Co
- landlord
- university physical plant
- controller
- property manager
- business dept
- in house
- business manager
- Hetch Hetchy power and water
- stationary engineer
- operation manager for the LLC company
- have problems with meter polarity and PV system so no one checks

29. Who Was Trained In The Operation Of The Photocontrols?

Categorized answers: this respondent, some of the maintenance staff, some occupants, all occupants, all maintenance staff, another building manager

- web site training manual
- electricians two day training session 5 people
- someone who is no longer there
- on site facility IT manager
- we designed and put in place so no formal training
- campus electrical maintenance supervisor
- an architect who works for SCE
- the electricians, all are now different
- there was a training session organized, but no one showed up to it.
- it is likely to be the FDO
- our electrician
- Engineers and operations manager
- staff electrician
- specifically designated controls mechanic who manages.
- three of us, two other managers
- on site operations manager
- all the staff
- teachers
- stationary engineer, he's not happy, doesn't want to have too much to do with it

Interviewee Title

- Comm. Analyst
- Director of Finance
- Facilities
- facilities manager
- Principal
- facilities operations manager
- project manager for city
- Facilities
- facilities and engineering dept
- Asst. Director of Facilities
- Principal
- building manager
- Head Custodian
- Custodian
- Facilities
- financial coordinator
- chief engineer
- Senior Project Manager

- District Engineer
- property manager
- Operations manager
- Facilities Manager
- Director of Operations
- maintenance manager
- operations manager
- Building Engineer
- Office Manager
- Green Building Program Advisor (LEED accredited)
- Director of Maintenance
- Executive Assistant
- Director of Facilities
- Project Manager
- Facilities Manager
- Owner
- Director of Facilities
- facilities manager
- Operations Manager
- Associate Store Manager / Architect
- Director of Library
- Water resources manager
- architect and occupant
- facilities dept
- Assistant Director of Operations
- Title One Coordinator
- energy manager for the district
- ask for operations manager
- Operations Manager
- District Manager
- Project Manager
- PARK PLANNER
- Maintenance
- facilities director
- District Facilities Manager.
- superintendent
- superintendent
- superintendent
- superintendent
- City Inspector
- Councilwoman
- Maintenance
- Facilities
- Operations Manager
- Facilities Manager / post office / Lighting consulting and sales
- Architect / Facilities Manager
- On Staff Architect, works in the building
- Chief Engineer Campus Energy Manager
- supervisor
- senior librarian
- Energy Manager
- Engineer
- project manager / architect
- Assoc. Director
- Director Energy and Utility / Architect / Client
- Office Manager
- Senior Manager
- Architect / dir of construction,
- Supervisor of Maintenance
- Maintenance
- Site Manager
- director of maintenance and operations
- Maintenance
- Director of Maintenance and Support Services
- Operations Manager
- project manager from public works department
- Director of Facilities Development
- Project Manager
- Operations Steward for the building / exec director of bio preserve
- General Manager
- Director of Property Management
- Energy Manager
- Director / Architect
- director of facilities
- Head of Facilities
- Director of Support Services
- facility manager
- Vice President
- President of major tenant / Development Mgr.
- postmaster
- Director of Energy
- supervisor of maintenance
- Operations Manager
- Architect / Director of Facilities
- Designer, Owner / Financial Officer Controller
- assistant VP
- facilities / superintendent
- Partner
- VP of Operations
- Project Manager for District
- Asst Principal
- associate principle, engineer
- chief station engineer / director of operations
- building services manager
- Director of Facilities
- Business Service Officer 2

- Designer for the ABD building
- Director of Facilities
- Director of Facilities
- Director of Facilities
- Architect

APPENDIX D

ONSITE SURVEY: ANSWERS TO OPEN-ENDED QUESTIONS

Q2_1_2. What are your Responsibilities?

- Facilities and Construction
- Supervisor of children
- Engineer
- Maintenance of building
- First point of contact for complaints and problems with building physical systems, passes them on to building maintenance people if required.
- Responsible for all activities in the childcare center, calls on central TESC maintenance staff for electrical, mechanical, carpentry etc.
- All aspects of company and building maintenance
- General Library mgmt.
- Running the building systems, organizing academic projects
- Did the tenant improvement for the office space. Senior green building design consultant on architecture projects for the firm
- Administration of library, liaising with central maintenance staff
- building and lands maintenance
- architect
- Operations and Maintenance
- Sr. Librarian
- Req. Management Team
- All physical maintenance
- Facility Maintenance
- Mechanical, electrical and safety systems, energy bills, janitorial, tenant improvements
- all facilities, accounts, office supplies, HR
- In charge of the county library system, mostly in the staffing and maintenance departments
- Directing facilities and construction
- building systems, finances, office admin
- Facilities Mgr
- Project manager for project construction and design
- Directing facilities and construction
- Directing facilities and construction
- first point of contact for occupant issues w building, but also has non-facilities duties
- Maintenance of several buildings operated by Lane County
- Capitol Planning, Design and Construction
- O&M
- Public Outreach & Facility Tour Guide
- Business Mgr.
- In charge of construction and modernization
- Building Engineer and Facilities Mgr.
- manages construction projects, design and operation
- mechanical and electrical systems, gets quotes and bids for work
- all building services
- All building systems
- Business services, maintenance and purchasing
- Project Management
- Facilities maintenance
- Maintenance of electrical & mechanical system, and building fabric
- supervising a crew of tradesmen
- Plant maintenance and utilities
- Facilities Maintenance
- Head Electrician

Q2_1_3. What is your Job Title?

- Exec. Director, Facilities Operation
- Unit Director
- Associate Principal
- Partner
- Office Manager
- director
- President / CEO
- Librarian 2
- Operations analyst
- Senior Project Architect.

- senior librarian
- Director of Finance
- architect
- Facilities Mgr/Direct of Academic Admin.
- Sr. Librarian
- Pre-Construction Executive
- Assistant Principal
- Facility Maintenance Mechanic
- Chief Engineer
- office administrator
- Deputy Director
- Director of Facilities and Construction, Los Altos
- Dir. Facilities
- Project Manager
- Director of facilities and construction, Los Altos
- Director of Facilities and Construction for Los Alt
- Water Resources Analyst
- Facilities Manager
- Projects Engineer
- Energy Manager
- Sustainability Specialist
- Business Mgr.
- Director of Facilities
- Building Engineer and Facilities Mgr.
- Project manager
- lead engineer
- building services engineer
- chief custodian
- Bus. Services. II Officer
- Asst Director of Projects and Programs
- Maintenance engineer
- supervisor of building trades
- Chief Staff Engineer
- Director of Energy and Utilities
- Chief Engineer
- Head Electrician

Q2_2_2. What are the Primary Activities that occur in the Building?

(List excludes “offices”, “classrooms”, “library”)

- After School Rec Center for Children
- Campus day care
- Mechanical and electrical engineering
- teaching, grad research, commercial research
- cooking on 1 st floor, admin on 2nd
- library reading room, offices for admin
- Scientific research, labs, computer simulation
- Meetings, Seminars, Training, Offices
- public relations area in shop front
- Library stacks, reading room, children’s homework
- Social and educational activities for UW students
- Community room
- office space, nurse's station, pharmacy
- Gym / Rec Center
- Lab/class/offices
- residence for sisters, nursing care for seniors
- office work, jail, shooting range, gym, 911 call center
- intermediate schooling (grades 6-8)

Q2_4_3. What was the Main Reason(s) for Installing the Photocontrol System?

- Test on self before recommending to district
- energy efficiency
- Developer wanted to put together a "green" package to make the building LEED certified and qualify for PGE Earth Advantage
- To save energy
- It's a state building, so it has to meet certain environmental criteria
- To demonstrate the system to company’s clients, and to save energy
- Save energy and use natural light
- to demonstrate new eco technologies and reduce energy consumption - not mainly to save money since energy is generated on site
- Test the system since their office recommends it to their clients. Also to get energy savings on lighting
- Building participated in an incentive program run by a local utility

- to save energy
- sustainability
- LEED
- Energy Savings, Living lab, demo, so could tell clients, education how it performs on a longer term
- energy saving
- As a showcase -- the building is LEED certified and is used a demonstration building for energy efficiency
- To obtain "Energy Tax Credits" from the city of Portland, although the building did not eventually qualify
- Wanted LEED platinum rating, and also for PR reasons to show clients and partners
- Energy Conservation, the architect was a proponent, and got an award from SCE for the lighting design
- School district policy to increase daylight levels in schools to improve learning and save energy
- don't know
- Cut energy use, green building, max lighting control
- Energy efficient; Part of the LEED design
- district policy of getting daylight into classrooms to enhance test scores and save energy
- district policy to save energy and improve student performance
- To save energy and to get LEED points. Low cost construction and low cost O&M were goals.
- Energy conservation is an unwritten policy of the county; usually they use occupancy sensors, this Is the first building with photocontrols
- Management wanted the best building possible
- Energy Savings
- Environmental and Electrical Savings
- energy savings, modernization plan
- Dim lights to save energy
- energy efficiency
- City required photocontrols as a condition of the building permit
- for LEED certification (silver)
- "It was just part of the design", it's a "state of the art building" - he doesn't exactly know why they were installed
- Energy Savings
- Energy savings
- SMUD has a policy of adopting energy efficiency measures in its own buildings, and wanted to adopt them in this building for PR reasons
- doesn't know
- energy saving
- Energy Conservation
- Savings by Design Bldg. beat T24 by 20%
- Energy Efficiency
- Energy Savings

Q2_4_4. What is your Understanding of the Design Intent of the System?

- Outside lights on, inside light off, save energy
- dims / daylight
- To save energy by switching the lights off when people aren't there or when there's enough daylight. The fact that the system is automatic and works in the background without user intervention is a big plus
- Each room has a master off switch to make it easier for occupants to switch their lights off when they leave. Lights in offices dim when enough daylight is available.
- light sensors turn lights off when it's sunny, motion sensors turn lights off when no-one's there, not sure whether it's "and" or "or". Light sensor may control the amount of light, not just the switching
- turns off the office lights when there's adequate exterior lighting
- on/off switching
- Suspended fixtures can be switched between auto and manual mode. In manual mode they can be dimmed up and down
- The system has been designed to modulate the electric lighting levels in response to the amount of available daylight in the space. The daylight is measured using photocells that sense light from work surfaces below sensors
- lights turn on and off automatically on a time clock, they switch off about half an hour after the building is vacated (she

didn't mention the photocontrols because they don't work)

- to make best use of available daylight, to provide good lighting and save energy
- not asked in this early version of the interview
- Manual on-photocell dimming in open spaces; manual on - photocell off in corridor 2nd floor, save money, save energy
- dimming w/ outside light
- Turn on lamp in perimeter fixtures off when there is adequate daylight
- dims down all the lights in the room
- Dim the lights when there is daylight, turn them off when there is enough daylight.
- First and second rows of perimeter lights on south and west facades dim down gradually. Fully automatic, no occupant control
- dims the corridor lights when it's bright outside
- When the weather is overcast/dark/gloomy, the lights come ON, and when the weather is sunny, the lights turn OFF
- Dim lights down when daylight levels are high
- to turn the lights off when there's a certain level of darkness
- Turn off lights when daylight sufficient
- dims lights down when daylight levels are high
- dims lights down when daylight levels are high
- Central computer switches lights on a time clock that can be overridden by local switches. One switch panel per zone allows either hard on, hard off or auto
- Senses daylight coming through the window to supplement daylight, and most rooms have an occupancy sensor as well
- Dimming with daylight
- Talk to Taft Electric
- lights dim when there is adequate daylight
- dimming photo controls
- switches off first row of lights
- Not asked in this early version of the protocol
- to save energy. They didn't want a time clock because the building has 24/7 operation
- as daylight changes, lights dim on the inside as light gets brighter on the outside. To maintain a constant amount of light. Doesn't know how occupancy sensors interact with photocells
- Dimming
- Switching based on central photosensor and EMS, re-circuited for daylight control
- doesn't know
- dims lights in perimeter rooms
- Energy Conservation
- On/Off switch for perimeter lighting over reading cubicles
- Turn the outer lamps off on close to windows and center lamps on inner cir. when there is adequate day light
- Dimming to save energy

Q2_4_17. Please Describe anything that is Unsatisfactory about the Control System's Operation

(List excludes "nothing")

- Savings do not justify the costs
- not easy to adjust, not intuitive, sensors way too high
- Teaches don't like the fact that the system is fully automated, because it reduces their ability to control the lighting to support the activities they're doing with the kids
- only does switching, not dimming, and it doesn't save any energy
- Design and fixture placement inadequate, not enough light at task level
- The location of the photosensors does not provide best representation of the daylight on average workstations.

