# Photocontrol System Field Study

*Final Report*

Southern California Edison

An Edison International Company

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# 1. PROJECT BACKGROUND

The primary scope of this study is the actual energy savings of photocontrol systems when used in conjunction with skylighting. Photocontrols are lighting control devices that reduce electric lighting power consumption in response to daylight available inside of buildings. Skylighting is the use of skylights to bring daylight inside buildings.

We have chosen to investigate the operation of photocontrols in conjunction with skylighting because we hypothesize that this type of daylighting application is the type that is most likely to have sustained savings due to its simplicity. Understanding what separates well-functioning photocontrol systems from malfunctioning ones under the more predictable luminous environment in skylit buildings will help to develop guidelines on how to apply photocontrols successfully for long term energy savings.

In many quarters, it is believed that photocontrol systems rarely work regardless of their application. We believe that this perception is from the many case studies and reports of photocontrol failure in the most arduous daylighting controls application -- controlling lighting in a sidelit office. This perception has resulted in requirements for photocontrols being pulled from energy standards. In the 1989 version of ASHRAE 90.1, photocontrols were required whenever the area exemption was used for skylights. By the 1999 version of ASHRAE 90.1, the maximum allowable skylight area was severely reduced and photocontrols were not required because as one committee member stated, "we think that photocontrols don't work or are disabled."

The only way to answer whether this presumption of photocontrol failure in all applications is true or not is to survey a large enough sample of buildings, monitor their performance and compare that performance to engineering estimates of the predicted savings. If indeed this presumption of failure is true, this hinders the use of a substantially large commercial building energy efficiency measure.

Getting to the bottom of the success rates of photocontrols in skylit applications is critical for three reasons:

1. Skylighting with photocontrols is a significant feature of the statewide Savings by Design program.
2. The energy savings potential for skylighting is large as most commercial floor space is directly under a roof. Validating the energy savings of photocontrols with skylighting could inform the mix of future energy efficiency programs.
3. Skylighting with photocontrols has been proposed for all commercial spaces greater than 25,000 SF and with ceiling heights greater than 15 feet. This

research can inform decision-makers at the California Energy Commission on the advisability of going forward with this code proposal.[1]

The technical energy savings potential of photocontrol systems is huge. Electric lighting accounts for over one third of all commercial electricity consumption, and over one quarter of peak demand for commercial buildings and 11% of peak demand for all uses in California. As shown in Table 1, over 65% of ceiling area is directly below a roof and therefore, there is a significant amount of building area that could be daylit with skylights.[2]

| Floors | Total Area (Million sq ft/yr) | Fraction of All Building Stock | Area Under Roofs (Million sq ft/yr) | Fraction Under Roofs |
|---|---|---|---|---|
| One | 563 | 51% | 563 | 51% |
| Two | 266 | 24% | 133 | 12% |
| Three | 97 | 9% | 32 | 3% |
| 4 to 9 | 132 | 12% | 22 | 2% |
| > 9 | 51 | 5% | 3 | 0% |
| Total | 1,109 | 100% | 754 | **68%** |

*Table 1: U.S. Annual Commercial Buildings Construction Area Segmented by Number of Stories and Fraction of Total Area Under a Roof*

For many years, the Southern California Edison Company (SCE) and to a lesser extent the other investor owned utilities in California have promoted the use of skylighting with photocontrols as an energy efficiency measure through their Savings by Design program that encourages high-performance nonresidential building design and construction. Savings By Design offers building owners and their design team incentives to help offset the costs of energy-efficient buildings, along with design assistance services.

A 1999 study[3] had found that 25% of the photocontrol systems that were sampled was not functioning properly. In these buildings with problems, occupants were overriding the photocontrol systems because of inadequate system commissioning. Problems included insufficient light levels, unsatisfactory training of building operators, insufficient system documentation, incorrect location of sensors, and general user dissatisfaction with the overall performance

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[1] PG&E, Codes and Standards Enhancement Initiative: Updates to Title 24 Treatment of Skylights http://www.energy.ca.gov/2005_standards/documents/2002-05-30_workshop/2002-05-17_SKY-LT_PROP_T24.PDF

[2] Table B9. *Year Constructed, Floorspace, 1999.* from Buildings Energy Consumption Survey (CBECS), US Energy Information Administration. http://www.eia.doe.gov/emeu/cbecs Data is for an average year's new construction for the 10 year time period ending in 1999.

[3] RLW Analytics, Inc. for Southern California Edison, "Statewide Market Assessment and Evaluation Non-Residential New Construction Program Area - Building Efficiency Assessment Quarterly Reports. 4th Quarter 1999 through 3d Quarter 2000" June 4, 2001.

of the systems. In cases where the daylighting controls were not working per the design intent, the surveyors found the systems in the override position.

The study recommended that the SBD program might consider requiring the commissioning of photocontrol systems to insure operational performance met the design intent. It was recommended that commissioning of the system also include staff training and documentation to operate and troubleshoot the systems during periods of sub-optimal performance, which is when system overrides commonly occur. Photocontrol systems that are not working per the design intent represent lost savings, because skylights increase building cooling loads, unless the photocontrol system (or manual operator) turns off electric lighting in the presence of daylight.

A follow-on study of the Savings by Design program conducted by RLW Analytics for the California investor owned utilities[4] found that daylighting controls (primarily with toplighting) was responsible for 18% of the energy savings for the California statewide nonresidential new construction programs in 4th quarter 1999 through all of 2001. The total energy saved by photocontrols is 17,600 MWh/yr. Of the 9 systems that were sampled only 1 system was not operational. However, this one site brought the savings down to 63% of its technical potential.

SCE subsequently commissioned this field study to analyze a larger sample of the existing photocontrol installations in southern California. The purpose of this study is to understand the installation and maintenance practices that cause the systems to either perform or fail, and to assess the magnitude of energy savings from the various levels of system success or failure. The Heschong Mahone Group, Inc. (HMG) conducted the study for SCE and visited 46 photocontrol installations, 44 of these sites were also daylit with skylights.

[4].RLW Analytics prepared for California's Investor Owned Utilities, "Final Report 1999-2001 Building Efficiency Assessment (BEA) Study: An Evaluation of the Savings by Design Program," (4th Quarter 1999 through 4th Quarter 2001) April 1, 2003.

# 2. PROJECT OUTLINE

The field study concentrated on non-residential new construction in Southern California that had significant daylighting from skylights and had photocontrols.

## 2.1 Project Goals

There were several goals for this study of skylighting and photocontrols:

- Survey existing photocontrol applications, both working and non-working, in skylit (and a few side-lit) buildings
- Establish how well the photocontrol systems are functioning and how much lighting energy and overall building energy the photocontrol systems are saving
- Describe the design characteristics of both unsuccessful and successful systems
- Identify the system characteristics most associated with success or failure of photocontrol systems
- Develop guidelines for proper installation and management of photocontrol systems
- Recommend program enhancements to encourage the installation of successful photocontrol systems ahead of the 2005 effective date of the new Title 24 changes

The photocontrol installation and management guidelines are included in this report as an appendix, but are intended to be a stand-alone document. The guidelines were developed through interaction with photocontrols manufacturers and designers and are intended to be distributed amongst the manufacturers, specifiers, designers and building operators.

## 2.2 Project Stages

The project involved three distinct phases:

1) Site selection: Generating a database of existing building stock in Southern California that had daylighting with photocontrols, and screening the sites for eligibility
2) Onsite data collection: Collecting performance and name plate data on the photocontrol system, space design and operating parameters from the sites selected for the study
3) Data analysis and reporting: Analyzing the site characteristics and photocontrol characteristics with the aim of establishing any patterns or

reasons for the performance or non-performance of the photocontrol systems. The aim is to identify the ‘weak links’ in the photocontrols design, installation and maintenance processes that hinder successful operation of the photocontrol systems. This phase also involved the generation of the photocontrols installation and maintenance guidelines.

While this study analyzed the reasons for performance or non-performance of photocontrol systems, it did not look into improving the performance of systems that are operational. It also did not recommend any re-commissioning procedures on a site level.

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.

# 3. SITE SELECTION

To find appropriate sites for the study, we gathered data from the Savings By Design program, Building Energy Assessment study, and SCE's New Construction Assistance program contact databases. We also contacted photocontrol systems and skylight manufacturers, lighting designers, and architects to obtain their cooperation in contacting customer sites. We concentrated our efforts on the SCE service territory, but also looked farther afield when it was necessary to recruit sufficient candidates for the project.

The list of sites included 150 buildings with a variety of occupancy types, including C&I warehouse, retail, manufacturing, office and school buildings and various types of photocontrol systems ranging from individual fixture-mounted sensors to multi-zone control panels tied with the buildings energy management system. Primary emphasis was on non-residential buildings with daylighting from skylights along with photocontrols. While attempts were made to ensure a balance of building types, photocontrol system types, lamp types and building sizes in the sample, we did not employ any formal techniques of generating a sample that was representative of the entire population. Rather, the sample represents sites that are documented as having photocontrols by the utilities, designers or photocontrols manufacturers.

## 3.1 Screening Interview Process

HMG prepared a telephone survey with approval from SCE aimed at screening each building to ensure their eligibility for participation in the field study. The phone interviews were conducted from August 2002 to January 2003. A total of 150 sites were called. Contact was made with 70 sites. With the exception of a few sites, all buildings had installed photocontrol systems. We conducted phone interviews for 62 sites in total. Of these sites, we were successful in scheduling on-site surveys on 46 sites.

We explained in each telephone call the nature of the project and Edison's sponsorship, the kinds of information we will be gathering on-site, and the level of cooperation we will need from the site representative. The objective of the script was to obtain permission to conduct the on-site survey. It was also to confirm our information about the key photocontrol system characteristics. The scheduling for the on-site survey was completed at the end of each call.

The interview script consisted of the following sections:

1. Qualifying Questions: This section determined if the site is appropriate for the study.
2. Building Specific Questions: This section gathered general information of the building and customer satisfaction of the photocontrol system.

3. On-site Recruitment: In this section, we recruited on-sites, scheduled the survey, and collected the logistical information for the survey.
4. Photocontrol System Questions: This section gathered general information of the photocontrol system for sites we have scheduled a survey.
5. Daylighting Questions: This section was completed for sites we were unable to receive permission for a survey. It gathered additional information on the photocontrol system.
6. Detailed Building Specific Questions: This section covered building information used in SkyCalc runs. Similar questions were asked during the on-site survey.

Each phone call lasted on average fifteen minutes. In Figure 1, the key questions for recruitment are represented in a flowchart. The complete phone interview is attached in the appendix.

