Sidelighting Photocontrols Field Study

Final Report 11/1/05

Submitted to:
Gregg Ander, FAIA and Jack Melnyk, P.E.
Southern California Edison Co.
6042 N Irwindale Ave Suite B
Irwindale, CA 91702

Steven L Blanc
Pacific Gas and Electric Company
3400 Crow Canyon Rd.
San Ramon, CA 94583-1356

David Cohan
Northwest Energy Efficiency Alliance
529 SW Third Avenue, Suite 600
Portland, OR 97204

HMG Job 0416

Submitted by:
HESCHONG MAHONE GROUP, INC.
11626 Fair Oaks Blvd. #302
Fair Oaks, CA 95628
Phone:(916) 962-7001
Fax: (916) 962-0101
e-mail: info@h-m-g.com
website: www. h-m-g.com

Copyright

Disclaimer

Acknowledgements

Project Managers for this project included Jack Melnyk at Southern California Edison Co., Steven L Blanc at Pacific Gas and Electric Company, and David Cohan Northwest Energy Efficiency Alliance.

The project was conducted by the Heschong Mahone Group, Inc. Key HMG project staff included Lisa Heschong, Principal Investigator; Jon McHugh, Technical Director; Abhijeet Pande, Owen Howlett, Erin Reschke, and Brian Sipp.

TABLE OF CONTENTS

TABLE OF FIGURES

ERRATA – MARCH 14TH 2006

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.

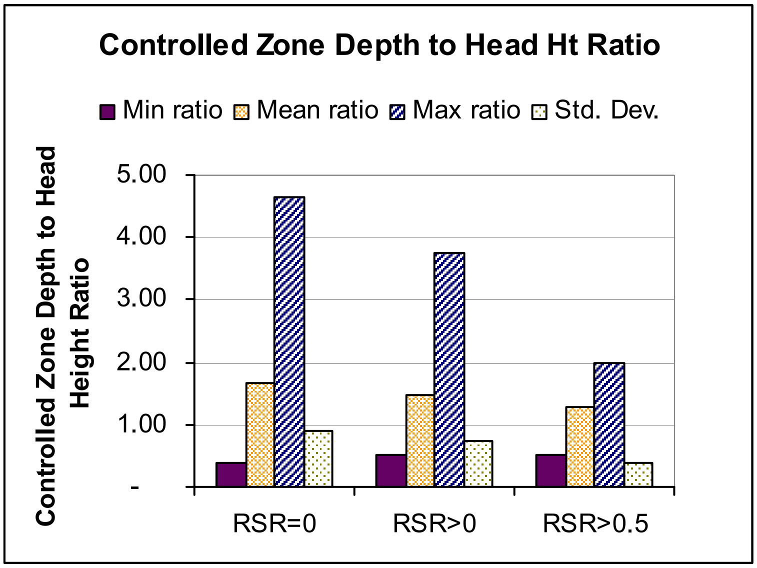

Figure 3: Revised ratio of control zone depth to head height – relationship with RSR

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.

		Energy Performance (for space with RSR>0)			
Explanatory Variable	**Functional (RSR=0 vs. 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.