- does not work at all
- System is not connected, does not work.
- Adjusting is very difficult due to location on ceiling. Control did not do the initial 100 hr burn-in
- lights over desks are too dim
- Switching tends to create complaints; Absence of sun-shades on south makes people close blinds and then lights are on 100%
- doesn't ever dim the lights down
- The control system dimmed the lights too often and turned lights OFF too often even when there was not enough daylight in the space
- lights levels in second row are too low
- The lights switch OFF too often. The library staff does not like the lights turning OFF
- In the student project room in the mornings, the lights cycle on and off during meetings sometimes
- Doesn't work yet, difficult to integrate with EMS and other control systems
- Difficult to understand
- In south facing offices there's not enough light when blinds are closed because the sensor switches the lights off
- Not BacNet compatible, had to use GE converter and Wattstopper Panel
- Sensors are too sensitive. Space gets too dark as you move away from windows.
- System components were incompatible -- both ballasts and bulbs. PS was wired wrongly to the ballast
- Originally, Unenco sensors were installed; these are now being replaced by Wattstopper. Unencos cycle on and off at odd times of day, i.e. late afternoon when it's getting dark
- it doesn't work
- Just doesn't work very well
- Tenant doesn't like it - not designed properly
- Cube partitions were higher than designed and that caused less light in space. The way lights were circuited also contributed to too many lamps being turned off
- Needs override, too complex-can't diagnose problems, Problems affect multiple fixtures in large area.

Q2_4_22. If Anyone was Trained in the Use of the System, who did the Training?

- LC&D
- Vista Electric
- Christenson Electric
- Lutron will train eventually
- Keithley Welsh
- WattStopper
- Taft Electric
- The electrical contractor or installer
- Taft Electric
- Keithley Welsh
- Milligan, employed by controls manufacturer Nexlight
- Sasco

Q2_4_26. What would you do Differently if you Installed Another Photocontrol System?

(List excludes "nothing")

- Probably would not install one.
- Set up open loop system, instead of closed loop. Install sensors in a better place (looking out of window).
- Would install window shades from the beginning - shades were installed as a retrofit measure after a few months due to complaints from occupants about direct sunlight. The facilities manager is very happy with them.
- Would have installed more photocontrol systems. [The phone interviewee believed that some of the private offices didn't have photocontrols, but in fact they all do].

- Wouldn't install one - teachers wouldn't want it because it takes control away from them
- put in dimming, would consider going to another controls manufacturer, depending on cost
- would re-zone uncontrolled lighting, would put photocontrols in the admin offices as well
- Try to install sensors over more central workstations that are not affected by outside glare sources.
- Would want occupancy sensors in conference rooms to make system fully automatic rather than having to flick a switch
- Make sure that the contractor connects it! Architect had not been told by contractor that the system was not connected and was not working.
- Better commissioning process
- Comprehensive lighting control plan
- would ensure that school maintenance staff were trained in how to use the system
- Would not install this system - too expensive, proprietary components. The ballasts in particular are very expensive and hard to find (since they are proprietary)
- Would use the same system, but would further research the area it would control, i.e. would use lower partitions so that daylight gets to second row workstations
- Nothing. Doesn't know what other options exist, would consult engineer
- County would not like to install such a control system, unless the savings are demonstrated to be significant. This is due to the all or nothing nature of the control system in this building where all the lights were turning OFF at once in the original sc
- Install a non- proprietary system that the engineers can adjust to meet changing needs.
- A more simplistic PC approach - overrides
- Include more local control for private offices, to allow each office o have adjustable sensitivity to accommodate occupant needs
- Would want contractor to burn lamps in for 100 hours before installing to reduce lamp failures.
- No motion sensors, central control only
- Use a different Contractor
- Trial before installing onsite
- Would investigate either adding middle row to controlled circuits, or installing dimming instead of switching
- Would want a graphical interface to see how the system is set up
- Make sure building staff are trained in how it works - site host did not realize that photocontrols were not working.
- Talk to staff and see what they want
- Install correct number of fixtures for the space 2) Coordinate fixtures with layout of room 3) Utilize task lighting
- Have the owner more involved in design & contractor oversight
- Take cubicle partition heights into consideration. Less # of lamps/area being off
- Less complex, Training, Support, replacement parts available

Q2_6_2. Was the Problem with the System due to any changes made to the System, the Space or the Electric Lighting? If so Please Describe

- Partition heights increased

Q2_6_3. Briefly Describe any Complaints that the Occupants have made Regarding the Control System

- dark areas, no manual override in restrooms
- does not work
- Lamps burning out too fast, uncertainties
- lights in the student project room cycle during am
- None, nothing working yet
- lights switch off when sun shines on closed blinds

- Too dim in center to back of spaces
- conditions too bright
-
- Unable to troubleshoot

Q2_6_4. What Problems do you Perceive with the Control System?

- does not work
- controls seem to cause frequent lamp/ballast fails
- second row desks too dark due to 5'6" partitions
- Also, do not think the savings are adequate.
- Proprietary only, engineers cannot adjust
- complex system
- Can't adjust sensitivity in each space separately
- No understanding of how contractor wired sensors
- Too many lights are off
- Light cannot be controlled in a group within a room

Q2_7_1. What Happened to Render the System Inactive?

- Never worked
- Was never turned on - managers are happy w/o controls
- Unsure
- Photocells were not connected when installed.
- Not installed correctly, wires not connected

APPENDIX E

ON-SITE SURVEY INSTRUMENT

Site name ______________________________

Site code ______________________________

Address ______________________________

Date/ Time of Arrival ______________________________

Surveyor ______________________________

Site Host ______________________________

Site Host Phone # ______________________________

Electrician Name ______________________________

Electrician Phone # ______________________________

Electrician Time of Arrival ______________________________

Notes ______________________________

Equipment checklist and pre-survey procedures

Equipment List

	In	Out		In	Out		In	Out
Compass			Tape measure			HOBO CTs		
Watch			Illuminance meter			TOU Lighting loggers		
Pens: black, blue, red, green			Fluke meter			Cables for loggers		
Pencil			Tachometer			Laptop		
Writing pads			Hubble camera			Screwdriver set		
Blank survey forms			Tripod for Hubble			Clear duct tape		
Letter of introduction			Flashlight			Velcro sticky tape		
PG&E access agreement			Monopod for flashlight			Ceiling clips		
Laser rangefinder			HOBO 8-bit			Occupant surveys		
			HOBO 12-bit			Phone survey printed		

Pre-Survey Procedures

- ❑ Call to confirm appointment
- ❑ Mao to site, parking directions
- ❑ Electrician confirmed?
- ❑ Charge camera batteries
- ❑ Charge Laptop
- ❑ Launch loggers
- ❑ Change logger batteries if needed1. Arrival and Departure

1.1 Tasks on Arrival

1.1.1 Exterior Illuminance ________ fc

1.1.2 Time ________

1.1.3 Sky condition: Clear / partly cloudy / overcast

1.1.4 Take exterior photographs and record numbers, include sign outside building, facades, window details, shading details

jpg numbers ❑ ________________________________

- Meet host and find a place to store equipment, plans etc. during visit

1.2 Close out with electrician

Thank electrician for their help and let them know that you would like them to pick up the loggers in 10 days to 2 weeks and to send them to us.

- Give electrician self addressed FED –Ex Package for loggers.
- Give electrician contact name and number for arranging pick up time
- Give electrician a copy of the sketch plan showing hobo locations
- Give electrician a copy of the table in 1.4 listing loggers to be collected

1.2.1 Time electrician left site ________

1.3 Tasks on Departure

1.3.1 Exterior Illuminance ________ fc ________

1.3.2 Time ________________________

1.3.3 Sky condition: Clear / partly cloudy / overcast

- Note any promises made to host

____

- Give host the pre-paid envelope if he/she will be collecting loggers from site

1.4 List of loggers to be collected

❑ ❑ Logger type ❑ ❑ Serial # ❑ ❑ What it's logging (circuit #) ❑ ❑ Other notes

	Logger type	Serial #	What it's logging (circuit #)	Other notes
Space #1	Fedex envelope tracking #			
Space #2	Fedex envelope tracking #			
Space #3	Fedex envelope tracking #			
Space #4	Fedex envelope tracking #			

2. INTERVIEW

The Heschong Mahone Group, Inc. has been asked by PG&E, SCE and NEEA[34] to conduct field surveys to understand how much energy photocontrol systems save and how well they work. This survey should take 2 to 4 hours and if it is OK with you I will only need you to show me around for about half of that time. We have contracted with an electrical contractor to place power loggers in the space. This contractor should show up at _________.

Discuss overall goals of the study, goals of this survey

• Do you have the building plans?	
• Is there a copier or a nearby copy shop so I can make TWO copies of the plans?	
• Is there an office or other space I can store my equipment, plans etc during this site visit? *If yes, move equipment into space during site visit.* Interview with Facilities Manager	
• Confirm the arrival time of the electrician:	
• Confirm the departure time of the electrician:	

2.1 Interviewee

2.1.1 Name (if different from site host)	(free text)
2.1.2 What are your responsibilities?	(free text)
2.1.3 What is your job title?	(free text)
2.1.4 How long have you worked in this building?	(years)

2.2 Overall building

2.2.1 When was the building first occupied?	(year) (month)
2.2.2 What are the primary activities that occur in the building?	(free text)
2.2.3 What is the approximate square footage of the building?	(square feet)
2.2.4 Is the surveyed space owner-occupied?	(yes / no)
2.2.5 What is the name of the electrical engineer?	(free text)
2.2.6 What is the name of the architect?	(free text)

[34] NEEA contact: Dave Cohan (503) 827-8416 x231, PG&E contact: Steve Blanc (925) 866-5570, SCE contact: Jack Melnyk (714) 394-0457.