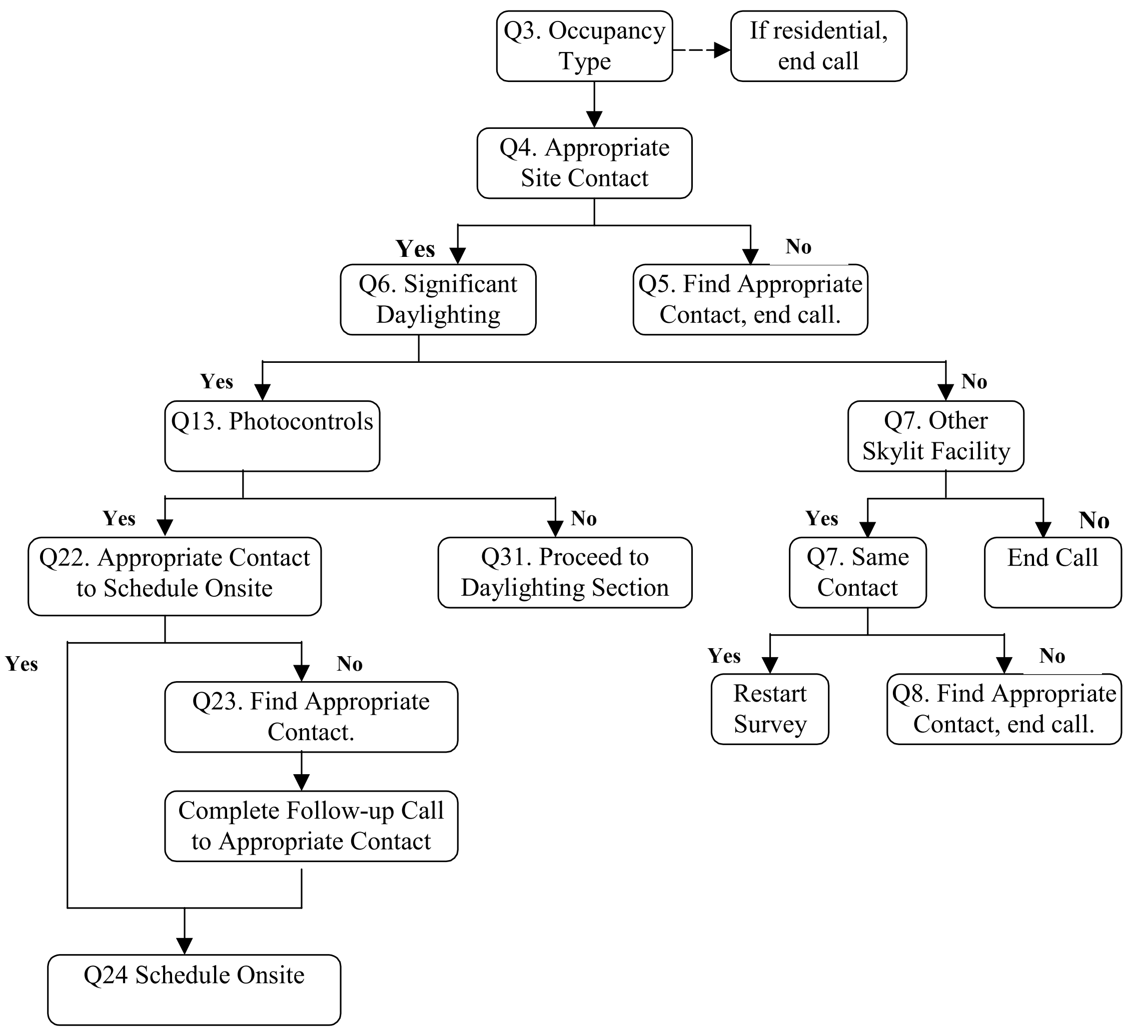


*Figure 1: Phone Interview Flowchart*

## 3.2 Screening Interview Responses

The interviewers used the standard script described above, and collected as much information as was allowed by the interviewee's schedule, and level of knowledge. A number of interviews had incomplete information. This was due to the focus of the interviewers to concentrate on obtaining permissions for on-sites and the contention that exact information would be collected in the on-site survey.

In Table 2, the breakdown of the occupancy type of the sites we contacted is shown. The most common occupancy type was C&I warehouse, consisting of 40% of the population. The prevalence of warehouse buildings in our population resulted from the high percentage of the building type in the Savings By Design contact database, our main source of site contacts.

| Occupancy Type | Number of Sites | % of Total |
|---|---|---|
| School | 3 | 5% |
| Office | 5 | 8% |
| Manufacturing | 12 | 19% |
| Retail | 17 | 27% |
| C&I warehouse | 25 | 40% |
| Total | 62 | 100% |

*Table 2: Occupancy Type Of Contact Population*

Of the interviews with completed answers to the floor area questions, most buildings were found to be over 100,000 sq. ft. In Figure 2, the distribution of floor area for the sites is shown. The large floor area of the buildings in the sample ties back to the prevalence of the warehouse occupancy type. Table 3, illustrates that over half of the sites are controlling their entire lighting system with photocontrols.

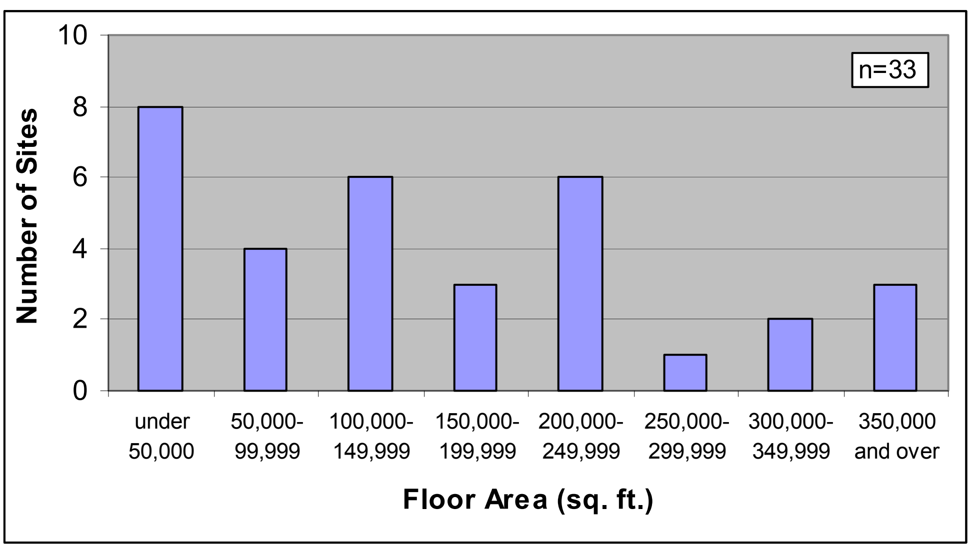


*Figure 2: Floor Area Of Buildings*

| % of Floor Area on PC System | Number of Sites | % of Total |
|---|---|---|
| under 50% | 2 | 6% |
| 50%-99% | 13 | 39% |
| 100% | 18 | 55% |
| total | 33 | 100% |

*Table 3: Percent Of Floor Area On The Photocontrol System*

In the survey, we asked each contact specific questions on the operation of their lighting and photocontrol systems. Table 4, provides a breakdown of the reported type of lighting systems. The table is also segmented by whether or not permission was granted for an on-site survey. The most common lamp type was metal halide.

| Agreed to On-site | Type of Lighting System | Number of Sites | % of Subtotals |
|---|---|---|---|
| no | not noted | 6 | 50% |
| | fluorescent | 1 | 8% |
| | high pressure sodium | 1 | 8% |
| | metal halide | 4 | 33% |
| | total | 12 | |
| yes | not noted | 5 | 17% |
| | fluorescent | 5 | 17% |
| | fluorescent/metal halide | 2 | 7% |
| | high pressure sodium | 3 | 10% |
| | metal halide | 14 | 48% |
| | total | 29 | |
| not noted | not noted | 21 | |

*Table 4: Type Of Lighting System*

Similar to the previous table, we also asked what type of photocontrol system was installed in each site. In Table 5, it is shown that most buildings used an on/off control type, regardless if they agreed to an on-site survey or not.

| Agreed to On-site | Type of Photocontols | Number of Sites | % of Subtotals |
|---|---|---|---|
| no | not noted | 6 | 50% |
| | on/off | 4 | 33% |
| | stepped | 2 | 17% |
| | total | 12 | |
| yes | not noted | 5 | 17% |
| | on/off | 20 | 69% |
| | stepped | 4 | 14% |
| | total | 29 | |
| not noted | | 21 | |

*Table 5: Type Of Photocontrol System*

When asked if the photocontrol systems was working, most answered in the affirmative (Table 6). Contacts were also asked how satisfied they were with the operation of the photocontrol system in their building. For those who answered, the majority was very satisfied (Table 7). Dissatisfaction with the photocontrol system stemmed mainly from incorrect setpoints.

| Agreed to On-site | Does PC System Work? | Number of sites | % of Total |
|---|---|---|---|
| Yes | No | 3 | 5% |
| | Yes | 25 | 40% |
| | Do not know | 1 | 2% |
| No | No | -- | -- |
| | Yes | 8 | 13% |
| | Do not know | 4 | 7% |
| | Not Answered | 21 | 34% |
| Total | | 62 | 100% |

*Table 6: Photocontrol System Performance*

| Satisfaction | Number of sites | % of Total |
|---|---|---|
| very dissatisfied | 0 | 0% |
| somewhat dissatisfied | 3 | 5% |
| neither satisfied nor dissatisfied | 1 | 2% |
| somewhat satisfied | 4 | 6% |
| very satisfied | 27 | 44% |
| not answered | 27 | 44% |
| Total | 62 | 100% |

*Table 7: Satisfaction With Photocontrol System*

## 3.3 Final Sample Size

The telephone screening surveys resulted in the selection of 46 sites that surveyors from HMG visited to conduct an onsite study. We collected site level characteristics on all the 46 sites visited.

In addition we also collected real-time power consumption data on the sites for roughly two weeks. While we planned to install loggers on all 46 sites, we did not receive loggers or data from 9 sites:

- 1 site – had no daylight and photocontrols
- 2 sites – Could not install loggers
- 4 sites – Loggers not returned
- 1 site – Logger data loss
- 1 site – Incomplete site data

We therefore had 37 sites where we could verify the energy savings. Of these 37 sites, 4 sites were side-lit and we could not estimate savings for those 4 sites due to limitations of our energy analysis tool (SkyCalc). Thus the energy savings verification was conducted on 33 of the 46 sites visited.

# 4. ONSITE PROCEDURES

Surveyors from HMG carried out the onsite surveys between December 2002 and April 2003. The surveyors were well trained in the skills needed for the onsite surveys and had experience of conducting similar surveys. The primary surveyor assigned for the project visited 37 of the 46 sites visited, and was supplemented with an additional surveyor on 4 of sites. The second surveyor alone visited 5 sites.

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. Both the protocol and data entry forms were reviewed and approved by the program managers at SCE before we used them on any site.

## 4.1 Onsite Protocol

There were three main components to the survey on each of the sites visited during this project –

- Interview to ascertain design intent, use patterns, history of usage and problems if any.
- Physical inspection –
  - Record existing daylighting conditions, electrical lighting layout, task layout and surface properties
  - Record the condition of the photo-controller, photo-sensor and other controls equipment installation and maintenance. Record any problems and probable causes
  - Record the power consumption of the electrical lighting system under various control conditions.
- Generate a SkyCalc run to determine savings potential.

### 4.1.1 Site Interviews

1) Whom to interview?

   a) Initial Contact (pre-screening survey)

   b) Occupants of the actual space (if different than the initial contact)

   c) Decision maker (if different than the contact, or the occupants)

2) What to ascertain?

a) Historical information-

i) When was the photocontrols system installed?

ii) How well is the photocontrols system working?

iii) If not working well, when did the problems arise?

iv) Are these problems related to other changes made to the building / occupancy

v) How are these systems been maintained

vi) Do they have any suggestions about good installation, design and maintenance practices?

b) Photocontroller information –

i) Make and model number of the photosensor

ii) Make and model of the controller

iii) Is the controller part of a larger EMS system?

iv) If so, description of the EMS system and the control logic

v) How does the controller ‘talk’ with the sensor and the lighting system? Are there relay panels and how are they operated?

vi) Software controls on the controller?

c) Plans and documentation – do they have any of the following available for copying or reference?

i) Set of plans showing electrical lighting and control layout

ii) Photocell location and control diagram

iii) Photocell and controller documentation

d) Nature of problems (if any)-

i) Describe if the problem is: (select from the list)

- Controls do not maintain appropriate light levels
- Controls do not achieve optimum energy savings
- Controls seem to cause frequent lamp or ballast failure

- Lights switch on/off too frequently
- Controls too difficult/expensive to calibrate or maintain
- Controls irritate occupants
- Occupants disabled for unknown reasons
- Failed for unknown reasons
- Other: Specify ____________________________

ii) Source of problems -

- Design problem
- Equipment problem
- User intervention
- Calibration/ commissioning problem
- Other : describe ___________________________

iii) Describe the problems – (story)

__________________________________________________________

________________________________________________________

e) Functional requirements – note down the following for each of the spaces

i) Tasks

ii) Illumination levels desired

iii) Desired performance of lights (dimming/ switching levels sought)

iv) Which lights to be controlled? And which to be left out?

#### 4.1.2 Site Observations And Measurements

1) Gather *SkyCalc* inputs
2) Determine sensor and control system location
3) Record physical state of the equipment (record with photos) [5]
4) Record response of sensors and controller to light levels
5) Measure daylight and electric light levels over the space
6) Determine the circuit layout for luminaries

[5] Confirm the owners agreement before taking photographs.

7) Acquire electrical plans, equipment manuals, and EMS program criterion

### 4.1.3 SkyCalc Inputs

The approximately 30 questions below are most easily answered by filling out the input tab in SkyCalc spreadsheet. If this is done on site one can quickly gain the site contact's interest as controls savings at the sites that have been filtered for inclusion into the program are likely to be large.

