Photocontrols and Daylighting Savings from Skylights: Urban Myths and Realities from a Field Study

Abhijeet Pande; Lisa Heschong; Jon McHugh,P.E.,LC
Heschong Mahone Group, Inc.
Gregg Ander, FAIA; Jack Melnyk, P.E.
Southern California Edison Company

Synopsis

The use of daylight in buildings provides tremendous potential for saving energy. Daylight-responsive lighting controls (photocontrols) which reduce electric lighting in response to available interior daylight illuminance are the next frontier for saving energy with lighting controls. However, many anecdotal reports of photocontrol performance through the 1990's have been negative, reporting taped-over photocells and cut control wires.

Our hypothesis is that many of these negative reports are for photocontrol systems that have been applied to spaces that are sidelit with windows and that the success rate for photocontrols under skylights would be much higher. This paper describes site surveys of 46 photocontrol systems under skylights, the calculation methods used, and the findings of this study.

About the Authors

Abhijeet Pande is a project manager at the Heschong Mahone Group Inc. He specializes in energy end-use and energy savings analysis in commercial and multifamily residential buildings. He is also experienced in education and distance learning projects. Prior to HMG Abhijeet studied at Arizona State University, where he worked on an ASHRAE funded research on hydronic radiant cooling and heating systems.

Lisa Heschong is a principal of the Heschong Mahone Group, Inc. Ms. Heschong led the team that found a correlation between the presence of daylight in classrooms and improved student performance, and has completed three additional studies looking at how daylight and window characteristics influence human performance in offices, schools and retail buildings.

Jon McHugh is the technical director of the Heschong Mahone Group, Inc. He is the primary author of *SkyCalc*, a skylighting design tool. Jon has been deeply involved in the Title 24 code development process in California. He helped generate the Time Dependent Valuation model, which provides the new economic basis for Title 24. He initiated and oversaw the proposal to require skylighting and photocontrols in warehouses and other big box buildings. He has also managed code change proposals for duct sealing, air conditioning and multi-family water heating.

Gregg Ander, FAIA is the Chief Architect for the Customer Service Business Unit of Southern California Edison. He is the manager of SCE's Design and Engineering Services. He is the author of over 65 technical and design related articles and was the executive producer of four

"Environmental Showcase" television programs for NBC. He recently received the Corporate Architect Award from the California Council of the American Institute of Architects (AIA).

Jack Melnyk, P.E. is a lead program/project engineer at Southern California Edison, responsible for lighting, design and engineering services. He conducts new technology assessments, facility audits, trains company personnel, conducts inter utility/industry liaison, and gives customer and in-house design and specification assistance.

Introduction and Background

Better understanding of photocontrol performance in skylight buildings is especially needed now as there is a growing interest in skylighting. Without effective photocontrols, adding skylights to buildings typically only increases overall building energy consumption, whereas with photocontrols energy consumption can be reduced. Reports of increased student test scores and increased retail sales associated with daylighting (HMG 2001, 2003), have school districts and retailers demanding skylights in their new buildings. Other motivating forces behind increased skylighting include the LEED ratings which provide credit for daylighting and another credit for energy savings when photocontrols are applied, and the California Title 24 Code that requires skylighting and photocontrols for big-box retail buildings.

Magnitude of Potential Energy Savings

In the past, photocontrols were recognized as critical for extracting energy savings from skylighting. In the 1989 version of the ASHRAE/IESNA 90.1-1989 standard for energy efficient design of new commercial buildings, a fairly generous skylight area was allowed if photocontrols were installed. However, due to reports of photocontrol failure, newer energy codes such as ComCheck-EZ and the International Energy Conservation Code (IECC) have dropped the requirement for photocontrols and drastically reduced the allowable skylight areas. The 1999 revision of the ASHRAE/IESNA 90.1-1999 standard also reduced allowable skylight areas and dropped the requirement for photocontrols.