2.3 Space specific questions for guide

- Can we use hand-held light meters to take readings at various points around the space? (yes / no)
- Will it be possible for us to switch the lights off for a few minutes during these readings? (yes / no)
- Can we use a digital camera to take brightness readings at three points within the space? (yes / no)
- Can we place light loggers inside light fixtures? (yes / no)
- Can we attach a current logger around wires inside the light fixtures?[35] (yes / no)
- Can we attach a current logger to the electrical circuit panel? (yes / no)
- Can we place loggers near one workstation in each space? (we will discuss this with the person working in that space) (yes / no)
- Can we leave these loggers in place for two weeks? (yes / no)
- Can we distribute one-page surveys to the occupants of the spaces? (yes / no)

2.4 History of photocontrol system

2.4.1 When was the photocontrol system installed? (year)

2.4.2 Was it installed as a retrofit? (yes / no)

2.4.3 What was the main reason(s) for installing the photocontrol system?

(free text)

2.4.4 What is your understanding of the design intent of the system?

(free text)

2.4.5 Who installed the photocontrol system?

(free text)

2.4.6 Do any records exist of any commissioning process or settings? (yes / no)

2.4.7 Was it subsequently recommissioned? (yes / no)

[35] A split core current transformer is used to measure current. The coil fits round the wire without the wire being removed from its terminal or any exposure to bare wire. The logger is smaller than a pack of cigarettes.

2.4.8 (If so, by whom?)

(free text)

2.4.9 Have any components of the control system been replaced?	(yes / no)
2.4.10 Have you had to replace the PC lamps more often than other similar non-controlled lamps?	(yes / no)
2.4.11 Have you had to replace the PC ballasts more often than other similar non-controlled ballasts?	(yes / no)
2.4.12 Has the system been adjusted since initial set-up?	(yes / no)
2.4.13 Is the automatic photocontrol system in your building currently working?	7 Yes, it works extremely well. 6 Yes, it works reasonably well 5 Uncertain, but it may be working somewhat 4 Uncertain, I really don't know 3 Uncertain, but it's probably not working 2 No, it is not working very well 1 No, it absolutely is not working at all
2.4.14 How long has it been in this condition?	(years)
2.4.15 What percentage of lighting energy used by the controlled lights do you think the photocontrol system saves?	7 91-100% reduction in lighting energy use 6 76-90% 5 50-75% 4 25-49% 3 10-25% 2 1-10% 1 0% reduction in lighting energy use 0 I cannot judge
2.4.16 How satisfied are you with the current operation of the photocontrol system?	7 Completely satisfied 6 Satisfied 5 Somewhat satisfied 4 Neither satisfied or dissatisfied 3 Somewhat dissatisfied 2 Dissatisfied 1 Completely dissatisfied 0 I cannot judge

2.4.17 Please describe anything that is unsatisfactory about the control system's operation	(free text)
2.4.18 Did this building participate in any program promoting energy efficiency or providing design assistance, such as: (check all that apply)	❑ Help from local utility program ❑ Savings by Design ❑ Better Bricks ❑ Daylighting Lab consulting ❑ Seattle Lighting Design Lab consulting ❑ LEED ❑ CHPS (Coalition for High Performance Schools) ❑ Other, describe:
2.4.19 Who currently manages the energy performance of the building? (check all that apply)	❑ The maintenance staff ❑ An on-site facility manager ❑ A corporate level energy manager ❑ An outside contractor ❑ An ESCO company ❑ Don't know Other, Specify:
2.4.20 Was anyone specifically trained in the operation of the photocontrol system?	❑ Yes ❑ Uncertain ❑ No
2.4.21 If yes, who was trained?	❑ Some of the maintenance staff ❑ All the maintenance staff ❑ The on-site facility manager ❑ Another company manager ❑ Some of the occupants ❑ All of the occupants ❑ Don't know ❑ Other, Specify:

2.4.22 If yes, who did the training?

- ❑ The on-site facility manager
- ❑ Another company manager
- ❑ The electrical contractor or installer
- ❑ The architect or design engineer
- ❑ A commissioning agent
- ❑ The controls manufacturer
- ❑ Don't know
- ❑ Other, Specify: ______

2.4.23 Do you have any warranties, service agreements or any other contractual arrangements that cover the photocontrol system?

- ❑ Warranty
- ❑ Service agreement
- ❑ Other contract

2.4.24 If you needed to re-adjust the photocontrol system in the future, who would do this?

- ❑ The occupant(s)
- ❑ An on-site facility manager
- ❑ Another company manager
- ❑ Maintenance staff
- ❑ The electric contractor or installer
- ❑ A commissioning agent
- ❑ The architect or design engineer
- ❑ A utility company representative
- ❑ The manufacturer
- ❑ Don't know
- ❑ Other, Specify: ______

2.4.25 Have you called the photocontrols manufacturer or installer or anyone else to ask for assistance? (yes / no)

2.4.26 What would you do differently if you installed another photocontrol system?

(free text) ______

2.5 Functioning of PC system in each space

Space name and location, notes	# spaces of this type	average sq ft of spaces	How well does the PC system work?				To be surveyed? (No/1/2/3/4)
			0	1	2	3	

0 = no functionality at all

1 = some functionality but needs to be fixed

2 = functional but could be improved

3 = highly functional, very few / no problems

2.6 Photocontrol systems that have problems:

2.6.1 When did these problems first occur? (year) ______________

2.6.2 Was the problem in the photocontrols system operation due to any changes made to the system, to the space or to the electric lighting system? If so, please describe how the changes led to the problems. (yes / no)

____

2.6.3 Briefly describe any complaints that the occupants have made regarding the control system:

- ❑ Controls create lighting conditions that are too dark or gloomy
- ❑ Controls create lighting conditions that are unnecessarily bright
- ❑ Electric lights switch or dim on and/or off too frequently
- ❑ Controls cause electric lights to flicker
- ❑ Other:

  (describe) ____

2.6.4 What problems do you perceive with the control system?

- ❑ Don’t understand how controls are supposed to work
- ❑ Controls too difficult/expensive to calibrate or maintain
- ❑ Controls do not achieve sufficient energy savings
- ❑ Controls seem to cause frequent lamp or ballast failure
- ❑ Other:

  (describe) ____

2.7 Inoperative Photocontrol Systems:

2.7.1 What happened to render the system inactive?

- ❑ Stopped working by itself?
- ❑ Disabled by occupant?
- ❑ Disabled by management at the request of occupants?
- ❑ Disabled by management?
- ❑ Disabled by contractor on purpose?
- ❑ Disabled by contractor by accident?

  (describe) ____

3. TOUR BUILDING

3.1 Rule set for selecting spaces:

- If you are going to survey more than one space, pick a system that is working well as defined by your contact and one space that is not working well.
- If all spaces are working equally well, select spaces of different orientations or different geometries
- Pick those spaces that are easier to monitor or more secure, photosensor is available etc.
- Consider diversity requirements (e.g. we may need more “other” spaces than classrooms)

Once the survey spaces are selected, ask to make photocopies of the plans and elevations. Note the scale of the plans

3.2 Time plan for survey:

- Note the times of any events that are important for the survey (when occupants arrive or leave, when staff are available, when lights can be turned off or on, surveyor’s lunch time, etc.)

Electrician arrives ____________________

Electrician departs ____________________ Other events ____________________

Lunch Break ____________________ Other Breaks ____________________

	Space name	Expected time in	Expected time out	Reason selected
Space #1				
Space #2				
Space #3				
Space #4				

4. SITE SURVEY – SPACE 1

Define the space to be surveyed – it should not include any areas lit by daylight that does not come through the window(s) being surveyed. It should include any uncontrolled lights that contribute a significant amount of illumination to the photocontrolled area.

Introduce yourself to the occupants, and hand out occupant survey sheets (only to people in the study area).

4.1.1 # of occupant surveys handed out ______________

4.1.2 # of occupant surveys received ______________

4.2 Key space dimensions

4.2.1 Space square footage ______________ sq feet

4.2.2 Survey space square footage ______________ sq feet

4.2.3 Photocontrolled square footage ______________ sq feet

4.2.4 Ceiling height
(if not flat, then enter average ceiling height and show ceiling heights on sketch elevation) ______________ feet

4.2.5 Partition height feet

4.2.6 Room shape (rectangular, L-shape etc.) ______________

4.3 Surface reflectances

Note illuminance within each circle. Where applicable, number the circles left to right across field of view

4.3.1 Floor ______________ %

4.3.2 Walls ______________ %

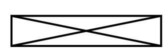
4.3.3 Partitions ______________ %

4.3.4 Ceiling ______________ %

4.4 Daylighting Strategy

Daylighting strategy	(Unilateral, opposing windows, corner windows at right angles, windows with inset monitors)
View windows	(Y/N)
Clerestory on exterior wall	(Y/N)
Roof monitor or clerestory inset from exterior wall	(Y/N)
Interior light redirecting devices:	(Diffuse light shelves, specular light shelves, laser cut panels, holographic film)

4.5 Sketch Plan

- Dimensions length and width of space (pencil)
- Location of partitions (pencil)
- Location, and wattage of each fixture (black) 
- Location of photosensor(s) including mounting height, facing direction (blue) **PS# ○**
- Location of photocontroller (blue) **PC# ☐ (ensure PC number corresponds to PS number)**
- Location of light switches (blue) **LS# §**
- Note which fixtures are controlled by which sensor (write “PS1” etc. next to fixture)
- Note which fixtures are controlled by which switch (write “LS1” etc. next to fixture)
- Note whether any fixtures are controlled by time clocks or occupancy sensors (note next to fixture “OS1”, “OS2” etc.)
- Location and serial numbers of current and light loggers (red) **L#**
- Location of “critical task” including distance from walls (red) **Task→**

4.6 Sketch elevations of four walls

- Position and dimensions of windows
- Reflectance of floor, ceiling, four walls, desks, partitions
- Position, elevation and slat angle of blinds

4.7 Windows

Note only features that are at least 1' in size, ignore narrow window surrounds, reveals etc.

Description	Window 1	Window 2	Window 3	Window 4
Orientation (compass direction)				
Ceiling height by window (ft)				
View Windows				
Number of windows				
Head height from floor				
Window height				
Window width				
# of glazing layers				
Fraction of blind or shade coverage, and elevation and slat angle if applicable				
Vertical Illuminance inside of glass				
Time of inside illuminance measurement				
Simultaneous vertical Illuminance on room side of blind or shade				
Simultaneous vertical Illuminance outside glass in same orientation as window				
Type of blinds (Xtal / Vcal / roller, light / medium / dark, solid / perf)				
*Tvis glass (inside glass vs outside)				
*Tvis blind or shade (inside blind vs inside glass)				
Logger Number				
Overhang projection length				
Transmittance of overhang				
Reflectance of overhang				
Vertical distance between window head and bottom of overhang				

Clerestory Windows				
Number of windows				
Head height from floor				
Window height				
Window width				
# of glazing layers				
Fraction of blind or shade coverage, and elevation and slat angle if applicable				
Vertical Illuminance inside of glass				
Time of inside illuminance measurement				
Simultaneous vertical Illuminance on room side of blind or shade				
Simultaneous vertical Illuminance outside glass in same orientation as window				
Type of blinds (Xtal / Vcal / roller, light / medium / dark, solid / perf)				
*Tvis glass (inside glass vs outside)				
*Tvis blind or shade (inside blind vs inside glass)				
Overhang projection length				
Transmittance of overhang				
Reflectance of overhang				
Vertical distance between clerestory head and bottom of overhang				

Interior Light shelves				
Height of top of lightshelf				
Light shelf projection				
Light shelf transmittance				
Light shelf reflectance				

Side fins				
Fins for windows only, clerestory only or both?				
Right fin projection length				
Distance from window to R fin				
Left fin projection length				
Distance from window to L fin				
Reflectance of fin				
Transmittance of fin				