- Building occupancy

For rooms containing skylights gather the following information:

- Dimensions: height, floor area
- Colors of walls, roof, floors
- Lighting source: fluorescent, metal halide, high pressure sodium
- Fixture type: high bay, low bay, industrial strip, downlight, indirect
- Fixture mounting height
- Lighting control: on/off, 1/2 off, 2 level plus off, 3 level plus off, dimming
- Design footcandles
- Fixture count and wattage
- Lighting schedules: weekday and weekend hours
- Shelving or rack height and width
- Aisle width
- Number of skylights
- Skylight dimensions
- Skylight glazing: single vs double and glazing color
- Light well height and color
- Safety grate or insect screen Y/N
- Space heated?
- Heating system: gas furnace, heat pump, etc.
- Space cooled?

## 4.2 Troubleshooting

1) Daylighting Issues

a) Is the daylighting distribution from the fenestration uniform across the control area?

i) Actions:

- Record location and numbers of windows/ skylights
- Record the type of glazing
- Record light distribution patterns without electric lighting (if possible)
- Record light distribution patterns with electric lighting
- Identify lighting quality problems (glare, dark spots, etc.)

ii) Possible causes of failure –

- Use of clear glazing – beam sunlight penetration
- Inadequate diffusion of daylight
- Large variance in light levels across the control area
- Glare potential

b) What are design lighting conditions?

i) Action –

- Interview site contact for desired light level criteria and satisfaction with current light levels (data available from 'user dissatisfaction' issues above)
- Record equipment types
- Measure existing light levels
- Measure daylight levels with/without electric light
- Record electric light levels

ii) Possible causes for failure

- Insufficient daylighting due to skylight sizing/ obstructions to skylight.
- Electric lighting levels too high for the task, resulting in excessive lighting
- Dark surface colors or low reflections resulting in lesser diffusion of light

2) Hardware Issues

a) Where is the photocontroller? Is it operational?

i) Actions –

- Record exact location of controller and ease of access to the controller.
- Record type of photocontroller, relay/control panel setup, number of control inputs, etc.
- Calculate wattage controlled and maximum wattage reduction
- Record schedule and other parameters needed to run *SkyCalc*
- Observe display panel for signs of operation
- Confirm that input & output wiring is intact

ii) Possible causes of failure –

- No power provided to unit
- Unit turned off
- Unit has failed
- Wiring has been damaged or removed

b) Where are the photosensors? Are they operational?

i) Actions –

- Count number of control zones, assess their condition, describe control strategy (open loop, closed loop) and what sensors see
- Take meter readings of photosensor control signal at the photocontrol unit

ii) Possible causes of failure –

- Photosensors have been removed or damaged
- Photosensors are redirected, blocked or otherwise disabled
- Signal wire from photosensor to controller is damaged or missing

c) What are the calibration settings for the controller?

i) Actions –

- Record settings on controller
- Attempt to determine if the settings have been changed after installation
- Observe controller response to changes in photosensor readings
- Check inputs from each photosensor
- Determine if controller maintains desired lighting conditions

ii) Possible causes of failure –

- Initial calibration was wrong, or subsequent changes made were wrong
- Loss of calibration due to sensor or controller wear and tear
- Calibration out of sync with changed usage patterns.

d) How is the controller integrated into other energy management systems?

i) Actions –

- Record the various control panel's make and model number
- Identify the control sequence and determine how the panels 'talk' to each other
- Determine if any of the panels was replaced/added after the initial installation and calibration

ii) Possible causes of failure-

- Incompatible hardware added after the initial installation
- Hardware malfunction on one of the panels
- Incorrectly configured panels
- Lack of in-house expertise on changing the control settings, leading to disabling of control panels.

3) User dissatisfaction

a) Are the users satisfied with the design light levels?

i) Actions –

- Record the user satisfaction on a scale of 1-5, with 5 being very satisfied and 1 very unsatisfied
- Record reasons for dissatisfaction
- Record suggestions for desired levels

ii) Possible causes of failure –

- Task requirements changed after installation
- User preferences differ from design intent

b) Are the users affected by the changes in light levels due to the photo controls

i) Actions –

- Record type of daylighting controls used (stepped, dimming etc)

- Interview site contact about awareness of differing light levels
- Record on a scale of 1-5 level of satisfaction over the consistency of lighting levels with 5 being most consistent and 1 being most inconsistent
- Record suggestions about light levels

ii) Possible causes of failure-

- Cycling due to improper thresholds or inadequate time delays
- Sudden changes in light levels due to inappropriate settings on stepped controls
- Improper equipment selection

c) Are the users happy about turning off electric lighting

i) Action –

- Record on a scale of 1-5 level of satisfaction over the ability to switch off electric lighting with 5 being most satisfied and 1 being most unsatisfied
- Record user preferences on minimum lighting levels using electric lighting

ii) Possible causes of failure

- User preferences for keeping lights on despite the need for electric lights
- Business compulsions (e.g. stores)
- Lack of user knowledge about daylight controls

d) Is the equipment being maintained properly?

i) Actions –

- Record physical state of the hardware
- Interview site contact for maintenance schedules

ii) Possible causes of failure –

- Dust accumulation
- Equipment aging
- Physical damage

# 5. ENERGY SAVINGS POTENTIAL

How well a given control system was performing was evaluated by comparing the potential energy savings of the system with the actual measured savings. The potential savings of the photocontrol system was calculated by applying a daylighting control function (such as shown in Figure 3) to interior illuminances that can be expected over the course of a given time period. Note that savings are importantly a function of both the function type (such as 10% dimming, or two-level plus off switching), and the target illumination settings for these functions. In many cases, we did not know the actual target illumination settings or the precise control function specifications, but we deduced these based upon the interviews onsite, the surveyors observations, the electric lighting system type and the lighting power density.

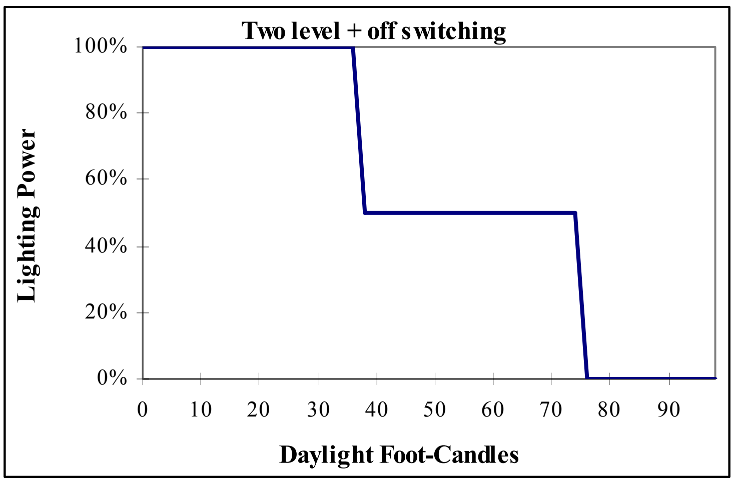


*Figure 3: Example of a Daylighting Control Function (for a Two Level + Off Switching Control)*

While the surveyors took spot measurements of the interior illuminance levels at the time of survey, we needed to estimate the interior illuminances over the extended period of analysis (2 weeks of data collection). The calculations needed to estimate interior illuminances in diffusing skylighting systems are quite simple and are based upon the concept of daylight factor, which is the ratio of interior illuminance to global horizontal illuminance outdoors.

*Interior Illuminance = Ambient Global Horizontal Illuminance x Daylight Factor*

Hourly global horizontal irradiances and dewpoint temperatures during the monitoring period were obtained from SCE weather stations in the vicinity of the site. The global horizontal irradiances where decomposed into diffuse and direct beam components via the Erbs correlation[6]. These irradiance values were then converted into illuminance values via the use of the Perez luminous efficacy correlation, which is a function of irradiance and dewpoint temperature.[7]

If the spaces we surveyed were unoccupied, it would be quite simple to measure the daylight factor by turning off all interior lighting and measuring interior and exterior illuminances simultaneously. However, we did not have this luxury and thus the daylight factor had to be estimated from the Lumen Method and skylight transmittance calculation embedded in SkyCalc. The daylight factor is calculated by the following relation:

*Daylight factor = SFR x Tvis x DF x Well Efficiency x Coefficient of Utilization*

Where,

SFR = total skylight area to floor area ratio

Tvis = visible transmittance of glazing and diffusers

DF = dirt factor, loss of glazing transmittance due to glazing weathering and dirt, 70%

Well efficiency = fraction of light entering a light well that exits it

Coefficient of Utilization = faction of light that leaves the light well that makes it to the task surface. This is a function of space geometry and reflectances.

Multiplying the calculated Daylight Factor times the hourly external illuminance during the monitoring period yielded the interior hourly illuminances. Applying these interior illuminances to the control function resulted in estimated power reduction factors for each hour of the monitored period for the 33 of 46 sites that were skylit and had monitored data.

Comparing the actual energy savings from monitored electric power data during daylit hours to the idealized savings estimate from SkyCalc resulted in a “realized savings ratio” for the 33 sites with power measurements. The realized savings ratio is an indication of how well the system is performing relative to predicted savings calculated for a system that works as designed.

## 5.1 Monitored Power Fraction

The monitoring equipment recorded amperage levels on the lighting circuits at 4-6 minute intervals over approximately a 2-week period. Since the installed loggers were returned by the site operators at their convenience, the amount of time the loggers were collecting data on the sites varied largely (2 weeks to 2 months), however the data collection was limited to a maximum of approximately

[6] Erbs, D.G. et al, "Estimation of Diffuse Radiation Fraction for Hourly, Daily and Monthly Average Global Radiation," Solar Energy, 1982, Vol 28, p293.

[7] Perez, R. et al., Modeling Daylight Availability and Irradiance Components from Direct and Global Irradiance," Solar Energy, 44(5), pp.271-289.

3 weeks due to limitations of the datalogger. These amperage readings were converted to hourly averages. The hourly averages were compared to the maximum amperage readings for the lighting system at full power based on the highest instantaneous power reading during the monitored period. The resulting “monitored power fraction” represents the percentage of the lights that are on over the course of each hour. These hourly ratios represent a “snapshot” system operation for the monitored period.

It should be noted that the sole information that was logged was periodic amperage readings for the circuits under the control of the photocontrol system. These current readings could only tell the time and the amount of power consumption of the circuits. This data could not directly indicate if other controls on the same circuit such as light switches, time clocks occupancy sensors etc reduced energy consumption.

## 5.2 Realized Savings Ratio

The realized savings ratio of the photocontrol system is the ratio of the monitored power fraction to the calculated potential power fraction. The operating schedule of each site as well as daylight hours were taken into account so that hours when the photocontrol system was not controlling the lights and times when the building was not in use would not influence the average realized savings ratio.

A realized savings ratio of 100% typically means that the photocontrol system is operating ideally for its building and lighting characteristics and its control strategy. Realized savings ratios below 100% indicate that the photocontrol system is not saving as much energy as predicted by SkyCalc. Conversely, realized savings ratio over 100% indicates that the electric lighting is being turned off more than SkyCalc estimation. In some instances, the cause for the discrepancy may be occupants using manual overrides to turn the lighting system on or off independently of the photocontrols. Realized savings ratios significantly higher than 100% indicate that while the photocontrol system is saving more energy, it may be doing this at the cost of light levels in the space that are too low.

# 6. FIELD SURVEY OBSERVATIONS

Surveyors from HMG visited each of 46 sites, and conducted a survey of the buildings. A standard data entry form was developed by HMG and approved by the SCE program managers to collect site-specific data required for developing a characteristics database as well as to generate a savings analysis. The following discussion summarizes the site characteristics found at the 46 sites.

## 6.1 Site Characteristics

The 46 sites visited included four building types. The greatest number of sites (44%) was classified as manufacturing/warehouse, and the second most common (37%) was retail. About 10% of the sites were classified as offices and 10% as classrooms. The high concentration of manufacturing/warehouse and retail buildings in our sample is a result of the high percentage of the above building types in the Savings By Design contact database, our main source of site contacts. The manufacturing/warehouse and retail applications also account for the 'low hanging fruit' in the existing potential for daylighting controls, as these building types typically have large open spaces that can be easily skylit to provide uniform daylight penetration.

| Building Type | # Sites |
|---|---|
| Manufacturing/ Warehouse | 20 |
| Retail | 17 |
| Office | 5 |
| Classrooms | 4 |

*Table 8: Building Types Visited*

The building vintages ranged from building commissioned in 1993 to buildings commissioned in 2002. However, 29 of the 46 buildings were commissioned in the last three years. We also verified onsite that the photocontrol systems found onsite were the original systems that were installed at the time of building commissioning, so the building vintage can be used as a good proxy for age of the photocontrol system.