The California investor utilities have recognized the energy savings potential of skylighting and through programs such as Savings by Design, have given incentives to their customers to install skylights and photocontrol systems. The systems that were installed during the 1999 to 2001 program years saved 8.7GWh/yr, or 21% of the energy savings of California’s nonresidential new construction energy efficiency programs. (RLW Analytics 2003).

Given that skylighting with photocontrols was very cost-effective in certain applications and was being applied fairly broadly in certain market niches (primarily warehouse, big box retail and groceries) a change in thinking about skylighting was under way in the California energy code community. Where skylights were previously seen only as a source of heat losses and heat gains, and the role of energy codes was to minimize the impact of skylights, a new consensus began to emerge that skylights with photocontrols was a method of saving energy in commercial buildings and should be required in some circumstances. Key in the debate over requiring skylights in the 2005 revision of the California Title 24 building energy efficiency standards was whether photocontrols can reliably save energy.

The Southern California Edison (SCE) Codes and Standards program funded this study specifically to answer the questions around the reliability of photocontrols under skylights. The intent was to provide systematically collected data to help inform the evaluation of the feasibility of a skylighting requirement in the California Title 24 building energy efficiency standards.

Hypothesis

The primary hypothesis of this research was that photocontrols in skylit (toplit) spaces are more likely to be successful than is popularly believed. One explanation for this is that these opinions are formed based upon anecdotes rather than a systematic evaluation of successes and failures. When controls work properly no one notices but when they fail the lights are too dim or are not controlled frequently enough to realize significant savings and people remember these instances of failure. The other explanation is that photocontrols are lumped together regardless of the application and no differentiation is made between photocontrols in toplit versus sidelit applications. Due to the more straightforward design typical of toplit designs and the more straightforward and simple photocontrol systems that follow as a result, we expect photocontrols under skylights to work better and to be less frequently disabled than those used with sidelighting.

Though the above discusses the relative reliability of savings from sidelighting versus toplighting, this study is not a comparative one. The purpose of the study is to investigate in a systematic manner the monitored energy savings of photocontrols in toplit buildings and how these measured results compare with calculated predictions of their theoretical performance.

Method

The project involved three distinct phases: site selection, site data collection and savings analysis.

Site Selection

We initially generated a list of 150 buildings in the Southern California (primarily SCE's service territory) from various SCE program databases and photocontrol systems and skylight manufacturers, lighting designers, and architects.

We prepared a telephone survey with approval from SCE aimed at screening each building to ensure their eligibility for participation in the field study. We completed phone interviews for 62 eligible sites in total. The objective of the script was to identify that the building was toplit, contained a photocontrol system and to obtain permission to conduct the on-site survey. We also confirmed our information about the key photocontrol system characteristics in each building.

The scheduling for the on-site survey was completed at the end of each call. Of the 62 eligible sites, we were successful in scheduling on-site surveys on 46 sites.

On site data collection

We collected site level characteristics on all the 46 sites scheduled during the telephone surveys. We developed a standard data collection protocol in order to ensure that we collected the same information on all the sites, with similar levels of detail. Further we developed a set of data entry forms that the surveyors used to note the onsite information.

An onsite interview was conducted that focused on the practicalities of operating and maintaining the photocontrol system. The surveyor interviewed the site contact, and also the space users when possible to get different perspectives on the photocontrol system performance. Where the decision maker was different from the site contact, the surveyor interviewed the decision maker in addition to the site contact and users. The onsite interviews collected historical information such as the age, level of satisfaction, nature of problems, maintenance practices and suggestions about installation, design and maintenance practices for photocontrol systems as expressed by the site contact.

After conducting the short interview(s) the surveyor then proceeded to record the physical and control characteristics of the space using standard data entry forms. Of primary importance were details about the skylights, physical characteristics of the space that affect lighting (such as surface colors), details about the type and operation of the photocontrol system and details about the luminaires themselves.

While sample light level and power levels were measured during the site visit, energy consumption of the lighting system was recorded over a two week period to judge the performance of the photocontrol system over a variety of outdoor illuminance and sky conditions. The surveyors installed portable current dataloggers on the lighting circuits identified during the site visit as being controlled by the photocontrol system.