* Calculated value

4.8 Photosensor calibration and other data

Photosensor Numbers	PS#1	PS#2	PS#3	PS#4
Manufacturer				
Model Number				
Distance from closest daylight aperture (ft)				
Sensor orientation (down at floor, looking out window, floor by window, side wall, back wall, up)				
Sensor receiving direct light from pendants? (Yes, No)				
Sensor shielded or masked? (yes, No)				
Physical damage, lens broken etc. (Yes, No)				
Lens dirty, discolored? (Yes, No)				
Lens taped over? (Yes, No)				
Wires connected? (yes, No)				
Connects to: (single level switching control, multi-level switching control, dimming control panel, directly to dimming ballasts)				
Spot reading fc:				
Time spot reading taken:				
Time sensor covered over				
Description of control adjustment settings				
Logger Number:				
Other notes on photosensors:				

4.9 Photocontroller Panel Data (may not apply)

4.9.1 Manufacturer, model number	(free text)
4.9.2 What space does the panel control?	(1/2/3/4)
4.9.3 Panel type	(master controller/slave or secondary controller/relay panel/stand-alone/other)
4.9.4 What photosensor is attached to this panel? (check all that apply)	PS1 PS2 PS3 PS4
4.9.5 Is there remote access to the panel?	(yes/no)
4.9.6 If software access, note software name and version#	(yes/no)
4.9.7 Is the panel connected to or part of an EMS system?	(yes/no)
4.9.8 Other notes on panel	(free text)

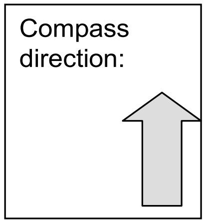
4.10 Critical Task Logger Calibration

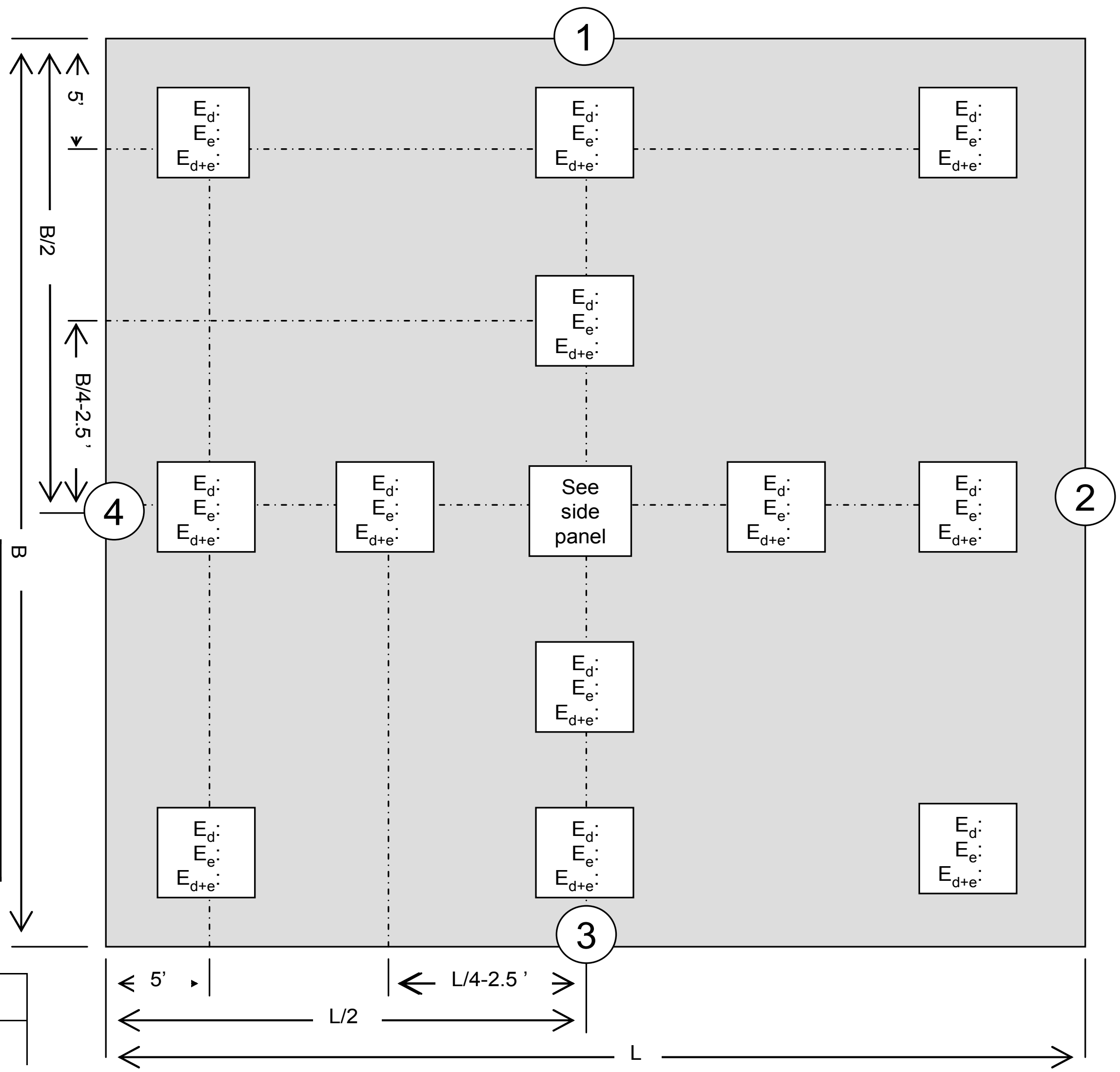
NOTE: ALSO FILL IN THE ILLUMINANCES ON THE ATTACHED SHEET

At or near the “critical task” workstation, i.e. the workstation where the occupant is most likely to complain that light levels are too low. This will usually be under the last row of controlled fixtures. Oftentimes, the hobo cannot be located at the task but is placed nearby (such as on top of partition near desktop which is critical task.

4.10.1 Spot measurement of illuminance at logger with lights on	fc	Time:	
4.10.2 Spot measurement of illuminance at logger with lights off	fc	Time:	
4.10.3 Spot measurement of illuminance at critical task, lights on	fc	Time:	
4.10.4 Spot measurement of illuminance at critical task, lights off	fc	Time:	

4.11 Working plane illuminance measurements





Center of room:

	E_d	E_e	E_{d+e}
Facing 1			
Facing 2			
Facing 3			
Facing 4			
Horizontal			

4.14.1 Time lights off	
4.14.2 Time lights on	

4.12 Light Fixture Data

	Circuit #1	Circuit #2	Circuit #3	Circuit #4	Circuit #5	Task lights
Photosensor attached?	PS#	PS#	PS#	PS#	PS#	N/A
Level of control (1, 2, …N/A)						
Controlled by light switch?	LS#	LS#	LS#	LS#	LS#	N/A
Connected to occupancy sensor? (Y/N)						
Automatic control type: (dimming, on/off, multi-level (hi-lo ballast, lamps within fixture, alternating fixtures, alternating rows)						
Manual override type (off-override, on-override, on <u>and</u> off-override, dimming override)						
Depth of control zone from closest daylight aperture						
Lamp type (T5,T8,CFL,MH, other)						
Tachometer RPM						
Wattage per lamp	W	W	W	W	W	W
# lamps/ fixture						
# fixtures on circuit in surveyed zone						
Total # of fixtures on circuit						
Mounting type (recessed, surface mounted, suspended, wall, undercabinet, task, floor, other)						
Mounting height						
Light distribution (direct, indirect, direct/indirect, other)						
Controller type (diffuser, prismatic, parabolic, other)						
Lamp color (shown on lamp)	K	K	K	K	K	K
Logger Number						
Initial amps/ time*						
Amps on or high /time*						
Amps off or fully dimmed/ time*						

* Install logger before taking amp readings. Amps on or high is performed by covering photosensor if possible

4.13 Digital Images for Reference

Note the location and orientation of each photograph on the plan with an arrow, use green pen. Beside each arrow note the jpg number of the photograph, and the time of day. Take photos at least the following locations:

- General space layout – jpg#
- Close-up of light switches / control interface – jpg#
- Close-up of window details – jpg#
- Blinds/Curtain details, including actuators – jpg#
- Overhangs, light-shelves, clerestories – jpg#
- Close-up of light fixtures – jpg#
- Close-up of photosensor and model number (if possible) – jpg#
- Close-up of control panel – jpg#
- View from main window (use fisheye lens) – jpg#
- Photo of critical task location including logger – jpg#:

4.14 'Hubble' luminance images

T A K E H U B B L E I M A G E S W I T H E L E C T R I C L I G H T S T U R N E D O F F !

- View from center of space facing 90° clockwise from window # ____________
- Time that images were taken ____________

Exposure time (seconds) / Camera aperture (f-stop)	8	5.6	4	2.8
bulb*				
8"				
4"				
2"				
1"				
½"				
¼"				
1/8"				
1/15"				
1/30"				
1/60"				
1/125"				
1/250"				
1/500"				
1/1000"				
1/2000"				

- View from center facing 90° clockwise from window # ____________
- Time that images were taken ____________

Exposure time (seconds) / Camera aperture (f-stop)	8	5.6	4	2.8
bulb*				
8"				
4"				
2"				
1"				
½"				
¼"				
1/8"				
1/15"				
1/30"				
1/60"				
1/125"				
1/250"				
1/500"				
1/1000"				
1/2000"				