7 of the 46 buildings had been retrofitted with photocontrols, and the retrofits had occurred in the last three years. The building vintages for these sites were adjusted to reflect the photocontrol system vintage.

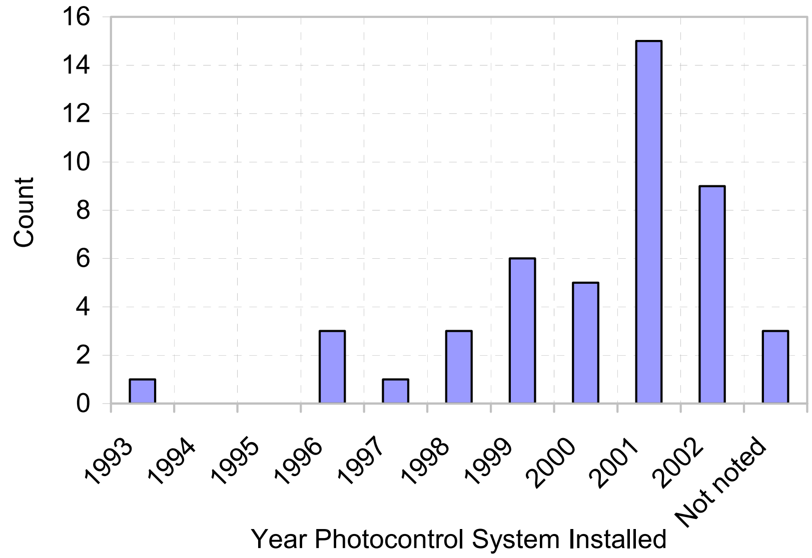


*Figure 4: Vintages of Buildings Surveyed*

There were two main lighting system types found in the survey population – HID (high intensity discharge) and fluorescent luminaires. The HID's were found predominantly in the manufacturing/warehouse spaces while the fluorescents were common in the office and classroom buildings.

| Building Type | # Sites with Fluorescent Lamps | # Sites with HID Lamps |
|---|---|---|
| Manufacturing/ Warehouse | 3 | 17 |
| Retail | 11 | 6 |
| Office | 5 | -- |
| Classroom | 4 | -- |

*Table 9: Lighting System Types Surveyed*

There are various types of photocontrol devices commercially available in the market ranging from single fixture controllers to whole building EMS-tied control systems. HMG found five different types of controllers in the buildings surveyed (see Table 10):

1) Fixture Integrated – The photosensor is mounted either on the light fixture or on the ceiling next to the fixture. Each fixture (or group of fixtures) is controlled with the sensor directly, without any additional master controller. These sensors are typically used in high-end applications and cost considerably more than other sensors for the loads they control. We found these fixture-integrated sensors in 3 of the 46 sites (7%) – 2 in retail applications and 1 in office application.

2) Outdoor Sensors – This type of controller is ideally suited for outdoor lights, and has the photosensor looking at the sky or ambient light levels outside. In our sample, these controllers were used to control indoor lights by using a co-relation between outdoor and indoor illuminance levels. These controllers work well for large warehouse type spaces where there are uniform light levels throughout the space, and there are no critical tasks that require different light levels and controls. We found these outdoor sensors in 3 of the 46 sites (7%), all of which were manufacturing/warehouse applications.

3) Power Packs – These are relay switches that drive a set of lighting circuits. Often the power packs are line voltage relays that drive a set of low voltage relays, that in turn the lights ON or OFF. The power packs can take input from a photosensor, time clock or occupancy sensor. These sensors are typically used for smaller spaces where there are limited number of lighting circuits, and are typically used with ON/OFF or Hi/Lo controls algorithms. We found power packs in 8 of the 46 sites (18%) – 2 in manufacturing/warehouse applications, and 3 each in office and classroom applications.

4) Control Panel – This is a centrally located controller that can control various lighting zones and circuits independent of each other. The control panels have intelligence built-in that allows them to perform tasks such as load-management, peak demand reduction, time sweeps etc. and have the capability of being programmed either remotely or using a user interface on the panel. These types of controls are ideally suited for large spaces with higher connected loads, or with spaces where different circuits need to be controlled independent of each other, while allowing master sweep controls. We found that the control panels were the second most common types of controllers in our sample – 13 of the 46 sites (29%). All but one of these controllers were found in manufacturing/warehouse type applications (12 sites), with the one exception being an office building.

5) EMS Tied – These are control panels that have been integrated with the buildings' energy management system (EMS). The EMS system can override the control panel for such tasks as load management, emergency shutdowns, time sweeps etc. These controls are typically found in buildings that have centralized energy management policies, and where load management is critical. We found that these EMS tied controllers were the most common types of controls – 16 of 46 sites (35%). 2 of the sites were manufacturing/warehouse applications, while there were 14 sites that were retail applications. 10 of the 14 retail sites visited had central (corporate) energy management policies that demanded aggressive energy savings.

*Figure 5: Images of Controller Types*

*Figure 5* shows representative photos of the different types of photocontrol systems surveyed by HMG.

HMG also found three sites where no photocontrol system was installed in contradiction to the information received during the telephone screening survey. On one site there was no significant daylight penetration in that there were only a couple of skylights in a 125,000 sf site, and the lights were on a timer clock. On one other site the lights were being controlled using an occupancy sensor, while the third site did not have any lighting controls installed.

| Photocontroller Type | EMS Tied | Control Panels | Power Packs | Outdoor Sensors | Fixture Integrated |
|---|---|---|---|---|---|
| Manufacturing/ Warehouse | 2 | 12 | 2 | 3 | -- |
| Retail | 14 | -- | -- | -- | 2 |
| Office | -- | 1 | 3 | -- | 1 |
| Classroom | -- | -- | 3 | -- | -- |
| *Total* | *16* | *13* | *8* | *3* | *3* |

*Table 10: Photocontroller Types Surveyed*

## 6.2 User Satisfaction With Photocontrol System Operation

During the onsite surveys, the surveyors asked the building operators about their satisfaction levels with the photocontrol system operation. The intent of the question was to find out if the building operators felt that the photocontrol systems were performing as per their expectations. The expectations of the site operators do not always reflect the design intent, and in many cases the building operators are not aware of the design intent. It was not possible for the surveyors to judge the design intent by their observations onsite, or asking the site operators since the design intent was not documented onsite. The surveyors therefore noted the site operators' satisfaction level with the control system, and backed it up with their own observation of the control state and additional interviews with other site personnel wherever possible.

This section reports on the site operator reported satisfaction levels with the photocontrol system, and 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 report in section 7, Energy Savings in Surveyed Systems.

### 6.2.1 User Satisfaction Levels

User satisfaction was reported on a subjective scale, ranging from systems that are non-operational to systems that are working well as per site operator's expectations.

1) Overridden photocontrols – On these sites, the building operators were not satisfied with photocontrol system operation, and would often (at least once a day) override the photocontrol systems by manually turning the lights ON or OFF. Of the 46 sites we visited, the site operators reported that they were overriding the systems on 5 sites.

2) Photocontrol not working – On these sites, the photocontrol systems were reported as being not working at all i.e. they were installed but never turned lights OFF or dimmed the lights as programmed. The operators did not bypass the controls, but rather the installers and operators were unable to get the controls to work as designed. We found 2 of the 46 sites had photocontrols not working.

3) Photocontrols working with problems – On these sites, the site operators reported that they were generally happy with the operation of the control system, but wished that the system worked a little better. The problems ranged from lights being controlled too often causing cycling of lights, to lights being controlled too conservatively, resulting in the system keeping the lights ON when the operators would prefer them to be OFF. The problems were not severe enough for the site operators to override the system, but given the opportunity they would like to see the system settings changed to improve the

control function. 20 of the 46 sites visited were reported to have photocontrols working with some problems.

4) Photocontrols working well – On these sites, the site operators were satisfied with the control system operation, and the control system controlled the lights as per the site operators expectations. 16 of the 46 sites had photocontrols that were working well per the site operators.

5) No photocontrols – On these sites, no photocontrol system was installed. Instead either an occupancy sensor or time clock was controlling the lights.

| User Stated Photocontrol Status | # Sites |
|---|---|
| Overridden photocontrols | 5 |
| Photocontrols not working | 2 |
| Photocontrols working w. problems | 20 |
| Photocontrols working well | 16 |
| No Photocontrols | 3 |

*Table 11: Photocontrol Operational Status Reported by Site Operators*

While HMG did not find any photo control systems that had failed physically, almost 60% the sites had some problems with the photocontrol operation or photocontrols that were not believed to be working per the expectations of the site operators and users.

This initial classification of the photocontrol operational status was later revised during the analysis of the measured power consumption data from the sites and is presented in Section 7, Energy Savings in Surveyed Systems of this report.

### 6.2.2 User Satisfaction Reasons

HMG further investigated the reasons for the site operator's satisfaction or dissatisfaction with the photocontrol systems through the onsite interviews. These responses were tallied for systems that were not working, working with problems or overridden.

***Reasons for disabling photocontrol systems (5/46 sites)***

| Stated reasons for disabling system: | # Sites (5/46 sites) |
|---|---|
| Setpoint too high | 2 |
| Setpoint too low | 1 |
| Lights do not dim down enough | 1 |
| Setpoint not calibrated for actual usage | 1 |
| Problems exist since time of installation/ commissioning | 5/5 sites |

*Table 12: Stated Reasons for Disabling Photocontrol System*

For the 5 sites where the site operators had disabled the photocontrol system, the stated reason for discomfort with the system was incorrect setpoints. Setpoint is the threshold illuminance level set for the photocontrol system to control the lights.

Two sites were reported to have the setpoint set too high, i.e. the lights were being turned OFF at a setpoint that was too high compared to the amount of light needed in the space. This would result in the lights being ON at higher levels of daylighting in the space than what the site operators would require.

On one site the site operator felt that the setpoint was too low, i.e. the lights were being turned OFF at light levels deemed to be insufficient by the site operator. This would result in the lights being OFF more often than what the site operator would expect or like.

On one site there was enough daylight available most of the time and the site operator wanted a control scheme that would turn the lights OFF. However, the dimming controls on the lighting system did not allow the lights to be turned OFF, so the site operator disabled the control system and manually turned the lights OFF.

On one site the photocontrol system was commissioned and calibrated before the warehouse stacks were stocked, and once the stocks were stored in place, the available daylight levels dropped. Due to this reduction in available light, the control system did not turn OFF the lights as often as the site operator expected, and the control system was therefore bypassed to turn the lights OFF.

For all the 5 sites, the site operators reported that the problems existed since the time of commissioning of the photocontrol systems, indicating that the commissioning process may have not completely succeeded in satisfying the user needs. It could also point to a possible disconnect between design intent and the expectations of the site operators.

### *Reasons for photocontrol system not working (2/46 sites)*

In addition to the above 5 sites with disabled system, site operators reported that two of the sites visited had systems that were not working at all. One of the two sites was a recent construction and the system had not been fully commissioned yet. At the second site, the system had been commissioned but it never worked as intended. An electrician had been called to troubleshoot the problem three times, but could not figure out how to get the system to work.

### *Stated problems with working photocontrol systems (20/46 sites)*

| Stated problems with working systems | # Sites (20/46 sites) |
|---|---|
| Inappropriate switching | 6 |
| Setpoint too low | 5 |
| Setpoint too high | 2 |
| Manual overrides (due to energy policies) | 2 |
| Problem not stated | 5 |
| Problems exist since time of installation/ commissioning | 13/20 sites |

*Table 13: Stated Problems With Working Systems*

Of the 20 sites that were reported to be working with problems, we got more details on the problems from 15 sites. The problems were all related to the operation of the photocontrol system, and were not caused by any equipment failure.

The most common complaint (6 sites) was that the lights were not being controlled in a consistent manner. All six sites had switching systems, and the site operators were not happy with the number of times the systems were being turned OFF by the photocontrols and also the amount of time the systems were being turned OFF. While this problem could be caused by the setpoints being too high or low, it could also be a function of the time delays set on the control system.

On 5 other sites, the site operators reported that they felt the setpoint was too low and the lights were being turned OFF or dimmed when the daylight available in the space was not adequate to provide needed illumination. On 2 sites, the site operators reported that they felt the setpoint was too high and the lights were not being turned OFF or dimmed when there was adequate daylight available in the space.

On 2 sites, the site operators had manually overridden partial circuits to save more energy than the photocontrols were saving. This was due to a directive form the corporate office during the California energy crisis.