Of the 46 sites we visited, three sites had occupancy sensors not photocontrols, four sites were sidelit and were not to be analyzed to limitations of our energy analysis tool (SkyCalc) and seven sites had logger problems so the data was not collected. Thus the energy savings verification was conducted on 32 of the 46 sites visited.

Energy Savings Analysis Method

The primary metric used to evaluate how well photocontrols are performing was a ratio of the energy savings measured from existing system divided by the energy savings predicted from an "ideal" system modeled using the SkyCalc software. We called this metric the Realized Savings Ratio and the equation is given below.

$$\text{Realized Savings Ratio} = \frac{\text{Measured Energy Savings}}{\text{Predicted Energy Savings}}$$

A realized savings ratio less than one indicates that the photocontrol system is not saving as much energy as it could. While a photocontrol system with a realized savings ratio greater than one is saving more energy than predicted, it is likely doing so with the consequence of insufficient light levels within the space.

Since different control strategies produce different levels of energy savings, the predicted energy savings were drawn from a model making use of the same control strategy installed on site. The predicted energy savings fraction is a function of the interior illuminance and the type of control used. To calculate interior illuminance, we made use of the Lumen Method for Skylighting as described in the Daylighting chapter of the IESNA Handbook (2000).

The Southern California Edison electric utility has a network of weather stations collecting hourly temperatures, relative humidity, and global horizontal irradiance (the total heating power of sunlight across all wavelengths). Using this data, we were able to calculate the outdoor horizontal illuminance. Interior illuminance is the product of the daylight factor and the outdoor horizontal illuminance. As shown below the daylight factor describes the fraction of light that makes it from outdoors to the work surface inside.

Daylight factor = SFR x Tvis x WE x DF x CU

where,

SFR = skylight area to floor area ratio.

Tvis = overall visible transmittance of skylight glazings and diffusers or lenses in the light well

WE = well efficiency, the fraction of light entering the well that leaves the light well. We use the algorithms developed for SkyCalc that perform a Lumen method calculation for the light well

DF = Dirt factor, this accounts for dirt build-up on the skylight and in the light well. This analysis used a 70% dirt factor as recommended in the IESNA handbook for horizontal glazing in clean areas.

CU = Coefficient of utilization, the fraction of light leaving the light well that makes it to the “work surface” 30 inches above the floor assuming a Lambertian distribution of light.

Using the control algorithms contained in SkyCalc, we were then able to predict when the photocontrols **should** switch or dim the electric lighting. Regardless of the control strategy, the control level could be summarized in a power fraction—the ratio of lighting wattage at a particular moment divided by the total lighting wattage. Looking at only the hours of operation and only daylight hours, we compared the power fraction for the predicted system to the actual measured data.

Results

Results from phone interviews, site interviews and the comparison of monitored data to energy savings estimates were compiled and compared to identify trends in the data. The information below summarizes a larger analysis contained in the Photocontrol Field Study final report. (HMG 2003b).

On site interviews

The surveyors asked the building operators about their satisfaction levels with the photocontrol system operation with the intent to find out if the building operators felt that the photocontrol systems were performing per their expectations. It should be noted that these observations do not always match up with the actual state of the control system, as observed through short-term monitoring reported later in this paper.