- View from doorway toward main window

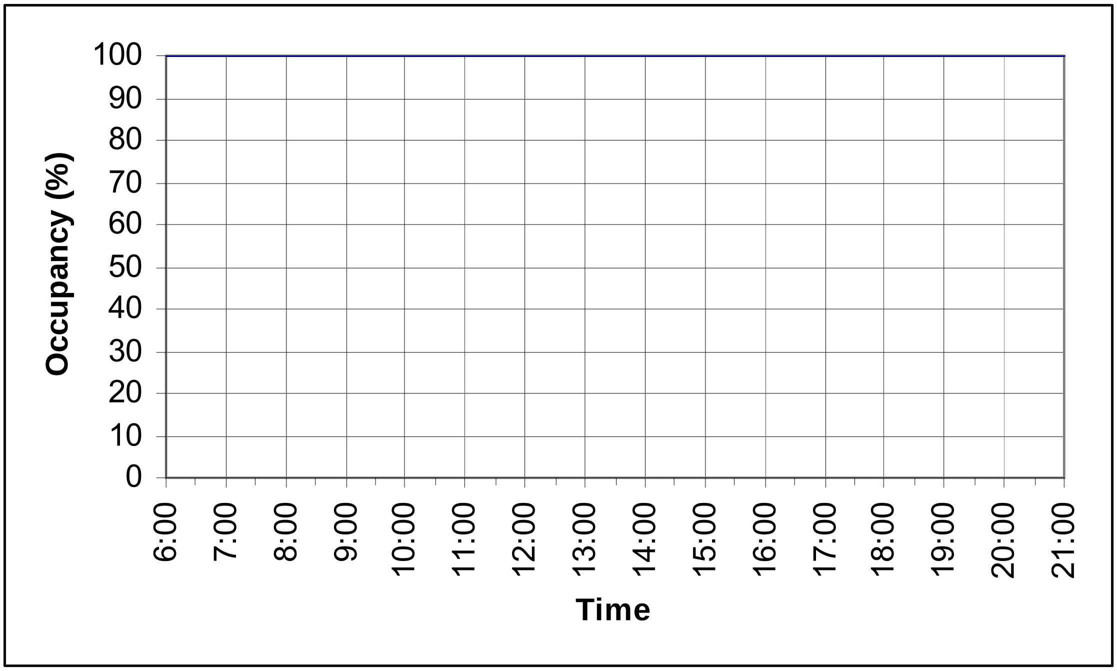
- Time that images were taken

____

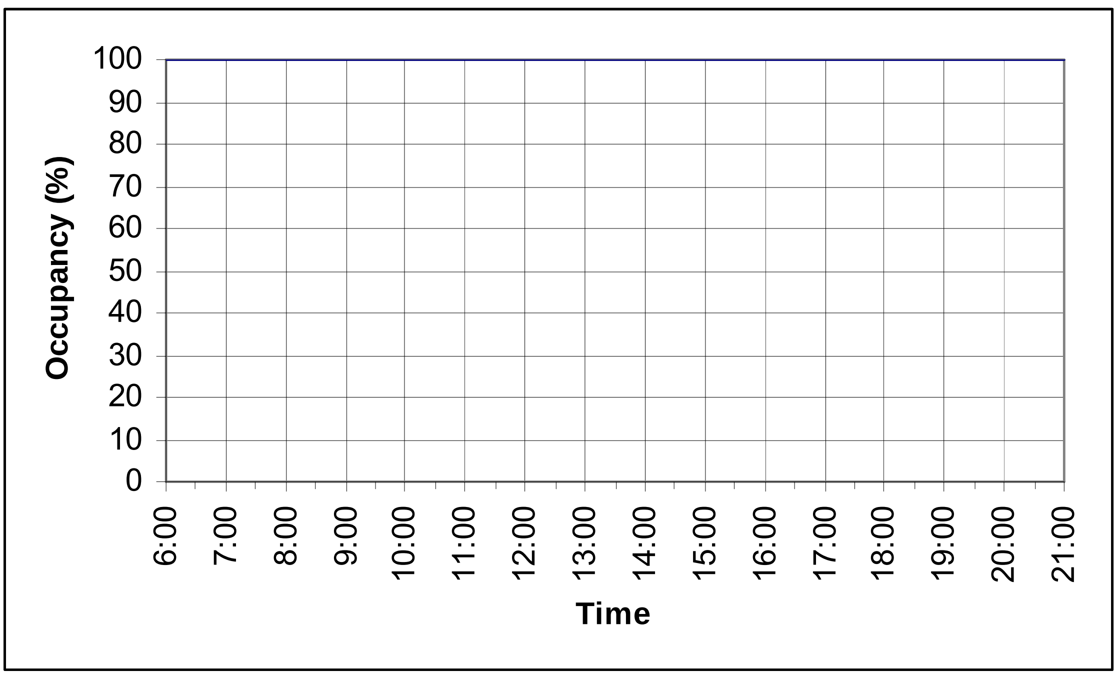
Exposure time (seconds) / Camera aperture (f-stop)	8	5.6	4	2.8
bulb*				
8”				
4”				
2”				
1”				
½”				
¼”				
1/8”				
1/15”				
1/30”				
1/60”				
1/125”				
1/250”				
1/500”				
1/1000”				
1/2000”				

4.15 Occupancy Schedules

Monday – Friday



Weekend



Occupancy schedule notes:

APPENDIX F

TABLES OF FINDINGS FOR ON-SITE SURVEY

List of tables:

Definitions: a list of system characteristics considered in the analysis of on-site monitored data, grouped by type

Summary: Summary findings of the onsite analysis, sorted by the number of the five output variables where each characteristic had a significant association.

Functionality: Inputs to the calculations if a characteristic was more likely to be found functioning or not functional (RSR=0 v RSR>0), sorted by p-value.

RSR: Inputs to the calculations if a characteristic was more likely to have a higher RSR (realized savings ratio) for the population where RSR>0, sorted by p-value.

FLH: Inputs to the calculations if a characteristic was more likely to have a higher FLH (full load hour savings per day) for the population where RSR>0, sorted by p-value.

EUI: Inputs to the calculations if a characteristic was more likely to have a higher EUI (lighting only energy use intensity savings, in Kwh per square foot of controlled area per year) for the population where RSR>0, sorted by p-value.

Demand: Inputs to the calculations if a characteristic was more likely to have higher demand reduction (lighting and HVAC power reduction, in Watts per square foot of controlled area per year) for the population where RSR>0, sorted by p-value.

Descriptive Statistics: descriptive statistics for the population of each characteristic, by RSR=0 or RSR>0, sorted by type.

LIST OF EXPLANATORY VARIABLES

Category	Explanatory Variables
Control zone	Area of daylight control zone (sf)
Control zone	Depth of control zone (ft)
Control zone	Distance of photosensor to window (ft)
Control zone	Ratio of window head ht to depth of control zone
Control zone	Size of controlled load (Watts)
Controls	If dimming v switching
Controls	If single daylight circuit v multiple circuits
Controls	If photosensor is looking down
Fenestration Design	If space has high windows (>8') v low only
Fenestration Design	Net Tvis of windows w blinds
Fenestration Design	Ratio of (net Tvis * window area) to control area
Fenestration Design	Ratio of window area to control area
Fenestration Design	Tvis of glass
Fenestration Design	Window head height (ft)
Luminaires/illuminance	If luminaires use direct light distribution
Luminaires/illuminance	Illuminance ratio, from front to back of room
Luminaires/illuminance	Illuminance ratio, horizontal min to max
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average
Luminaires/illuminance	Illuminance ratio, vertical min to max
Occupants	If "other" type space
Occupants	If classroom space
Occupants	If library space v all others
Occupants	If office space
Occupants	If open office v all others
Occupants	If owner occupied building
Occupants	If private office space v all others
Operator	If building has off-site management
Operator	If site host has records of PC settings
Operator	If occupants were trained about PC system
Operator	If site host believes system is working (1-7)
Operator	If site host is satisfied w system (1-7)
Space or bldg design	Ceiling height in room
Space or bldg design	If large bldg (>50,000 sf) v all others
Space or bldg design	If office bldg
Space or bldg design	If office bldg or K-12 school
Space or bldg design	If small bldg (<15,000 sf) v all others
Space or bldg design	If space has partitions
Space or bldg design	K-12 school building
Space or bldg design	Number of years building has been occupied
Space or bldg design	Number of years of PC operation
Space or bldg design	Room size (sf)
Space or bldg design	Weighted reflectance of surfaces
Window Type	If daylight comes from only one direction
Window Type	If space has clerestory v no clerestory
Window Type	If space has only north facing windows
Window controls	If windows have blinds

TABLE OF SUMMARY FINDINGS

Category	Explanatory Variables	Count of Significant findings count p	RSR=0 vs. >0 Functional	For RSR>0 where p<0.10 RSR	FLH	EUI	Demand
Controls	If dimming v switching	5	**0.0118**	(0.0088)	(0.0598)	(0.0835)	(0.0298)
Control zone	Ratio of window head ht to depth of control zone	4	(0.0427)		(0.0385)	(0.0001)	(0.0869)
Control zone	Distance of photosensor to window (ft)	4		(0.0047)	(0.0010)	(0.0011)	(0.0062)
Occupants	If library space v all others	4	(0.0207)		**0.0969**	**0.0004**	**0.0046**
Fenestration Design	Ratio of (net Tvis * window area) to control area	3			**0.0021**	**0.0000**	**0.0015**
Fenestration Design	Ratio of window area to control area	3			**0.0056**	**0.0000**	**0.0159**
Controls	If photosensor is looking down	3	**0.0307**	(0.0309)	(0.0801)		
Space or bldg design	Number of years of PC operation	3			**0.0004**	**0.0001**	**0.0139**
Window Type	If space has clerestory v no clerestory	2			(0.0553)	(0.0923)	
Controls	If single daylight circuit v multiple circuits	2	(0.0000)	(0.0855)			
Window controls	If windows have blinds	2			(0.0133)	(0.0295)	
Operator	If site host has records of PC settings	2			(0.0074)	(0.0282)	
Occupants	If classroom space	2	**0.0005**		(0.0841)		
Space or bldg design	If small bldg (<15,000 sf) v all others	2		**0.0105**	**0.0284**		
Space or bldg design	K-12 school building	2	**0.0012**		(0.0669)		
Luminaires/illuminance	Illuminance ratio, horizontal min to max	2	(0.0163)				**0.0776**
Control zone	Depth of control zone (ft)	1	**0.0015**				
Window Type	If daylight comes from only one direction	1	(0.0150)				
Window Type	If space has only north facing windows	1	**0.0937**				
Fenestration Design	Net Tvis of windows w blinds	1	**0.0039**				
Fenestration Design	Window head height (ft)	1	**0.0110**				
Fenestration Design	If space has high windows (>8') v low only	1	**0.0325**				
Operator	If building has off-site management	1					**0.0549**
Operator	If occupants were trained about PC system	1	**0.0009**				
Occupants	If "other" type space	1			**0.0868**		
Occupants	If office space	1	0.0000				
Occupants	If open office v all others	1	(0.0107)				
Occupants	If owner occupied building	1	**0.0008**				
Space or bldg design	If large bldg (>50,000 sf) v all others	1	(0.0002)				
Space or bldg design	If office bldg	1	(0.0019)				
Space or bldg design	If space has partitions	1	(0.0000)				
Luminaires/illuminance	If luminaires use direct light distribution	1	(0.0088)				
Fenestration Design	Tvis of glass	1	**0.0258**				
Operator	If site host believes system is working (1-7)	1	**0.0000**				
Operator	If site host is satisfied w system (1-7)	1	**0.0297**				
Space or bldg design	Weighted reflectance of surfaces	1	(0.0623)				
Space or bldg design	Ceiling height in room	1	**0.0654**				
Luminaires/illuminance	Illuminance ratio, from front to back of room	1	(0.0008)				
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average	1	(0.0020)				
Space or bldg design	Room size (sf)	0					
Control zone	Size of controlled load (Watts)	0					
Control zone	Area of daylight control zone (sf)	0					
Luminaires/illuminance	Illuminance ratio, vertical min to max	0					
Occupants	If private office space v all others	0					
Space or bldg design	Number of years building has been occupied	0					
Space or bldg design	If office bldg or K-12 school	0					

Notes: Table sorted by count of significant findings per explanatory variable
Values in bold indicate a positive influence of the explanatory variable on the outcome variable (RSR, FLH, EUI, Demand)
Values in paranthesis indicate a negative influence of the explanatory variable on the outcome variable (RSR, FLH, EUI, Demand)