All the mentioned problems seem to indicate that the control settings needed to be fine-tuned in order to make the systems work better and fully satisfy the building operators needs. Of these 20 sites, site operators on 13 sites reported that the problems exist since the time of commissioning, indicating that the commissioning process may have not completely succeeded in satisfying the user needs. It could also point to a possible disconnect between design intent and the expectations of the site operators.

## 6.3 User Satisfaction With Photocontrol System Vs. Site Characteristics

HMG further analyzed the observed site data to seek patterns of success or failure of the photocontrol systems (as reported by site operators) associated with specific site characteristics. We compared various building and photocontrol characteristics against the five photocontrol operational status definition explained above.

| Building Type | Over-ridden | Not Working | Working w problems | Working Well |
|---|---|---|---|---|
| Manufacturing/Warehouse | 3 | 1 | 9 | 6 |
| Retail | -- | 1 | 7 | 8 |
| Office | 2 | -- | 1 | 2 |
| Classroom | -- | -- | 3 | -- |

*Table 14: Photocontrol Operation vs. Building Type*

Plotting the operational status of the photocontrols against the building type shows that there are working systems in all the building types, and there is no clear indication of any building type being incompatible with photo controls. Overall the retail applications seem to do better than other buildings types, which could be attributed to the fact that most of the retail buildings have floor plans and systems designed centrally and have identical setups on a number of sites. The office and school applications are harder to implement due to the complex functional requirements from the lighting system. However, it should be noted that the small sample size precludes us from making any prediction of conditions in the overall population.

| Controller Type | Over-ridden | Not Working | Working w problems | Working Well |
|---|---|---|---|---|
| EMS tied | 1 | 1 | 6 | 8 |
| Control Panels | 2 | 1 | 5 | 5 |
| Power packs | 1 | -- | 5 | 2 |
| Outdoor Sensors | 1 | -- | 1 | 1 |

*Table 15: Photocontrol Operation vs. Controller Type*

Plotting the operational status of the photocontrols against the type of photocontrol system also indicates a good spread of performance across the types. No particular product type is seen to be prone to failure more than other types, or of being completely incompatible with the controls objectives. The larger control types such as control panels and EMS tied system typically tend to perform well per the site operators due to the fact that most of these systems are installed in retail and manufacturing/warehouse applications where there is a corporate energy policy as well as service contracts to keep the systems running efficiently.

| Lamp Type | Over-ridden | Not Working | Working w problems | Working Well |
|---|---|---|---|---|
| Fluorescent Lamps | 2 | 1 | 10 | 9 |
| HID Lamps | 3 | 1 | 10 | 7 |

*Table 16: Photocontrol Operation vs. Lighting System*

Plotting the operational status against the lighting system controlled shows that both fluorescent and HID lighting systems lend themselves well to photocontrols. Both of them had almost identical performance records on the sites HMG visited.

Further we looked at the impact of the lighting control algorithm on the photocontrol system operation. The lighting control algorithm was categorized into four categories:

1) ON/OFF – here the photocontrol system turns the lights OFF when there is adequate daylight in the space and turns them ON when the daylight levels fall below a minimum threshold

2) Hi/Lo – Here the photocontrol system switches half the lights OFF on any given circuit or fixture when there is adequate daylight in the space. In a two lamp fixture, the control system will turn one light OFF when there is enough daylight, while in a circuit containing one lamp fixtures, it will turn half the lamps OFF

3) Multi-level Switching – here the photocontrol system turns lights OFF in a stepped manner. Thus in a multi-lamp fixture, the system will stage the lights so that as the daylight levels increase, an increasing number of lamps are turned OFF. Typical strategies in the category include – ½-OFF, 2/3-ON/OFF, 2+ levels and 3+ levels of control

4) Dimming – Here the photocontrol will linearly reduce the light output of the light fixtures with increasing daylight levels in the space. While fluorescent systems can be dimmed down to 0% light output, HID systems are typically dimmed to a 20% or 30% light output due to their long re-strike times

| Control Algorithm | Over-ridden | Not Working | Working w problems | Working Well |
|---|---|---|---|---|
| ON/OFF | 3 | -- | 9 | 4 |
| Hi/Lo | -- | -- | 3 | -- |
| Multi-level Switching | 1 | 1 | 7 | 8 |
| Dimming | 1 | 1 | 1 | 4 |

*Table 17: Photocontrol Operation vs. Lighting Control Algorithm*

The Hi/Lo and ON/OFF controls are the easiest to implement onsite while the dimming and multi-level switching involves more elaborate circuiting and equipment. As seen in Table 17 though, the site operators reported that all four control algorithms worked on various sites, and the dimming systems worked better than say the Hi/Lo systems. While the sample size precludes from making any estimates for the population, the limited results here show that any of the control algorithms can be successfully implemented onsite.

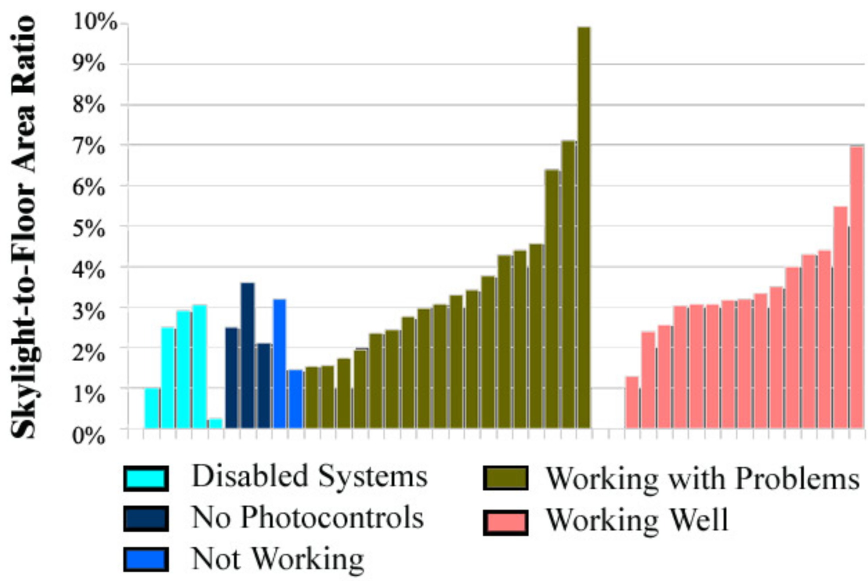


*Figure 6: Effect Of Skylight/Floor Area Ratio on Photocontrol Operation*

HMG then compared the operational status of the photocontrols against the skylight/floor area ratio at each of the sites, which is a proxy for the amount of daylight entering the space. While most of the sites with high SFR's (above 3%) were seen to be working or working well, there was no clear trend amongst the sites with lower SFR's (below 3%). Again there is no clear indication that there is a threshold of daylight level critical to good operation of photocontrols. A factor that can potentially skew this analysis is the fact that some of these sites also received daylight through side lighting, and that daylight component would not be captured by the figure above.

| Vintage | # Sites | Over-ridden | Not Working | Working w. Problems | Working Well |
|---|---|---|---|---|---|
| < 3 yrs | 29 | 14% | 3% | 41% | 34% |
| 3-6 yrs | 10 | -- | 10% | 20% | 60% |
| 7-10 yrs | 4 | 25% | -- | 75% | -- |
| Not Noted | 3 | -- | -- | 100% | -- |

*Table 18: Photocontrol Operation vs. System Vintage*

We also looked at the impact of the vintage of the photocontrol system on its operation as reported by the site operator. We found that there was no linear correlation between age of the system and its operational status. The older systems did however tend to have more problems than the newer systems, but our small sample size precludes any predictions for the population.

## 6.4 Site Characteristics Summary

Overall the photocontrol systems were reported to work well (16 of 46 sites) or work with some minor problems (20 of 46 sites) by the site operators. This is a very encouraging trend in that it debunks one of the urban myths surrounding photocontrols that they do not work and that the site operators are not happy with the photocontrol systems. There are however nagging problems with the photocontrol systems that were reported by the site operators. While the problems were not reported to be associated with any mechanical failure of the equipment, or with any of the building, lighting system and photocontrol system features, the problems were reported to be existing from the time of commissioning of the systems on most sites. Most commonly reported problems hinted that the photocontrol systems were not calibrated properly and therefore did not control the lights as effectively as the site operators expected. While most of the site operators tolerate these problems (20 of 46 sites that were reported as working with some problems), there are a few sites where the site operators feel it necessary to over-ride the photocontrol system in order to achieve desired energy savings and performance of the lighting system.

The site operators also showed a general lack of knowledge on how to change the photocontrol system setpoints and other settings, and the documentation on the procedures to do so was minimal at best on most sites. While the site operators had asserted during the telephone screening survey that their buildings had photocontrol systems, we still encountered three sites that did not have any photocontrols installed. Site operators on these three sites confused occupancy sensors or time clocks installed onsite with photocontrols.

While the small sample size precludes us from making any generalizations about the conditions in the overall population of non-residential buildings in California with daylighting and photocontrols, the study however presents a snapshot of the various conditions of photocontrol operation existing in the current market.

# 7. ENERGY SAVINGS IN SURVEYED SYSTEMS

The energy savings analysis was based upon the monitored power data from the sites along with SkyCalc analysis of the system as described in Section 5, Energy Savings Potential. The realized savings ratio is the measure of performance of the photocontrol system, and a system with realized savings ratio of 100% is assumed to be working per its technical potential and design intent.

In addition to the realized savings ratio, we also calculated the predicted annual savings for each site using SkyCalc. This kWh/yr savings estimate gives the magnitude of savings from the photocontrol system. For any given system, the realized savings ratio expresses the scope for improvement in system operation, while predicted annual savings provide the significance of the photocontrol system savings to the building operational budget.

The first task was to verify if the user reported operational conditions matched the actual system performance data. Of the 33 sites analyzed, users had stated that they were using manual overrides on three sites, had problems with the photocontrol system operation on 15 sites, and had no problems with the photocontrol operation on 13 sites.

We re-classified all the sites under two categories – systems that were operational without any manual controls (henceforth called operational sites), and systems that had manual overrides (henceforth called manual overrides).

Sites where the users informed us that they were controlling the lights manually, as well as sites where we observed manual override switched being used were categorized as manual overrides. In addition, on a number of sites the users had permanently turned a third to half of the lights OFF due to energy efficiency policies implemented due to the energy crisis. These sites were also classified as manual overrides. The manual overrides included actions such as:

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.
2. Consistent Manual Control – to achieve savings that the photocontrol system could not provide. Here the photocontrol system is not disabled, but is consistently overridden. On most sites, the users follow a regular schedule for operating the lights through manual control.
3. Disabled System – this is an extreme case where the photocontrol system is physically disabled by the users due to dissatisfaction with its operation.

In all the three cases, it is possible for the lights to be turned OFF or turned ON through manual action.

| Manual Override Status | # Sites Analyzed | Manual Overrides - Lights ON | Manual Overrides - Lights OFF |
|---|---|---|---|
| Occasional Manual Control | 5 | -- | 5 |
| Consistent Manual Control | 6 | -- | 6 |
| System Disabled | 1 | 1 | -- |
| Total # Sites | 12 | 1 | 11 |

*Table 19: Manual Override Status*

We observed that only one site from the 12 sites categorized as manually overridden was actually physically disabled. On this site, the photocontrol system was commissioned in an empty warehouse, and the light levels were insufficient once the warehouse was stocked. The users subsequently disabled the system and now manually control the lights such that lights are turned OFF only occasionally. On the rest of the 11 sites, the users were either occasionally or consistently turning the lights OFF.

For ease of presentation, the three categories of manual overrides described above are clubbed into one category called manual overrides henceforth.

| User Satisfaction | # Sites Analyzed | Operational | Manual Overrides | *Mean Annual Predicted Savings (kWh/sf)* |
|---|---|---|---|---|
| Working Well | 13 | 13 | -- | *1.53* |
| Working | 15 | 8 | 7 | *0.77* |
| Not Working | 1 | -- | 1 | *0.48* |
| Overridden | 3 | -- | 3 | *0.97* |
| No Photocontrols | 1 | -- | 1 | *0.36* |
| *Total # Sites* | *33* | *21* | *12* | |
| *Mean Annual Predicted Savings (kWh/sf)* | | *1.31* | *0.73* | |

*Table 20: Comparing User Satisfaction with Actual System Performance*

As seen in Table 20, 12 of the 33 sites monitored were using some form of manual controls in addition to or in lieu of photocontrols. All 3 sites that the users had reported to be manually overridden were indeed being operated manually, while 7 of the 13 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 any manual overrides. It is important to note that of the 12 manually overridden sites, only one site was overridden to be ON. The other 11 sites were overridden to turn the lights OFF, thus indicating that the users are using manual controls to achieve more savings.