User satisfaction was reported on a subjective scale, and categorized as -

1) *Photocontrols working well* – Site operators were satisfied with the control system operation, and the control system controlled the lights as per the site operators' expectations on 16 of the 46 sites.
2) *Photocontrols working with problems* – The site operators reported satisfaction with the control system, but wished that the system worked a little better on 20 of the 46 sites. Of these 20 sites, 13 sites reported that the problems exist since the time of commissioning, indicating the commissioning process may have not completely succeeded in satisfying user needs. It could also point to possible disconnect between design intent and site operators' expectations.
3) *Photocontrol not working* – The photocontrol systems were reported to be installed but never turned lights OFF or dimmed the lights as programmed on two of the 46 sites. One of the two sites, the system had been commissioned but it never worked as intended despite repeated attempts at troubleshooting.
4) *Photocontrols with supplemental switching* - The building operators often (at least once a day) supplemented the photocontrol systems by manually turning the lights OFF on four of the 46 sites visited. The stated reason was incorrect setpoints (too high). Setpoint is the threshold illuminance level set for the photocontrol system to control the lights. Thus users wished for more aggressive savings than possible with the more conservative photocontrol system configuration.
5) *Photocontrols overridden* – The building operators often (at least once a day) overrode the photocontrol systems by manually turning the lights ON at one of the 46 sites visited (a warehouse). The system had been commissioned when the high stacks were empty. Once the stacks were stocked, the boxes partially blocked light from skylights directly above the stacks, reducing the total light coming into the space.
6) *No photocontrols* – On these sites, no photocontrol system was installed. Instead either an occupancy sensor or time clock was controlling the lights.

Energy Savings Comparison

The first task was to verify if the user reported operational conditions matched the actual system performance data. We re-classified all the sites under two categories – systems that were operational without any manual controls (Fully Automated), and systems that had some level of manual control (Manual Assist). Of the 32 sites analyzed, two thirds or 21 sites were fully automated while 11 sites were manual assist. Sites included in the 'manual assist' category included:

1) *Occasional Manual Control* – to provide additional savings than what the photocontrol system alone can provide. Here the photocontrol system is still controlling the lights, but the users manually control lights occasionally to supplement the photocontrol operation. (five sites)
2) *Consistent Manual Control* – to achieve savings that the photocontrol system could not provide. Here the photocontrol system is not disabled, but the users follow a regular schedule for operating the lights through manual control. (four sites)
3) *Overridden System* – the photocontrol system is regularly bypassed by the users through a manual switch due to dissatisfaction with its operation. (one site)
4) *Disabled System* – this is an extreme case where the photocontrol system is permanently disables by the users due to dissatisfaction with its operation. (one site)

In all the cases it is possible for the lights to be turned OFF or turned ON through manual action. We observed that only one site from the 11 sites categorized as manual assist was actually physically disabled. It is also important to note that of the 11 manually overridden sites only one site was overridden to be ON. The other ten sites were using manual switches to turn the lights OFF, thus indicating that the users are supplementing energy savings by making use of their manual controls.

Table 1: Monitored sites with skylights and photocontrols

Building Type	Fraction of Sample	Fully Automated	Manually Assisted
Mfg/Warehouse	50%	10	6
Retail	38%	10	2
Office	3%	1	--
Classroom	9%	--	3

Table 1 illustrates the types of buildings that use skylights. Even though efforts were taken to locate a sample that represented each building type, 88% of the skylit buildings are either warehouse or retail.

This table also illustrates the impact of occupancy type on likelihood of manual intervention. Manufacturing and warehouses have large open areas that are amenable to automatic control. However, these sites usually do not necessarily have an energy manager and there are not aesthetic considerations about lights being controlled manually. Nonetheless, 2/3 of the systems we surveyed reported little manual control of lights. In contrast, retailers often have an energy manager who will try to maximize energy savings from lighting controls while being very conscious of minimizing under-lighting. Thus these systems are very well controlled and only 17% of the sites were manually controlled. These site surveys were conducted in summer/fall

2002, soon after California's energy crisis, and it is not surprising some store managers may use manual controls to show their concern for saving energy. In classrooms, teachers are turning off lights more in response to use patterns than available daylight. With a sample size of one we cannot say anything definitive about offices. Thus we can rank occupancies that are most likely to have fully functioning photocontrols from highest to lowest as follows: retail, manufacturing/warehouse, schools.