TABLE OF PHOTOCONTROL FUNCTION STATUS

		Variable	RSR=0	RSR>0	RSR=0		RSR>0		RSR=0		RSR>0		Diff	Diff	
Category	**Explanatory Variables**	**Type**	**Pop.**	**Pop.**	**Count**	**Mean**	**Count**	**Mean**	**Prop.**	**StDev**	**Prop.**	**StDev**	**Prop.**	**Mean**	**p =**
Operator	If site host believes system is working (1-7)	continuous	63	56		3.73		5.82		2.22		0.61		(2.09)	0.000
Controls	If single daylight circuit v multiple circuits	yes/no	63	59	55		33		87%		56%		0.31		0.000
Space or bldg design	If space has partitions	yes/no	59	59	37		15		63%		25%		0.37		0.000
Space or bldg design	If large bldg (>50,000 sf) v all others	yes/no	64	59	43		20		67%		34%		0.33		0.000
Occupants	If classroom space	yes/no	64	59	9		25		14%		42%		(0.28)		0.000
Occupants	If owner occupied building	yes/no	59	56	40		52		68%		93%		(0.25)		0.001
Luminaires/illuminance	Illuminance ratio, from front to back of room	continuous	47	52		8.12		3.45		9.40		2.41		4.67	0.001
Operator	If occupants were trained about PC system	yes/no	55	43	30		37		55%		86%		(0.32)		0.001
Space or bldg design	K-12 school building	yes/no	64	59	11		26		17%		44%		(0.27)		0.001
Control zone	Depth of control zone (ft)	continuous	64	59		17.79		24.00		9.22		11.85		(6.21)	0.001
Space or bldg design	If office bldg	yes/no	64	59	35		16		55%		27%		0.28		0.002
Occupants	If "other" type space	yes/no	38	46	1		1		38%		29%		0.00		0.002
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average	continuous	38	46		0.92		0.69		0.38		0.29		0.23	0.002
Fenestration Design	Net Tvis of windows w blinds	continuous	41	56		0.30		0.47		0.23		0.30		(0.17)	0.004
Occupants	If office space	yes/no	64	59	36		19		56%		32%		0.24		0.007
Luminaires/illuminance	If luminaires use direct light distribution	yes/no	64	59	39		22		61%		37%		0.24		0.009
Occupants	If open office v all others	yes/no	64	59	28		13		44%		22%		0.22		0.011
Fenestration Design	Window head height (ft)	continuous	63	59		9.24		10.76		2.64		3.78		(1.52)	0.011
Controls	If dimming v switching	yes/no	60	59	35		45		58%		76%		(0.18)		0.012
Window Type	If daylight comes from only one direction	yes/no	64	59	39		23		61%		39%		0.22		0.015
Luminaires/illuminance	Illuminance ratio, horizontal min to max	continuous	48	54		15.55		8.50		19.14		8.60		7.05	0.016
Occupants	If library space v all others	yes/no	64	59	12		3		19%		5%		0.14		0.021
Fenestration Design	Tvis of glass	continuous	48	59		0.60		0.69		0.22		0.19		(0.09)	0.026
Operator	If site host is satisfied w system (1-7)	continuous	47	52		4.60		5.29		1.88		1.19		(0.69)	0.030
Controls	If photosensor is looking down	yes/no	62	59	40		47		65%		80%		(0.15)		0.031
Fenestration Design	If space has high windows (>8') v low only	yes/no	63	59	43		50		68%		85%		(0.16)		0.032
Control zone	Ratio of window head ht to depth of control zone	continuous	63	59		0.66		0.54		0.34		0.29		0.12	0.043
Space or bldg design	Weighted reflectance of surfaces	continuous	64	59		0.61		0.58		0.09		0.09		0.03	0.062
Space or bldg design	Ceiling height in room	continuous	64	59		11.29		12.73		4.09		4.50		(1.44)	0.065
Window Type	If space has only north facing windows	yes/no	64	59	8		11		13%		19%		(0.06)		0.094
Window Type	If space has clerestory v no clerestory	yes/no	64	59	14		20		22%		34%		(0.12)		0.136
Control zone	Area of daylight control zone (sf)	continuous	64	59		758.67		1,006.71		754.97		1,076.05		(248.05)	0.139
Luminaires/illuminance	Illuminance ratio, vertical min to max	continuous	48	50		5.21		4.19		4.28		2.97		1.02	0.172
Control zone	Size of controlled load (Watts)	continuous	64	59		0.77		1.03		0.87		1.25		(0.25)	0.195
Fenestration Design	Ratio of window area to control area	continuous	63	59		0.39		0.33		0.38		0.34		0.07	0.299
Operator	If site host has records of PC settings	yes/no	49	49	22		27		45%		55%		(0.10)		0.312
Space or bldg design	Number of years of PC operation	continuous	59	55		2,001.78		2,002.07		2.63		3.28		(0.29)	0.598
Space or bldg design	Room size (sf)	continuous	64	59		1,047.82		1,147.85		845.36		1,283.70		(100.04)	0.608
Occupants	If private office space v all others	yes/no	64	59	8		6		13%		10%		0.02		0.684
Window controls	If windows have blinds	yes/no	41	56	53		48		84%		81%		0.00		0.685
Space or bldg design	Number of years building has been occupied	continuous	58	54		1,997.02		1,997.78		13.12		14.02		(0.76)	0.767
Fenestration Design	Ratio of (net Tvis * window area) to control area	continuous	41	56		0.13		0.14		0.26		0.21		(0.01)	0.774
Control zone	Distance of photosensor to window (ft)	continuous	64	59		9.71		9.38		7.89		5.60		0.33	0.789
Operator	If building has off-site management	yes/no	47	48	21		21		45%		44%		0.01		0.927
Space or bldg design	If office bldg or K-12 school	yes/no	64	59	46		42		72%		71%		0.01		0.933
Space or bldg design	If small bldg (<15,000 sf) v all others	yes/no	64	59	13		12		20%		20%		(0.00)		0.997

Notes: Table sorted by significance (p value) of explanatory variables
RSR=0 means a non-functional system
RSR>0 means a functional system

Pop. means population
Prop. means proportion

TABLE OF REALIZED SAVINGS RATIO

			RSR>0	RSR>0	RSR								
Category	Explanatory Variables	Variable Type	Count 1 (or all)	Count 2	Min	Max	Range	Std.Dev.	Mean 1	Mean 2 (or pop)	Diff Mean	Coef X	p =
Control zone	Distance of photosensor to window (ft)	continuous	59.00		0.00	2.22	2.22	0.38		0.53		(0.02)	0.005
Controls	If dimming v switching	yes/no	45.00	15.00					0.46	0.76	(0.30)		0.009
Space or bldg design	If small bldg (<15,000 sf) v all others	yes/no	12.00	47.00					0.78	0.46	0.31		0.011
Controls	If photosensor is looking down	yes/no	47.00	12.00					0.47	0.74	(0.27)		0.031
Operator	If site host has records of PC settings	yes/no	27.00	22.00					0.50	0.68	(0.18)		0.117
Space or bldg design	Number of years of PC operation	continuous	55.00		0.00	2.22	2.22	0.39		0.54		(0.02)	0.195
Space or bldg design	Room size (sf)	continuous	59.00		0.00	2.22	2.22	0.38		0.53		0.00	0.204
Fenestration Design	Ratio of window area to control area	continuous	59.00		0.00	2.22	2.22	0.38		0.53		0.18	0.227
Control zone	Depth of control zone (ft)	continuous	59.00		0.00	2.22	2.22	0.38		0.53		(0.03)	0.238
Operator	If building has off-site management	yes/no	21.00	27.00					0.64	0.51	0.13		0.275
Fenestration Design	Ratio of (net Tvis * window area) to control area	continuous	56.00		0.00	2.22	2.22	0.38		0.53		0.27	0.289
Window controls	If windows have blinds	yes/no	48.00	11.00					0.50	0.63	(0.13)		0.309
Operator	If site host is satisfied w system (1-7)	continuous	59.00		0.00	2.22	2.22	0.38		0.53		0.02	0.326
Fenestration Design	Window head height (ft)	continuous	59.00		0.00	2.22	2.22	0.38		0.53		(0.01)	0.355
Space or bldg design	If large bldg (>50,000 sf) v all others	yes/no	19.00	40.00					0.46	0.56	(0.10)		0.356
Control zone	Ratio of window head ht to depth of control zone	continuous	59.00		0.00	2.22	2.22	0.38		0.53		0.16	0.357
Operator	If occupants were trained about PC system	yes/no	37.00	16.00					0.50	0.60	(0.10)		0.393
Window Type	If space has clerestory v no clerestory	yes/no	20.00	39.00					0.47	0.56	(0.08)		0.434
Occupants	If library space v all others	yes/no	3.00	56.00					0.69	0.52	0.17		0.462
Luminaires/illuminance	If luminaires use direct light distribution	yes/no	22.00	37.00					0.57	0.50	0.07		0.500
Control zone	Area of daylight control zone (sf)	continuous	59.00		0.00	2.22	2.22	0.38		0.53		0.00	0.502
Luminaires/illuminance	Illuminance ratio, horizontal min to max	continuous	54.00		0.00	2.22	2.22	0.39		0.52		(0.00)	0.509
Space or bldg design	K-12 school building	yes/no	26.00	33.00					0.49	0.56	(0.06)		0.524
Window Type	If space has only north facing windows	yes/no	31.00	28.00					0.50	0.56	(0.06)		0.537
Luminaires/illuminance	Illuminance ratio, from front to back of room	continuous	52.00		0.00	2.22	2.22	0.39		0.52		0.01	0.549
Space or bldg design	Number of years building has been occupied	continuous	54.00		0.00	2.22	2.22	0.39		0.55		0.00	0.567
Luminaires/illuminance	Illuminance ratio, vertical min to max	continuous	50.00		0.00	2.22	2.22	0.40		0.52		(0.01)	0.577
Space or bldg design	Ceiling height in room	continuous	59.00		0.00	2.22	2.22	0.38		0.53		0.01	0.584
Space or bldg design	Weighted reflectance of surfaces	continuous	59.00		0.00	2.22	2.22	0.38		0.53	(0.58)	(0.31)	0.585
Operator	If site host believes system is working (1-7)	continuous	59.00		0.00	2.22	2.22	0.38		0.53		0.02	0.594
Occupants	If classroom space	yes/no	25.00	34.00					0.50	0.55	(0.05)		0.624
Space or bldg design	If office bldg	yes/no	16.00	43.00					0.58	0.51	0.07		0.626
Occupants	If "other" type space	yes/no	44.00	15.00					0.52	0.56	(0.05)		0.691
Occupants	If owner occupied building	yes/no	52.00	4.00					0.53	0.60	(0.06)		0.761
Window Type	If daylight comes from only one direction	yes/no	23.00	36.00					0.55	0.52	0.03		0.781
Occupants	If private office space v all others	yes/no	6.00	53.00					0.57	0.52	0.04		0.794
Space or bldg design	If space has partitions	yes/no	15.00	44.00					0.51	0.53	(0.02)		0.855
Occupants	If office space	yes/no	19.00	40.00					0.54	0.52	0.02		0.883
Fenestration Design	Tvis of glass	continuous	59.00		0.00	2.22	2.22	0.38		0.53		(0.03)	0.903
Controls	If single daylight circuit v multiple circuits	yes/no	33.00	26.00					0.60	0.53	0.78		0.904
Fenestration Design	Net Tvis of windows w blinds	continuous	56.00		0.00	2.22	2.22	0.39		0.54		(0.02)	0.922
Space or bldg design	If office bldg or K-12 school	yes/no	17.00	42.00					0.53	0.52	0.01		0.930
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average	continuous	46.00		0.00	2.22	2.22	0.40		0.54		(0.02)	0.931
Fenestration Design	If space has high windows (>8') v low only	yes/no	9.00	50.00					0.53	0.52	0.00		0.974
Occupants	If open office v all others	yes/no	13.00	46.00					0.53	0.53	(0.00)		0.980
Control zone	Size of controlled load (Watts)	continuous	59.00		0.00	2.22	2.22	0.38		0.53		0.00	0.991

Notes: RSR>0 means a functional system
Table sorted by significance (p value) of explanatory variables