Data in Table 20 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 1.53 kWh/sf. The sites that were working with some problems had much lower predicted savings with a mean savings of 0.77 kWh/sf. 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 a mean savings of 1.31 kWh/sf, while the manual overrides had a mean savings of 0.73 kWh/sf.

| | Operational (21 Sites) | Manual Overrides (12 Sites) |
|---|---|---|
| *Mean Annual Predicted Savings (kWh/sf)* | 1.31 | 0.73 |
| *Mean Realized Savings Ratio* | 0.92 *(Std. dev = 0.15)* | 1.07 *(Std. dev = 0.34)* |

*Table 21: Mean Predicted Savings vs. Savings Potential*

While the mean predicted savings projects the size or magnitude of savings, it does not indicate how much the system is performing in reference to its savings potential. The realized savings ratio provides that rating, and it is seen that the overridden system have a higher realized savings than the operational systems. Combining the two criterions, it may be surmised that the users are more prone to override 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 overrides will be over time, or when the energy crisis related policies elapse. Further, there is a much larger variance in the performance of systems with manual overrides than systems with operational controls as seen by the standard deviation of the realized savings ratio in Table 21.

## 7.1 Comparing System Operational Status with Site Characteristics

Once we had categorized the systems as operational or manual overridden we looked at the correlation between the operational status and various site characteristics to understand if any particular characteristic leads to more users overriding the systems.

| Age of System | # Sites Analyzed | Operational | Manual Overrides |
|---|---|---|---|
| < 3 years | 21 | 57% | 43% |
| 3-6 Years | 8 | 88% | 12% |
| 7-10 Years | 1 | 0% | 100% |
| Not Noted | 3 | 67% | 33% |
| *Total # Sites* | *33* | *21* | *12* |

*Table 22: System Operational Status vs. Age of System*

The first criterion that we looked at was the age of the photocontrol system, in order to understand if the photocontrol system performance degraded over time. As seen in Table 22, majority of the systems we analyzed were commissioned in the last 3 years, and over half of these systems were operational. 8 of the 33 sites analyzed were commissioned 3-6 years ago, and a large majority of these systems were operational. There was one system that was older than 6 years, and it was manually overridden.

It is important to note again that only one of the 12 overridden sites had the lights turned ON by the users. On all the other sites, users were overriding the systems to turn lights OFF to achieve more savings.

| Building Type | # Sites Analyzed | Operational | Manual Overrides |
|---|---|---|---|
| Mfg/Whse | 16 | 63% | 37% |
| Retail | 12 | 84% | 16% |
| Office | 1 | 100% | 0% |
| Classroom | 4 | 0% | 100% |
| *Total # Sites* | *33* | *21* | *12* |

*Table 23: System Operational Status vs. Building Type*

We then looked at the impact of building type on the photocontrol operational status. Majority of our sites were either manufacturing/warehouse or retail buildings. For these building types about 2/3$^{rds}$ of the systems were operational. The one office application we analyzed was also operational. The classroom operations proved to be much harder to analyze than the other building types. This was due to the changing schedules in the classrooms, along with changing needs for lighting for various activities in the classrooms. From the data it was not clear when the photocontrol system was operating to control the lights, and when the teachers were manually turning the lights OFF. It was clear though that the teachers were indeed turning the lights OFF at times in order to assist audio visual presentations as well when the classrooms were vacated for other activities such as breaks.

| Control Strategy | # Sites Analyzed | Operational | Manual Overrides |
|---|---|---|---|
| Open Loop | 13 | 54% | 46% |
| Closed Loop | 9 | 67% | 33% |
| Not Known | 11 | 73% | 27% |
| *Total # Sites* | *33* | *21* | *12* |

*Table 24: System Operational Status vs. System Control Strategy*

The system control strategy was noted on sites where the users were aware of the control strategy and where we could observe the photocell orientation and the photocontrol algorithm, Of the 33 sites analyzed we could not determine the control strategy on 11 sites, and of the rest, 13 sites were using open loop controls, while 9 sites were using closed loop controls. It was observed that both the control strategies resulted in over 50% of the systems being operational.

| Controller Type | # Sites Analyzed | Operational | Manual Overrides |
|---|---|---|---|
| EMS Tied | 11 | 73% | 27% |
| Control Panel | 10 | 70% | 30% |
| Control Pack | 5 | 20% | 80% |
| Outdoor Controls | 3 | 67% | 33% |
| Fixture Mounted | 3 | 100% | -- |
| Occupancy Sensor | 1 | -- | 100% |
| *Total # Sites* | *33* | *21* | *12* |

*Table 25: System Operational Status vs. Controller Type*

As explained in Section 6.3, there were six different controller types found onsite, and we looked at their impact on the operational status of the systems. While most of the controller types were found to have higher than 50% operational status, the control pack showed a higher rate of manual overrides. This is due to the fact that 4 of the 5 sites with control packs are classrooms where the teachers often control the lights manually in addition to photocontrols. Thus the results are not indicative of the controller type, but rather of the space occupancy. The one site where the users were using occupancy sensors instead of photocontrols was observed to be consistently manually operated.

| Control Algorithm | # Sites Analyzed | Operational | Manual Overrides |
|---|---|---|---|
| On/Off | 13 | 54% | 46% |
| Hi/Lo | 3 | 67% | 33% |
| Multi-level Switching | 12 | 60% | 40% |
| Dimming | 5 | 100% | -- |
| *Total # Sites* | *33* | *21* | *12* |

*Table 26: System Operational Status vs. Control Algorithm*

The control algorithm determines the steps in which the lighting system is controlled. The ON/OFF and multi-level switching systems were the most commonly found control algorithms, along with a few Hi/lo and dimming systems. All the dimming systems were found to be operational, while the other three control algorithms were seen to be operational in about 60% of the sites. It is clear from the table above that the complexity of the control algorithm is not a barrier to operational status of the photocontrol system.

| Lighting System | # Sites Analyzed | Operational | Manual Over-ride |
|---|---|---|---|
| Fluorescent | 14 | 57% | 43% |
| HID | 19 | 69% | 31% |
| *Total # Sites* | *33* | *21* | *12* |

*Table 27: System Operational Status vs. Lighting System*

It is a commonly held perception that HID lighting systems do not lend well to automated controls, and fluorescent systems are much better suited for automated controls. Our data indicated that this was not necessarily true, although HID systems we analyzed had relatively simple On/Off or switching controls.

| Incentives Received | # Sites Analyzed | Operational | Manual Over-ride |
|---|---|---|---|
| Yes | 11 | 64% | 36% |
| No | 13 | 77% | 23% |
| Don't know | 9 | 44% | 56% |
| *Total # Sites* | *33* | *21* | *12* |

*Table 28: System Operational Status vs. Incentives*

Lastly we looked at the impact of energy efficiency incentives on the performance of the photocontrol systems. These incentives are intended to help promote the use of photocontrols on sites where the users would have not considered installing photocontrols otherwise. We found that there were a greater percentage of photocontrol systems operational on sites that had not received incentives. This is probably due to the fact that the non-incented sites probably have users that are more energy conscious and make more concerted attempts at getting the system configured right.

## 7.2 Summary of Energy Savings Analysis

One of the urban myths surrounding photocontrols is that these controls do not save any energy. Most of these assumptions are based upon earlier applications of photocontrol technology in side-lit office type applications. Our data analysis showed that overall the photocontrol technology is working very well in skylit applications in variety of building types. More than half the sites analyzed were working properly and were savings about 92% of the technical potential of the photocontrols. This translated to about 1.53 kWh/sf energy savings on an average from the 21 operational sites of the 33 sites analyzed.

We also found 12 sites (36% of total sites analyzed) where the users were manually operating some or all of the lights in order to achieve higher savings than what the photocontrol system were designed to deliver. In many cases the energy crisis of 2001 had generated a momentum towards maximizing energy savings, and users had turned parts of their lighting circuits OFF permanently. Only one of these 12 sites had a photocontrol system physically disabled. It is important to note that the user overrides in all but this one site resulted in more savings than the original intent of the photocontrol system. The persistence of the manual control savings is an unknown factor that can potentially reduce savings over time. However, on only one site (where the system is disabled) would the savings reduce below the original intent of the photocontrol system design.

# 8. CONCLUSIONS

## 8.1 The cup is ¾ full

Overall the skylit systems we analyzed were functioning per the system design, with roughly a third of the sites showing user intervention to achieve higher than designed savings. On an aggregate the photocontrol systems are performing as planned and their realized savings are within 10% of the estimated potential savings. The systems that are being manually assisted show a greater range in savings achieved (20%-144% of potential savings) than the sites those are operational (60%-117% of potential savings). This shows that the photocontrol systems are better at maintaining steady savings when compared to manual controls, which have greater potential for variability.

## 8.2 The cup is ¼ empty

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.

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.

## 8.3 Urban Myths

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 mean savings from operational sites was 92% as compared to the savings potential, and shows that the photocontrol systems can indeed save energy as intended.

## 8.4 Need for better education on photocontrol system operation

While the surveyors did not observe anything fundamentally wrong about the photocontrol system design and intent, they however observed that there was a widespread lack of knowledge about the system capabilities amongst the building operators and users.

Many building operators and users often confuse photocontrols with other types of automated controls such as occupancy controls. We found that on 4 of the 46 sites visited, the building operators were wrongly labeling occupancy sensors, timers and other controls as photocontrols.

A third of the building operators on sites visited by HMG could not even find where their photocells and control units were located.

Most building operators lack the knowledge necessary to make temporary or permanent changes to the photocontrol system control settings. In most cases users find it easier to use manual overrides than recalibrate their control systems.

## 8.5 Need for better documentation on photocontrol systems

Further there is no clear documentation on the photocontrol system design intent and controller settings on most sites. The performance criterions for the photocontrol operation are not documented onsite, and there is no feedback to the users about the actual effectiveness of the photocontrol systems.

Most of the systems are not supported with adequate documentation to allow the users to learn about their capabilities and do not provide easy and step-by-step instructions on how to change their system settings.

The roles of the various actors involved in the photocontrol system design, installation and operation are often not well documented. This leads to a lack of clear direction when something does go wrong with the system or when the system does not perform optimally.

## 8.6 Future Investigations

Based upon the data collection and analysis we feel there is a need to further explore a number of issues critical to successful operation of photocontrol systems. These issues can be summarized with the following questions:

- Can existing equipment be used more effectively?
- Can the installation process be improved with better information?
- Can the calibration process be made easier and intuitive?
- Can we agree on installation/calibration guidelines or methods?
- How can we work with manufacturers to improve products?

We attempt at answering a few of these questions through the photocontrols guidelines we developed through this project.

## 8.7 Photocontrol Guidelines

The photocontrol guidelines address the manufacturers of photocontrol systems primarily, but also provide important information to building designers and users. The complete guidelines are provided in the appendix of this report, but we will summarize the intent of the guidelines below.

The guidelines aim to address the roles of the various actors involved in the photocontrol system design, installation, calibration and operation, and also lay out areas where these actors need to collaborate in order to facilitate a working photocontrol system. The guidelines are based upon three simple principles –

1) First, do no harm

    a) Make sure system does not interfere with the productivity of the users

2) Second, KISS

    a) Make the system simple, understandable and adjustable

3) Third, publish commissioning instructions

    a) To meet design intent and optimize energy savings

    b) To assist manufacturers in training their customers

# 9. APPENDICES

# PHOTOCONTROL SCREENING PHONE SURVEY

HESCHONG MAHONE GROUP
11626 Fair Oaks Blvd. #302
Fair Oaks CA 95628 (Sacramento area)
Phone (916)962-7001 Fax (916)962-0101 E-mail: info@h-m-g.com

## Photocontrol Screening Phone Survey

Hello, I am calling on behalf of Southern California Edison as a part of its ongoing efforts to increase energy efficiency in buildings. SCE has been actively promoting energy efficiency through the use of use of daylighting or natural lighting with lighting controls. We are conducting research on the effectiveness of these controls in non-residential applications, and your facility is one of several sites identified as having these lighting controls

*If you are calling SCE program participants add the following:*

We understand that you had participated in SCE's Savings by Design or Commercial New Construction Assistance Program and that daylighting controls were considered.

As a first part of this research I would like to ask you a few simple questions to learn about the daylighting in your facility. This should take about 30 minutes of your time. Is this a good time to talk?