Table 2: User Satisfaction and System Performance

User Satisfaction (subjective assessment)	Actual Performance (# Sites) Fully Automated	Manual Assist	Mean Predicted Savings kwh/sf.yr	Mean Realized Savings Ratio
Working Well	13	--	1.58	0.96
Working	7	7	0.90	1.02
Not Working	1	1	0.62	0.36
Supplemented	--	2	0.83	1.28
Overridden	--	1	1.16	0.69
Total # sites	***21***	***11***		
Mean Measured Savings kwh/sf.yr	1.39	0.79		
Mean Realized Savings Ratio	0.92	1.07		
Std. Dev. of RSR	0.15	0.34		

We then compared the revised system operation status to the user reported system status as shown in Table 2 above. The four manual assist categories are combined together for ease of presentation.

All three sites that the users had reported to be manually overridden or supplemented were indeed being operated manually, while seven of the 14 sites with some problems were being manually controlled in addition to photocontrols. All the 13 sites categorized by the users as working well were operational without the need for manual control of lights.

Data in Table 2 also shows the mean predicted annual savings for the sites under various categories. It was seen that the sites categorized by users as working well had the highest predicted savings with a mean savings of 1.58 kWh/sf. The sites that were working with some problems had much lower predicted savings with a mean savings of 0.90 kWh/sf. This implies that buildings with fewer skylights were more likely to require manual intervention. The last row of the table also shows the predicted mean savings for the operational systems and manual overridden systems overall. The operational systems had a much higher predicted savings with mean savings of 1.39 kWh/sf, while the manual assisted systems had mean savings of 0.79 kWh/sf.

While the mean predicted savings describe the size or magnitude of savings, it does not indicate how much the system is performing in reference to its theoretical savings potential. The realized savings ratio provides the comparison of actual savings to theoretical savings. While the manually assisted systems have a lower mean measured savings they have a higher realized savings ratio than the fully automatic systems. Combining the two criterions, it may be surmised that the users are more prone to manually assist systems that have lower predicted savings, and achieve more savings on such sites through more aggressive lighting control strategies. It is however not clear how persistent savings from manual assist will be over time, when public consciousness of the energy crisis declines. Not surprisingly, there is a much larger variance in the performance of systems that are manually assisted than systems with fully automated controls as seen by the standard deviation of the realized savings ratio in Table 2.

Further, we did not find any correlation between the status of the photocontrol system operation to the various system characteristics. Systems were being manually assisted partly due to increased energy awareness from the 2001 energy crisis in California, and partly due to commissioning errors with setpoints.

Conclusions

Results from the study can be viewed as the classic ‘glass half-empty’ or ‘glass half-full’ case depending on which success factors you look at.

The cup is ¾ full

On the positive side, photocontrol systems in toplit spaces were found to save very close to the amount of energy as predicted. The entire sample of 32 skylit buildings with photocontrols had measured savings that were 98% of theoretical energy savings. The results of this field study present compelling evidence that photocontrols under skylights reliably save energy, and therefore should enjoy the benefits of codes and standards support and utility incentives.

Urban Myths Debunked

There are number of assumptions and myths about the photocontrol systems that are well rooted in certain sections of energy consultants, designers and users. These include the belief that photocontrol systems do not function properly and that they fail often. It is also believed that in most cases users will disable the systems in order to negate the energy savings goals.

However this study found that these urban myths are just what they are – myths. We found that the photocontrols in skylit applications are working fairly well as compared to their technical potential. On sites where the users are manually controlling the systems, they are doing so in order to achieve higher savings than the photocontrol system was designed to deliver. None of the photocontrol systems had physically failed, nor had people taped over sensors or cut control wiring in order to negate the system performance.

The cup is ¼ empty

On the flip side, savings would have been lower if occupants did not supplement savings by turning off lights when sufficient daylight was available but the setpoint of the photocontrol had not been exceeded. Of the 32 sites analyzed, users were manually assisting the system operation on 11 sites (~1/3 of the sample). This manual switching strategy was often used because site staff often did not know how to adjust the photocontrol system.

The user satisfaction surveys showed that the most critical period in the photocontrol operation was the initial calibration of the photocontrol systems. Of the various problems expressed by users about the photocontrol system operation, incorrect setpoints was the most common. It was also seen that these problems that began at the commissioning stage never got fixed. In at least one case the users tried to troubleshoot the application by bringing external electricians, but even after repeated attempts the control system could not be fixed.