TABLE OF FULL LOAD HOUR SAVINGS

			RSR>0	RSR>0	FLH								
Category	Explanatory Variables	Variable Type	Count 1 (or all)	Count 2	Min	Max	Range	Std.Dev.	Mean 1	Mean 2 (or pop)	Diff Mean	Coef X	p =
Space or bldg design	Number of years of PC operation	continuous	55.00		0.01	10.79	10.78	2.19		2.24		(0.31)	0.000
Control zone	Distance of photosensor to window (ft)	continuous	59.00		0.01	10.79	10.78	2.15		2.16		(0.16)	0.001
Fenestration Design	Ratio of (net Tvis * window area) to control area	continuous	56.00		0.01	10.79	10.78	2.15		2.16		4.16	0.002
Fenestration Design	Ratio of window area to control area	continuous	59.00		0.01	10.79	10.78	2.15		2.16		2.23	0.006
Operator	If site host has records of PC settings	yes/no	27.00	22.00					1.66	3.34	(1.69)		0.007
Window controls	If windows have blinds	yes/no	48.00	11.00					1.84	3.59	(1.76)		0.013
Space or bldg design	If small bldg (<15,000 sf) v all others	yes/no	12.00	47.00					3.37	1.86	1.51		0.028
Control zone	Ratio of window head ht to depth of control zone	continuous	59.00		0.01	10.79	10.78	2.15		2.16		2.00	0.038
Window Type	If space has clerestory v no clerestory	yes/no	20.00	39.00					1.42	2.55	(1.13)		0.055
Controls	If dimming v switching	yes/no	45.00	15.00					1.87	3.11	(1.24)		0.060
Space or bldg design	K-12 school building	yes/no	26.00	33.00					1.59	2.62	(1.03)		0.067
Controls	If photosensor is looking down	yes/no	47.00	12.00					1.92	3.13	(1.22)		0.080
Occupants	If classroom space	yes/no	25.00	34.00					1.60	2.58	(0.98)		0.084
Occupants	If "other" type space	yes/no	44.00	15.00					1.88	2.99	(1.10)		0.087
Occupants	If library space v all others	yes/no	3.00	56.00					4.18	2.06	2.12		0.097
Luminaires/illuminance	If luminaires use direct light distribution	yes/no	22.00	37.00					2.75	1.82	0.93		0.110
Operator	If site host is satisfied w system (1-7)	continuous	59.00		0.01	10.79	10.78	2.15		2.16	(0.01)	0.22	0.112
Window Type	If space has only north facing windows	yes/no	31.00	28.00					1.91	2.45	(0.54)		0.138
Fenestration Design	Window head height (ft)	continuous	59.00		0.01	10.79	10.78	2.15		2.16		(0.11)	0.142
Space or bldg design	Number of years building has been occupied	continuous	54.00		0.01	10.79	10.78	2.22		2.23		(0.03)	0.200
Operator	If occupants were trained about PC system	yes/no	37.00	16.00					1.97	2.81	(0.85)		0.205
Control zone	Depth of control zone (ft)	continuous	59.00		0.01	10.79	10.78	2.15		2.16		(0.03)	0.238
Fenestration Design	If space has high windows (>8') v low only	yes/no	9.00	50.00					2.02	2.94	(0.92)		0.241
Operator	If building has off-site management	yes/no	21.00	27.00					1.95	2.68	(0.73)		0.283
Space or bldg design	Ceiling height in room	continuous	59.00		0.01	10.79	10.78	4.50		12.73		(0.06)	0.309
Window Type	If daylight comes from only one direction	yes/no	23.00	36.00					2.49	1.96	0.53		0.357
Space or bldg design	If office bldg or K-12 school	yes/no	17.00	42.00					2.57	2.00	0.56		0.366
Luminaires/illuminance	Illuminance ratio, from front to back of room	continuous	52.00		0.01	10.79	10.78	1.88		1.88		0.09	0.431
Control zone	Area of daylight control zone (sf)	continuous	59.00		0.01	10.79	10.78	2.15		2.16		0.00	0.452
Space or bldg design	Room size (sf)	continuous	59.00		0.01	10.79	10.78	2.15		2.16		0.00	0.452
Fenestration Design	Tvis of glass	continuous	59.00		0.01	10.79	10.78	2.15		2.16		1.05	0.489
Occupants	If private office space v all others	yes/no	6.00	53.00					2.72	2.10	0.62		0.508
Space or bldg design	If large bldg (>50,000 sf) v all others	yes/no	19.00	40.00					1.93	2.28	(0.35)		0.565
Operator	If site host believes system is working (1-7)	continuous	59.00		0.01	10.79	10.78	2.15		2.16		0.10	0.634
Luminaires/illuminance	Illuminance ratio, vertical min to max	continuous	50.00		0.01	10.79	10.78	1.90		1.92		(0.04)	0.651
Luminaires/illuminance	Illuminance ratio, horizontal min to max	continuous	54.00		0.01	10.79	10.78	1.86		1.89		(0.01)	0.665
Space or bldg design	Weighted reflectance of surfaces	continuous	59.00		0.01	10.79	10.78	2.15		2.16	(0.58)	(1.31)	0.678
Control zone	Size of controlled load (Watts)	continuous	59.00		0.01	10.79	10.78	2.15		2.16		(0.08)	0.721
Occupants	If owner occupied building	yes/no	52.00	4.00					2.17	2.58	(0.40)		0.725
Occupants	If office space	yes/no	19.00	40.00					2.26	2.12	0.14		0.820
Occupants	If open office v all others	yes/no	13.00	46.00					2.04	2.20	(0.15)		0.821
Controls	If single daylight circuit v multiple circuits	yes/no	33.00	26.00					1.46	2.72	(1.26)		0.846
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average	continuous	46.00		0.01	10.79	10.78	1.90		1.94		(0.14)	0.888
Fenestration Design	Net Tvis of windows w blinds	continuous	56.00		0.01	10.79	10.78	2.17		2.26		(0.02)	0.922
Space or bldg design	If space has partitions	yes/no	15.00	44.00					2.17	2.16	0.00		0.995
Space or bldg design	If office bldg	yes/no	16.00	43.00					2.68	1.97	0.70		0.820

Notes: RSR>0 means a functional system
Table sorted by significance (p value) of explanatory variables

TABLE OF EUI SAVINGS

Category	Explanatory Variables	Variable Type	RSR>0 Count 1 (or all)	RSR>0 Count 2	EUI Min	Max	Range	Std.Dev.	Mean 1	Mean 2 (or pop)	Diff Mean	Coef X	p =
Fenestration Design	Ratio of (net Tvis * window area) to control area	continuous	56.00		0.00	4.69	4.69	0.73		0.73		2.36	0.000
Fenestration Design	Ratio of window area to control area	continuous	59.00		0.00	4.69	4.69	0.73		0.73		1.31	0.000
Space or bldg design	Number of years of PC operation	continuous	55.00		0.00	4.69	4.69	0.75		0.75		(0.12)	0.000
Control zone	Ratio of window head ht to depth of control zone	continuous	59.00		0.00	4.69	4.69	0.73		0.73		1.21	0.000
Occupants	If library space v all others	yes/no	3.00	56.00					2.14	0.65	1.49		0.000
Control zone	Distance of photosensor to window (ft)	continuous	59.00		0.00	4.69	4.69	0.73		0.73		(0.05)	0.001
Operator	If site host has records of PC settings	yes/no	27.00	22.00					0.57	1.06	(0.49)		0.028
Window controls	If windows have blinds	yes/no	48.00	11.00					0.63	1.16	(0.53)		0.029
Controls	If dimming v switching	yes/no	45.00	15.00					0.63	1.02	(0.39)		0.083
Window Type	If space has clerestory v no clerestory	yes/no	20.00	39.00					0.50	0.84	(0.34)		0.092
Controls	If photosensor is looking down	yes/no	47.00	12.00					0.65	1.03	(0.39)		0.105
Occupants	If "other" type space	yes/no	44.00	15.00					0.64	0.98	(0.35)		0.115
Luminaires/illuminance	Illuminance ratio, horizontal min to max	continuous	54.00		0.00	1.83	1.82	0.47		0.61		(0.01)	0.117
Operator	If site host is satisfied w system (1-7)	continuous	59.00		0.00	4.69	4.69	0.73		0.73	(0.01)	0.07	0.141
Luminaires/illuminance	Illuminance ratio, vertical min to max	continuous	50.00		0.00	1.83	1.82	0.47		0.62		(0.03)	0.181
Space or bldg design	K-12 school building	yes/no	26.00	33.00					0.60	0.83	(0.23)		0.240
Control zone	Depth of control zone (ft)	continuous	59.00		0.00	4.69	4.69	0.73		0.73		(0.01)	0.241
Fenestration Design	Net Tvis of windows w blinds	continuous	56.00		0.00	4.69	4.69	0.74		0.75		0.38	0.257
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average	continuous	46.00		0.00	1.83	1.82	0.45		0.61		(0.26)	0.266
Occupants	If classroom space	yes/no	25.00	34.00					0.60	0.82	(0.21)		0.271
Space or bldg design	If small bldg (<15,000 sf) v all others	yes/no	12.00	47.00					0.93	0.67	0.26		0.278
Fenestration Design	Window head height (ft)	continuous	59.00		0.00	4.69	4.69	0.73		0.73		(0.02)	0.339
Space or bldg design	If office bldg or K-12 school	yes/no	17.00	42.00					0.86	0.67	0.19		0.378
Window Type	If daylight comes from only one direction	yes/no	23.00	36.00					0.82	0.67	0.15		0.455
Space or bldg design	Ceiling height in room	continuous	59.00		0.00	4.69	4.69	0.73		0.73		(0.01)	0.517
Operator	If occupants were trained about PC system	yes/no	37.00	16.00					0.69	0.84	(0.14)		0.530
Space or bldg design	Room size (sf)	continuous	59.00		0.00	4.69	4.69	0.73		0.73		0.00	0.535
Occupants	If private office space v all others	yes/no	6.00	53.00					0.55	0.75	(0.20)		0.538
Fenestration Design	If space has high windows (>8') v low only	yes/no	9.00	50.00					0.71	0.84	(0.13)		0.630
Space or bldg design	If office bldg	yes/no	16.00	43.00					0.79	0.70	0.09		0.681
Fenestration Design	Tvis of glass	continuous	59.00		0.00	4.69	4.69	0.73		0.73		0.18	0.726
Control zone	Size of controlled load (Watts)	continuous	59.00		0.00	4.69	4.69	0.73		0.73		0.03	0.735
Control zone	Area of daylight control zone (sf)	continuous	59.00		0.00	4.69	4.69	0.73		0.73		0.00	0.746
Space or bldg design	Number of years building has been occupied	continuous	54.00		0.00	4.69	0.76	0.76		0.74		0.00	0.746
Occupants	If owner occupied building	yes/no	52.00	4.00					0.73	0.85	(0.12)		0.759
Occupants	If office space	yes/no	19.00	40.00					0.68	0.75	(0.06)		0.767
Luminaires/illuminance	If luminaires use direct light distribution	yes/no	22.00	37.00					0.76	0.71	0.05		0.785
Operator	If building has off-site management	yes/no	21.00	27.00					0.76	0.81	(0.05)		0.840
Space or bldg design	If large bldg (>50,000 sf) v all others	yes/no	19.00	40.00					0.71	0.73	(0.03)		0.895
Space or bldg design	If space has partitions	yes/no	15.00	44.00					0.75	0.72	0.03		0.900
Space or bldg design	Weighted reflectance of surfaces	continuous	59.00		0.00	4.69	4.69	0.73		0.73	(0.58)	0.13	0.907
Occupants	If open office v all others	yes/no	13.00	46.00					0.75	0.72	0.03		0.909
Operator	If site host believes system is working (1-7)	continuous	59.00		0.00	4.69	4.69	0.73		0.73		0.01	0.928
Window Type	If space has only north facing windows	yes/no	31.00	28.00					0.73	0.72	0.01		0.940
Luminaires/illuminance	Illuminance ratio, from front to back of room	continuous	52.00		0.00	1.83	1.82	0.47		0.60		(0.00)	0.961
Controls	If single daylight circuit v multiple circuits	yes/no	33.00	26.00					0.57	0.85	(0.28)		0.966