- ❑ Yes
- ❑ No: Please specify a time: ___________________________
  *[Thank them for their time and end call.]*

### 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?**
   - ❑ Warehouse
   - ❑ Manufacturing
   - ❑ Retail/ commercial
   - ❑ Office
   - ❑ Other: specify - __________________________________________
   - ❑ Residential: [*Thank them for their time and end call.]*
4. **Are you the best person to talk to regarding the maintenance of the lighting and daylighting systems in your facility?**
   - ❑ Yes *[Skip to Q6]*
   - ❑ No

5. **Can you refer me to the person who is?**

   Name: ______________________________
   Phone: ______________________________
   Position/title: ______________________________

   *[Thank them for their time and end call.]*

6. **Is significant daylighting brought in through windows, skylights or clerestories?** *[Discuss with them as needed what we mean by "significant daylighting" to assure that it is a daylit building.]*
   - ❑ Yes
   - ❑ No

7. **Do you have any other facility that is daylit?**
   - ❑ No *[If yes for Q6, Skip to Q10, building-specific questions]*
   - ❑ No *[If no for Q6, thank them for their time and* ***end call****]*
   - ❑ Yes *[Continue with question 8,to get more contact information.]*

   8. **Are you the same contact for that facility?**
      - ❑ Yes

        *[Get site name and address in Q9. 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 *[Get all information in Q9]*

   9. **What is the facility's name and address?** ***{and other contact information, if needed}***

      Facility Name: ______________________________
      Address: ______________________________
      Contact Name: ______________________________
      Phone: ______________________________
      Position/title: ______________________________

*[If not responsible for any daylit sites, thank them for their time and end call.]*

## Building Specific Questions

10. **Does your company pay the utility bills for this facility?**
    - ❑ Yes *[Skip to Q12]*
    - ❑ No

11. **Who does pay the bills for electricity?** ______________________________

12. **Approximately what is the floor area of your facility?** __________________

**13. A photocontrol system reduces electrical lighting when there is available daylight in the building. Does this building have one of these photocontrol systems?**

- ❑ Yes *[Skip to Q15]*
- ❑ No *[Skip to Q28, Daylighting Questions]*
- ❑ Not sure

**14. Who can we contact to find out?**

Name: ___________________________________________
Phone: ___________________________________________
Position/title: _______________________________________

*[Thank them for their time and end call.]*

*[If no other contact, ask if they can find out. Continue the survey if you are confident that this person is the most knowledgeable person.]*

**15. Approximately what percentage of floor area is on the photocontrol system? __________%**

**16. Does the photocontrol system in your building currently work?** *[Does daylighting reduce the lighting?]*

- ❑ Yes
- ❑ No

**17. How satisfied are you with its operation?**

- ❑ Very satisfied *[Skip to Q19]*
- ❑ Somewhat satisfied *[Skip to Q19]*
- ❑ Neither satisfied or dissatisfied *[Skip to Q19]*
- ❑ Somewhat dissatisfied
- ❑ Very dissatisfied

**18. Please describe what is unsatisfactory about the control system's operation? Are there any particular situations when the control system does not work?**

____________________________________________________________
____________________________________________________________
____________________________________________________________
____________________________________________________________

## On-site Recruitment

Thank you for this information about your facility. In the second phase of this research project, we will be conducting a more thorough survey of facilities with photocontrols to assess their functionality. Based upon your responses you have provided so far, your facility would be a good candidate and would help to establish the energy efficiency benefits of daylighting.

If you agree, the onsite survey will be conducted by building researchers, will be non-intrusive to your operations, and will take between 1 and 3 hours. We will also conduct a short interview to understand the operation of the photocontrol system.

*[If needed tell them…] We will prepare a brief site report that estimates how much energy the photocontrol system is saving.*

**19. Would you be willing to have one of our surveyors visit your facility?**

- ❑ Yes
- ❑ No. If you decide that you are interested in participating, please contact me at (916) 962-7001. *[Skip to Q28]*

**20. We would prefer to have an electrician available to assist us for up to one hour. Do you have an electrician on site who can be present during our survey?**

- ❑ Yes *[Skip to Q22]*
- ❑ No

**21. Can you arrange for an approved electrical contractor/ technician to be available on site to assist us? Our company will pay for their time.**

- ❑ Yes
- ❑ No

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

- ❑ Yes… **What is the best time for our site visit?** *[Confirm that the electrician is available for about 1 hour on site]*

  Date: ______________________________
  Time: ______________________________
- ❑ No…**Who can we contact to get authorization to visit the site?**

  Name: ______________________________
  Phone: ______________________________
  Position/title: ______________________________

**23. Do you have access to the technical specs and/or electrical drawings that describe your photocontrol system?**

- ❑ Yes *[Confirm that they will be on site during the site visit.]*
- ❑ No…**Who can we contact to get access to these drawings/ specs?**

  Name: ______________________________
  Phone: ______________________________
  Position/title: ______________________________

## Photocontrol System Questions *[Ask only for sites we will be surveying]*

We a few questions that will help us understand the operation of the photocontrol system.

**24. What type of lighting system is controlled by the photocontrol system?** *[Multiple responses are okay]*

- ❑ Fluorescent
- ❑ Metal Halide
- ❑ High Pressure Sodium
- ❑ Other, Specify: ____________________

**25. How are the lights controlled?**

- ❑ Dimming
- ❑ On/Off Switching
- ❑ Stepped control *[increasing fraction of lights turn off as more daylight is available]*
- ❑ Other. Specify: ____________________

**26. What is the brand of the photocontrol system?** ____________________

____________________

**27. Where is the daylight photosensor located?**

- ❑ On the roof
- ❑ Under a skylight facing up
- ❑ On the ceiling facing down
- ❑ Facing a window
- ❑ Fixture mounted… **Orientation** ____________________
- ❑ Other: ____________________
- ❑ Don't know: **Could you please find out prior to our visit where the photosensor is located? This will save us a lot of time during the survey**.

***Skip to End*** *[We will collect daylighting questions during the onsite survey.]*

**Daylighting Questions** *[Ask only for sites we will **NOT** be surveying.]*

**28. What type of lighting system is in the daylit space?** *[Multiple responses are okay.]*

- ❑ Fluorescent
- ❑ Metal Halide
- ❑ High Pressure Sodium
- ❑ Other, Specify: ____________________

**29. How are the lights controlled?**

- ❑ Dimming
- ❑ On/Off Switching
- ❑ Stepped control [*an increasing fraction of lights turn off as more daylight is available.]*
- ❑ Other. Specify: ____________________

**30. Do you have a time clock or a manual control to turn off lights when there is sufficient daylight in the space?**

- ❑ Yes
- ❑ No

**31. Please explain how the control system works and how often electric lighting is reduced.** ______________________________

______________________________

______________________________

**32. Please describe the daylighting controlled area:**

a. What is the occupancy of daylit area? ______________________________

b. What is the square footage of daylit area? ______________________________

c. What are the typical hours of operation? ______________________________

d. What hours are the lights typically on? ______________________________

e. What is the daylighting source: *[multiple responses are okay]*

- ❑ Skylights…**How deep is the light well under the skylight?** ________
- ❑ Windows… **How tall are the windows?** ________
- ❑ Other ______________________________

f. What is the ceiling height? ___________

g. Are there high stacks or racks? *[primarily in warehouse, manufacturing or retail]*

- ❑ Yes… **How high are the stacks/racks?** ________
- ❑ No

h. What is the floor type?

- ❑ Concrete
- ❑ Tile
- ❑ Carpet
- ❑ Other ______________________________

i. What is the floor color ______________________________

j. What is the wall color ______________________________

k. What type of space conditioning serves the daylit area?

- ❑ Heating only
- ❑ Heating and air conditioning
- ❑ Evaporative cooling
- ❑ Ventilation only
- ❑ Other ______________________________

l. Do any activities generate duct or smoke inside of the building?

- ❑ Yes
- ❑ No

**End**

**These are all of our questions. Thank you for your time.**

## Responses to Typical Questions:

1) **Who are you?** I work for the Heschong Mahone Group, an energy efficiency-consulting firm. We've been hired by SCE to survey the characteristics of photocontrol systems in non-residential construction. My name is <name> and my phone number is (916) 962-7001 (also provide e-mail and web site if appropriate).

2) **Who can I call at SCE to verify this or ask questions?** Call Jack Melnyk at SCE's offices in Irwindale : (626) 633-7160.

3) **What are you selling?** Nothing. We are conducting a study to analyze the effectiveness of photocontrol systems in non-residential buildings. This research will be used to develop guidelines for the best photocontrol design and installation practices.

4) **Why are you interested in photocontrols?** We have heard varying reports on the extent of their use and energy savings. SCE has asked us to find good examples, and to prepare guidelines to help designers make the systems more effective.

# ONSITE PROTOCOL AND DATA ENTRY FORMS

**HESCHONG MAHONE GROUP**
11626 Fair Oaks Blvd. #302
Fair Oaks CA 95628 (Sacramento area)
Phone (916)962-7001 Fax (916)962-0101 E-mail: info@h-m-g.com

September 20, 2002

# SCE PHOTOCONTROLS BASELINE PROJECT –ONSITE PROTOCOL

To: Jack Melnyk, Gregg Ander

From: Jonathan McHugh, Abhijeet Pande and Douglas Mahone

## *ONSITE PROCEDURES*

There are three main components to the survey on each of the sites visited during this project –

1. Interview to ascertain design intent, use patterns, history of usage and problems if any.

2. Physical inspection –

   a. Record existing daylighting conditions, electrical lighting layout, task layout and surface properties

   b. Record the condition of the photo-controller, photo-sensor and other controls equipment installation and maintenance. Record any problems and probable causes

   c. Record the power consumption of the electrical lighting system under various control conditions.

3. Generate a sky-calc run to determine savings potential.

## *SITE INTERVIEWS*

**1** Whom to interview?

A Initial Contact (pre-screening survey)

B Occupants of the actual space (if different than the initial contact)

C Decision maker (if different than the contact, or the occupants)

**2** What to ascertain?

A Historical information-

i When was the photocontrols system installed?

ii How well is the photocontrols system working?

iii If not working well, when did the problems arise?

iv Are these problems related to other changes made to the building / occupancy

v How are these systems been maintained

vi Do they have any suggestions about good installation, design and maintenance practices?

B Photocontroller information –

i Make and model number of the photosensor

ii Make and model of the controller

iii Is the controller part of a larger EMS system?

iv If so, description of the EMS system and the control logic

v How does the controller 'talk' with the sensor and the lighting system? Are there relay panels and how are they operated?

vi Software controls on the controller?

C Plans and documentation – do they have any of the following available for copying or reference?

i Set of plans showing electrical lighting and control layout

ii Photocell location and control diagram

iii Photocell and controller documentation

D Nature of problems (if any)-

i Describe if the problem is: (select from the list)

- Controls do not maintain appropriate light levels
- Controls do not achieve optimum energy savings
- Controls seem to cause frequent lamp or ballast failure
- Lights switch on/off too frequently
- Controls too difficult/expensive to calibrate or maintain
- Controls irritate occupants
- Occupants disabled for unknown reasons
- Failed for unknown reasons
- Other: Specify ____________________________

ii Source of problems -

- Design problem
- Equipment problem
- User intervention
- Calibration/ commissioning problem
- Other : describe ___________________________

iii Describe the problems – (story)

____________________________________________________________________

_____________________________________________

E Functional requirements – note down the following for each of the spaces

i Tasks

ii Illumination levels desired

iii Desired performance of lights (dimming/ switching levels sought)

iv Which lights to be controlled? And which to be left out?

i Gather *SkyCalc* inputs

ii Determine sensor and control system location

iii Record physical state of the equipment (record with photos) [1]

iv Record response of sensors and controller to light levels

v Measure daylight and electric light levels over the space

vi Determine the circuit layout for luminaries

vii Acquire electrical plans, equipment manuals, and EMS program criterion

**1** Fenestration Issues

A Is the daylighting distribution from the fenestration uniform across the control area?

i Actions:

- record location and numbers of windows/ skylights
- record the type of glazing
- record light distribution patterns without electric lighting (if possible)
- record light distribution patterns with electric lighting
- identify lighting quality problems (glare, dark spots, etc.)

ii Possible causes of failure –

- Use of clear glazing – beam sunlight penetration
- Inadequate diffusion of daylight
- Large variance in light levels across the control area
- glare potential

B What are design lighting conditions?

i Action –

- Interview site contact for desired light level criteria and satisfaction with current light levels (data available from 'user dissatisfaction' issues above)
- Record equipment types
- Measure existing light levels
- Measure daylight levels with/without electric light
- Record electric light levels

ii Possible causes for failure

- Insufficient daylighting due to skylight sizing/ obstructions to skylight.
- Electric lighting levels too high for the task, resulting in excessive lighting
- Dark surface colors or low reflections resulting in lesser diffusion of light

[1] Confirm the owners agreement before taking photographs.