Need for better education and documentation on photocontrol system operation

Most of the building operators are not educated in the photocontrol system settings and controls, and do not know how to adjust the settings in order to achieve the right level of control. Thus even small problems have the potential of being constant irritants.

This implies that user interface and commissioning instructions could be improved. It is also indicative that this technology is still fairly new and not well understood. This finding that staff doesn’t adjust the control settings highlights how important initial commissioning is to long term energy performance of the systems.

From a review of manufacturer’ literature, we found that there was not much guidance to installers on the step by step methods required to commission photocontrols systems or to lighting designers on placement and selection of controls. To fill this gap Southern California Edison published the Photocontrol System Design Guidelines (HMG 2003c). These guidelines provide a generic format for developing more specific guidelines for their products.

This study did not address the reliability of photocontrols when used in conjunction with sidelighting. Given the large technical potential savings from this application of photocontrols, a follow-up study was commissioned by Southern California Edison (SCE), Pacific Gas and Electric Company (PG&E) and the Northwest Energy Efficiency Alliance (NEEA). This study looked at the energy savings and performance of photocontrols in sidelit applications for commercial buildings in California, Oregon and Washington states, and the results are being presented through a separate paper titled “Photocontrols and Daylight Savings in Sidelit Spaces – Success Factors in Design and Commissioning”.

Acknowledgements

This work was funded by California utility customers and administered by Southern California Edison under the auspices of the California Public Utilities Commission. Gregg Ander is the program manager for SCE’s codes and standards program and Jack Melnyk was the SCE project manager. Douglas Mahone was the HMG project manager. He was assisted by Jon McHugh, Abhijeet Pande and Sean Denniston of HMG.

We would also like to thank our technical advisory group which includes: Michael Bolton, Douglas Lighting Controls; Gary Fernstrom, PG&E; Pekka Hakkarainen, Lutron; Janith Johnson, SCE; Bill Lahey, Lighting Controls and Design; George Loisos, Loisos/Ubbelohde Architects; Gary Lowe, Day Light Controls; Richard Mistrick, Pennsylvania State University; Bob Munton, PLC Multipoint; Eric Oates, SCE; Doug Paton, Wattstopper; Michael White, Johnson Controls; and David Wilson, Lighting Controls and Design.

References

(1) [HMG] HESCHONG MAHONE GROUP, 2000, Photocontrols Operation Study - Phase I: Preliminary Report, produced for the Pacific Gas & Electric Company

(2) [HMG] Heschong Mahone Group, Inc. 2001. Re-Analysis Report: Daylighting in Schools, Additional Analysis. A report on behalf of California Energy Commission Public Interest Energy Research Program. www.newbuildings.org/pier

(3) [HMG] Heschong Mahone Group, Inc. 2003a. Daylight and Retail Sales. A report on behalf of California Energy Commission Public Interest Energy Research Program. www.newbuildings.org/pier

(4) [HMG] Heschong Mahone Group, Inc. 2003b *Photocontrol Field Study: Final Report.* A report on behalf of Southern California Edison. Copies available through becky.warren@sce.com

(5) Heschong, L. & McHugh, J., 2000, “Skylights: Calculating Illumination Levels and Energy Impacts,” *Journal of the Illumination Engineering Society*, Winter 2000.

(6) [PG&E] Pacific Gas & Electric Company 2002, “Updates to Title 24 Treatment of Skylights.” Codes and Standards Enhancement Initiative (CASE), 2005 Title 24 Building Energy Efficiency Standards Update. http://www.energy.ca.gov/2005_standards/documents/2002-05-30_workshop/2002-05-17_SKY-LT_PROP_T24.PDF

(7) RLW Analytics, 2003, *Final Report - 1999-2001 Building Efficiency Assessment (BEA) Study: An Evaluation of the Savings By Design Program*, A report produced on behalf of Southern California Edison, Study ID # 10029, http://www.calmac.org