Notes: RSR>0 means a functional system
Table sorted by significance (p value) of explanatory variables

TABLE OF DEMAND SAVINGS

Category	Explanatory Variables	Variable Type	RSR>0 Count 1 (or all)	RSR>0 Count 2	Demand Min	Demand Max	Demand Range	Demand Std.Dev.	Demand Mean 1	Demand Mean 2 (or pop)	Diff Mean	Coef X	p =
Fenestration Design	Ratio of (net Tvis * window area) to control area	continuous	56.00		0.00	1.64	1.64	0.35		0.39		0.70	0.001
Occupants	If library space v all others	yes/no	3.00	56.00					0.94	0.36	0.57		0.005
Control zone	Distance of photosensor to window (ft)	continuous	59.00		0.00	1.64	1.64	0.35		0.39		(0.02)	0.006
Space or bldg design	Number of years of PC operation	continuous	55.00		0.00	1.64	1.64	0.35		0.40		(0.04)	0.014
Fenestration Design	Ratio of window area to control area	continuous	59.00		0.00	1.64	1.64	0.35		0.39		0.32	0.016
Controls	If dimming v switching	yes/no	45.00	15.00					0.34	0.57	(0.23)		0.030
Operator	If building has off-site management	yes/no	21.00	27.00					0.54	0.33	0.21		0.055
Luminaires/illuminance	Illuminance ratio, horizontal min to max	continuous	54.00		0.00	1.64	1.64	8.60		8.50		(0.01)	0.078
Control zone	Ratio of window head ht to depth of control zone	continuous	59.00		0.00	1.64	1.64	0.35		0.39		0.27	0.087
Controls	If photosensor is looking down	yes/no	47.00	12.00					0.36	0.54	(0.19)		0.101
Operator	If site host has records of PC settings	yes/no	27.00	22.00					0.36	0.51	(0.16)		0.134
Control zone	Size of controlled load (Watts)	continuous	59.00		0.00	1.64	1.64	0.35		0.39		0.05	0.139
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average	continuous	46.00		0.00	1.21	1.21	0.31		0.36		(0.23)	0.143
Occupants	If office space	yes/no	19.00	40.00					0.30	0.44	(0.14)		0.154
Space or bldg design	Room size (sf)	continuous	59.00		0.00	1.64	1.64	0.35		0.39		0.00	0.157
Occupants	If private office space v all others	yes/no	6.00	53.00					0.21	0.42	(0.21)		0.164
Fenestration Design	Net Tvis of windows w blinds	continuous	56.00		0.00	1.64	1.64	0.35		0.41		0.20	0.197
Control zone	Area of daylight control zone (sf)	continuous	59.00		0.00	1.64	1.64	0.35		0.39		0.00	0.206
Window controls	If windows have blinds	yes/no	48.00	11.00					0.37	0.51	(0.14)		0.231
Space or bldg design	If small bldg (<15,000 sf) v all others	yes/no	12.00	47.00					0.50	0.37	0.13		0.245
Space or bldg design	If office bldg	yes/no	16.00	43.00					0.32	0.42	(0.10)		0.314
Occupants	If classroom space	yes/no	25.00	34.00					0.44	0.36	0.08		0.402
Space or bldg design	K-12 school building	yes/no	26.00	33.00					0.44	0.36	0.08		0.410
Space or bldg design	If large bldg (>50,000 sf) v all others	yes/no	19.00	40.00					0.34	0.42	(0.08)		0.427
Control zone	Depth of control zone (ft)	continuous	59.00		0.00	1.64	1.64	0.35		0.39		0.00	0.440
Operator	If occupants were trained about PC system	yes/no	37.00	16.00					0.42	0.34	0.08		0.457
Operator	If site host is satisfied w system (1-7)	continuous	59.00		0.00	1.64	1.64	0.35		0.39	(0.01)	0.02	0.481
Window Type	If space has only north facing windows	yes/no	31.00	28.00					0.42	0.36	0.06		0.517
Fenestration Design	Tvis of glass	continuous	59.00		0.00	1.64	1.64	0.35		0.39		0.16	0.517
Space or bldg design	Number of years building has been occupied	continuous	54.00		0.00	1.64	1.64	0.36		0.40		(0.00)	0.529
Occupants	If owner occupied building	yes/no	13.00	46.00					0.34	0.41	(0.06)		0.558
Occupants	If "other" type space	yes/no	44.00	15.00					0.38	0.44	(0.06)		0.569
Space or bldg design	Ceiling height in room	continuous	59.00		0.00	1.64	1.64	0.35		0.39		0.01	0.582
Luminaires/illuminance	If luminaires use direct light distribution	yes/no	22.00	37.00					0.37	0.41	(0.04)		0.636
Luminaires/illuminance	Illuminance ratio, vertical min to max	continuous	50.00		0.00	1.21	1.21	0.31		0.36		(0.01)	0.637
Fenestration Design	Window head height (ft)	continuous	59.00		0.00	1.64	1.64	0.35		0.39		(0.00)	0.693
Luminaires/illuminance	Illuminance ratio, from front to back of room	continuous	52.00		0.00	1.21	1.21	0.31		0.35		0.01	0.704
Window Type	If daylight comes from only one direction	yes/no	23.00	36.00					0.37	0.41	(0.03)		0.718
Operator	If site host believes system is working (1-7)	continuous	59.00		0.00	1.64	1.64	0.35		0.39			0.753
Occupants	If owner occupied building	yes/no	52.00	4.00					0.40	0.35	0.05		0.786
Fenestration Design	If space has high windows (>8') v low only	yes/no	9.00	50.00					0.40	0.37	0.03		0.812
Window Type	If space has clerestory v no clerestory	yes/no	20.00	39.00					0.38	0.40	(0.02)		0.865
Space or bldg design	Weighted reflectance of surfaces	continuous	59.00		0.00	1.64	1.64	0.35		0.39	(0.58)	(0.05)	0.930
Space or bldg design	If office bldg or K-12 school	yes/no	17.00	42.00					0.40	0.39	0.01		0.934
Space or bldg design	If space has partitions	yes/no	15.00	44.00					0.39	0.39	(0.00)		0.968
Controls	If single daylight circuit v multiple circuits	yes/no	33.00	26.00					0.43	0.35	0.08		0.990

Notes: RSR>0 means a functional system
Table sorted by significance (p value) of explanatory variables

TABLE OF DESCRIPTIVE STATISTICS

Category	Explanatory Variables	RSR=0					RSR>0							
		Count	Population	Proportion	Mean	Std. Dev.	Count	Population	Proportion	Mean	Min	Max	Range	Std. Dev.
Window Type	If space has clerestory v no clerestory	14	64	22%			20	59	34%					
Window Type	If daylight comes from only one direction	39	64	61%			23	59	39%					
Window Type	If space has only north facing windows	8	64	13%			11	59	19%					
Fenestration Design	Ratio of (net Tvis * window area) to control area		41		0.13	0.26		56		0.14	0.00	1.40	1.40	0.21
Fenestration Design	Ratio of window area to control area		63		0.39	0.38		59		0.33	0.06	2.19	2.13	0.34
Fenestration Design	Tvis of glass		48		0.60	0.22		59		0.69	0.05	1.00	0.95	0.19
Fenestration Design	Net Tvis of windows w blinds		41		0.30	0.23		56		0.47	0.00	0.90	0.90	0.30
Fenestration Design	Window head height (ft)		63		9.24	2.64		59		10.76	3.00	28.00	25.00	3.78
Fenestration Design	If space has high windows (>8') v low only	43	63	68%			50	59	85%					
Window controls	If windows have blinds	53	63	84%			48	59	81%					
Operator	If site host believes system is working (1-7)		63		3.73	0.61		56		5.82	0.00	7.00	7.00	1.42
Operator	If site host is satisfied w system (1-7)		47		4.60	1.19		52		5.29	0.00	7.00	7.00	2.06
Operator	If site host has records of PC settings	22	49	45%			27	49	55%					
Operator	If building has off-site management	21	47	45%			21	48	44%					
Operator	If occupants were trained about PC system	30	55	55%			37	43	86%					
Controls	If dimming v switching	35	60	58%			45	59	76%					
Controls	If single daylight circuit v multiple circuits	55	63	87%			33	59	56%					
Controls	If photosensor is looking down	40	62	65%			47	59	80%					
Control zone	Depth of control zone (ft)		64		17.79	9.22		59		24.00	6.00	86.00	80.00	11.85
Control zone	Size of controlled load (Watts)		64		0.77	0.87		59		1.03	0.06	7.06	6.99	1.25
Control zone	Area of daylight control zone (sf)		64		758.67	754.97		59		1,006.71	118.37	6,300.00	6,181.63	1,076.05
Control zone	Distance of photosensor to window (ft)		64		9.71	5.60		59		9.38	0.00	23.00	23.00	31.31
Control zone	Ratio of window head ht to depth of control zone		63		0.66	0.34		59		0.54	0.03	1.90	1.87	0.29
Occupants	If classroom space	9	64	14%			25	59	42%					
Occupants	If "other" type space	45	64	70%			44	59	75%					
Occupants	If library space v all others	12	64	19%			3	59	5%					
Occupants	If office space	36	64	56%			19	59	32%					
Occupants	If private office space v all others	8	64	13%			6	59	10%					
Occupants	If open office v all others	28	64	44%			13	59	22%					
Occupants	If owner occupied building	40	59	68%			52	56	93%					
Space or bldg design	Room size (sf)		64		1,047.82	845.36		59		1,147.85	118.37	8,127.00	8,008.63	1,283.70
Space or bldg design	Number of years building has been occupied		58		1,997.02	13.12		54		1,997.78	1,955.00	2,004.00	49.00	14.02
Space or bldg design	Number of years of PC operation		59		2,001.78	2.63		55		2,002.07	1,989.00	2,004.00	15.00	3.28
Space or bldg design	Weighted reflectance of surfaces		64		0.61	0.09		59		0.58	0.35	0.75	0.41	0.09
Space or bldg design	Ceiling height in room		64		11.29	4.09		59		12.73	7.80	34.00	26.20	4.50
Space or bldg design	If large bldg (>50,000 sf) v all others	43	64	67%			20	59	34%					
Space or bldg design	If small bldg (<15,000 sf) v all others	13	64	20%			12	59	20%					
Space or bldg design	K-12 school building	11	64	17%			26	59	44%					
Space or bldg design	If office bldg or K-12 school	46	64	72%			42	59	71%					
Space or bldg design	If office bldg	35	64	55%			16	59	27%					
Space or bldg design	If space has partitions	37	59	63%			15	59	25%					
Luminaires/illuminance	Illuminance ratio, from front to back of room		47		8.12	9.40		52		3.45	0.52	9.34	8.82	2.41
Luminaires/illuminance	Illuminance ratio, horizontal min to max		48		15.55	19.14		54		8.50	1.50	50.00	48.50	8.60
Luminaires/illuminance	Illuminance ratio, vertical min to max		48		5.21	4.28		50		4.19	1.00	17.02	16.02	2.97
Luminaires/illuminance	Illuminance ratio, horizontal std. dev./average		38		0.92	0.38		46		0.69	0.18	1.21	1.04	0.29
Luminaires/illuminance	If luminaires use direct light distribution	39	64	61%			22	59	37%					

Notes: RSR>0 means a functional system
RSR=0 means a non-functioning system
Table sorted by category of explanatory variables