**2** Hardware Issues

B Where is the photocontroller? Is it operational?

i Actions –

- Record exact location of controller and ease of access to the controller.
- Record type of photocontroller, relay/control panel setup, number of control inputs, etc.
- Calculate wattage controlled and maximum wattage reduction
- Record schedule and other parameters needed to run *SkyCalc*
- Observe display panel for signs of operation
- Confirm that input & output wiring is intact

ii Possible causes of failure –

- No power provided to unit
- Unit turned off
- Unit has failed
- Wiring has been damaged or removed

C Where are the photosensors? Are they operational?

i Actions –

- Count number of control zones, assess their condition, describe control strategy (open loop, closed loop) and what sensors see
- Take meter readings of photosensor control signal at the photocontrol unit

ii Possible causes of failure –

- Photosensors have been removed or damaged
- Photosensors are redirected, blocked or otherwise disabled
- Signal wire from photosensor to controller is damaged or missing

D What are the calibration settings for the controller?

i Actions –

- Record settings on controller
- Attempt to determine if the settings have been changed after installation
- Observe controller response to changes in photosensor readings
- Check inputs from each photosensor
- Determine if controller maintains desired lighting conditions

ii Possible causes of failure –

- Initial calibration was wrong, or subsequent changes made were wrong
- Loss of calibration due to sensor or controller wear and tear
- Calibration out of sync with changed usage patterns.

E How is the controller integrated into other energy management systems?

i Actions –

- Record the various control panel's make and model number
- Identify the control sequence and determine how the panels 'talk' to each other
- Determine if any of the panels was replaced/added after the initial installation and calibration

ii Possible causes of failure-

- Incompatible hardware added after the initial installation
- Hardware malfunction on one of the panels
- Incorrectly configured panels
- Lack of in-house expertise on changing the control settings, leading to disabling of control panels.

**3** User dissatisfaction

A Are the users satisfied with the design light levels?

i Actions –

- Record the user satisfaction on a scale of 1-5, with 5 being very satisfied and 1 very unsatisfied
- Record reasons for dissatisfaction
- Record suggestions for desired levels

ii Possible causes of failure –

- Task requirements changed after installation
- User preferences differ from design intent

B Are the users affected by the changes in light levels due to the photo controls

i Actions –

- Record type of daylighting controls used (stepped, dimming etc)
- Interview site contact about awareness of differing light levels
- Record on a scale of 1-5 level of satisfaction over the consistency of lighting levels with 5 being most consistent and 1 being most in-consistent
- Record suggestions about light levels

ii Possible causes of failure-

- Cycling due to improper thresholds or inadequate time delays
- Sudden changes in light levels due to inappropriate settings on stepped controls
- Improper equipment selection

C Are the users happy about turning off electric lighting

i Action –

- Record on a scale of 1-5 level of satisfaction over the ability to switch off electric lighting with 5 being most satisfied and 1 being most unsatisfied
- Record user preferences on minimum lighting levels using electric lighting

ii Possible causes of failure

- User preferences for keeping lights on despite the need for electric lights
- Business compulsions (e.g. stores)
- Lack of user knowledge about daylight controls

F Is the equipment being maintained properly?

i Actions –

- Record physical state of the hardware
- Interview site contact for maintenance schedules

ii Possible causes of failure –

- Dust accumulation
- Equipment aging
- Physical damage

## SKYCALPHOTO INPUTS

The approximately 30 questions below are most easily answered by filling out the input tab in SkyCalPhoto spreadsheet. If this is done on site one can quickly gain the site contact's interest as controls savings at the sites that have been filtered for inclusion into the program are likely to be large.

- Building occupancy

For rooms containing skylights gather the following information:

- Dimensions: height, floor area
- Colors of walls, roof, floors
- Lighting source: fluorescent, metal halide, high pressure sodium
- Fixture type: high bay, low bay, industrial strip, downlight, indirect
- Fixture mounting height
- Lighting control: on/off, 1/2 off, 2 level plus off, 3 level plus off, dimming
- Design footcandles
- Fixture count and wattage
- Lighting schedules: weekday and weekend hours
- Shelving or rack height and width
- Aisle width
- Number of skylights
- Skylight dimensions
- Skylight glazing: single vs double and glazing color
- Light well height and color
- Safety grate or insect screen Y/N
- Space heated?
- Heating system: gas furnace, heat pump, etc.
- Space cooled?

**Customer Name: *«Customer»***

Project Name: «Project»

Project Address: «Address» «City_» «Zip»

**Onsite Contact Name: «Contact»** **Title: «Title»**

**Phone Number: «Phone»** **Email: «Email»**

*Surveyor Notes:*

***Photolog:*** *(to be recorded onsite)*

Camera: ________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

Frame#____________ description _______________________________________________________________

1. When was the Photocontrols system installed?

2. Was the Photocontrols system a retrofit? What else was added/changed during the process of installing the photocontrols system?

3. What was the main reason(s) for installing the photocontrols system?

4. "Who (position or title) recommended that photocontrols be installed?" *(Architect, electrical engineer, owner, facilities manager, energy manager, utility etc.)*

5. Did you receive any design assistance or incentives to install the photocontrols system? If so, could you give a brief description of the nature of assistance received?

6. How is the photocontrols system currently working? Is it performing as per your original ideas?

***<u>If there are problems with photocontrols systems, ask the following, else skip to Q9</u>***

7. When did these problems first occur?

8. Was the problem in the photocontrols system operation due to any changes made to the building or the lighting system? If so, please describe the changes.

9. Briefly describe the nature of the problem with the photocontrols system? <u>Open ended</u>
   - ❑ Controls do not maintain appropriate light levels
   - ❑ Controls do not achieve optimum energy savings
   - ❑ Controls seem to cause frequent lamp or ballast failure
   - ❑ Lights switch on/off too frequently
   - ❑ Controls too difficult/expensive to calibrate or maintain
   - ❑ Controls irritate occupants
   - ❑ Occupants disabled the controls for unknown reasons
   - ❑ Failed for unknown reasons
   - ❑ Other: describe_______________________________________________

Expand:

***Photocontrols systems maintenance questions***

10. What regular maintenance are you performing on the photocontrols system (*if any*)?

11. Do you have access to the photocontrols manufacturers technical assistance or product support?
    - ❑ Yes
    - ❑ No

12. Do you have easy access to any other lighting maintenance and service personnel for the photocontrol system?
    - ❑ Yes
    - ❑ No

13. Do you have any recommendations on the *design / installation procedures* for the photocontrols system?

14. Do you have any recommendations on the *maintenance procedures* for the photocontrols system?

***If system is not working at all -*** *Possible recommissioning of photocontrols system:*

15. Do you have any plans for recommissioning your photocontrols system? If so, please describe in brief:

16. If you would need any assistance in the recommissioning process, what would be the nature of that assistance and from whom?

*Overall comments / suggestions*

***Space 1:*** ______________________________

- ❑ Occupancy Type: ______________________________
- ❑ Tasks performed:
  1: ______________________________ Illumination level desired: ______ *foot-candles*
  2: ______________________________ Illumination level desired: ______ *foot-candles*
  3: ______________________________ Illumination level desired: ______ *foot-candles*

***Space 2:*** ______________________________

- ❑ Occupancy Type: ______________________________
- ❑ Tasks performed:
  1: ______________________________ Illumination level desired: ______ *foot-candles*
  2: ______________________________ Illumination level desired: ______ *foot-candles*
  3: ______________________________ Illumination level desired: ______ *foot-candles*

***Space 3:*** ______________________________

- ❑ Occupancy Type: ______________________________
- ❑ Tasks performed:
  1: ______________________________ Illumination level desired: ______ *foot-candles*
  2: ______________________________ Illumination level desired: ______ *foot-candles*
  3: ______________________________ Illumination level desired: ______ *foot-candles*

***Space 4:*** ______________________________

- ❑ Occupancy Type: ______________________________
- ❑ Tasks performed:
  1: ______________________________ Illumination level desired: ______ *foot-candles*
  2: ______________________________ Illumination level desired: ______ *foot-candles*
  3: ______________________________ Illumination level desired: ______ *foot-candles*

***Space 5:*** ______________________________

- ❑ Occupancy Type: ______________________________
- ❑ Tasks performed:
  1: ______________________________ Illumination level desired: ______ *foot-candles*
  2: ______________________________ Illumination level desired: ______ *foot-candles*
  3: ______________________________ Illumination level desired: ______ *foot-candles*

***Space 6:*** ______________________________

- ❑ Occupancy Type: ______________________________
- ❑ Tasks performed:
  1: ______________________________ Illumination level desired: ______ *foot-candles*
  2: ______________________________ Illumination level desired: ______ *foot-candles*
  3: ______________________________ Illumination level desired: ______ *foot-candles*

**0207- SCE Photocontrols project** **Project ID# ________** **Surveyor ______________**

**Light Level Readings** **Survey Date____________**

**Space:** ______________________________________________________________

| ***reading #*** | ***location*** | ***lighting level*** | ***Light readings (foot candles)*** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | ***UP*** | ***DOWN*** | ***Vert 1*** | ***Vert 2*** | ***Vert 3*** | ***Vert 4*** | ***task*** |
| | Brightest | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | *Comments:* | | | | | | | |
| | Average | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | *Comments:* | | | | | | | |
| | Dimmest | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | *Comments:* | | | | | | | |
| | Photocell | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | *Comments:* | | | | | | | |
| | Task 1 | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | *Comments:* | | | | | | | |
| | Task 2 | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | *Comments:* | | | | | | | |
| | Task 3 | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | *Comments:* | | | | | | | |
| | Task 4 | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | *Comments:* | | | | | | | |

## Photo Sensor Information

Survey Date____________

| Photosensor # | 1 | 2 | 3 |
|---|---|---|---|
| **Manufacturer** | | | |
| **Model #** | | | |
| **Controlled Zones/Spaces** | | | |
| Attached to **control panel #** | | | |
| **Control Strategy**<br>*1 = open loop*<br>*2 = closed loop* | | | |
| **Location**<br>*1 = On the roof*<br>*2 = Under a skylight facing up*<br>*3 = On the ceiling facing down*<br>*4 = Facing a window*<br>*5 = Fixture mounted*<br>*6 = Other (specify)* | | | |
| **Orientation /View**<br>*1 = Sky*<br>*2 = Skylight*<br>*3 = Ceiling*<br>*4 = Side wall*<br>*5 = Floor*<br>*6 = Fixture*<br>*7 = Other (specify)* | | | |
| **Photo sensor shielded/masked?** | | | |
| **Operational?** *(Y/N)* | | | |
| **Physical Damage?**<br>*1 = none*<br>*2 = lens broken*<br>*3 = casing broken*<br>*4 = wiring exposed/damaged*<br>*5 = wiring disconnected*<br>*6 = wiring short-circuited*<br>*7 = other (describe)* | | | |
| **Visible Tampering?**<br>*1 = none*<br>*2 = lens taped over*<br>*3 = control wiring tampered*<br>*4 = sensor re-oriented*<br>*5 = other (describe)* | | | |
| **Lens clean?**<br>*1 = Clean*<br>*2 = Dirt deposition*<br>*3 = Smoke deposition*<br>*4 = Lens discoloration*<br>*5 = Other (Describe)* | | | |
| **Notes** *(if any)* | | | |

## Lighting Control Panel Information

Survey Date____________

| Lighting Control Panel # | 1 | 2 | 3 |
|---|---|---|---|
| **Manufacturer** | | | |
| **Model #** | | | |
| **Control Zone/Space** | | | |
| **Panel Type**<br>*1 = master controller*<br>*2 = Slave or secondary controller*<br>*3 = Relay Panel*<br>*4 = Other (specify)* | | | |
| Attached to **photo sensor #** | | | |
| **Location** | | | |
| **Remote access to the control panel?**<br>*If software access, note software name and version #* | | | |
| **Part of an EMS System?** *(Y/N)* | | | |
| **EMS System Manufacturer** | | | |
| *Describe how control panel fits into the EMS system* | | | |
| **Recent changes to control panel?** *(Describe if Yes)* | | | |
| **Operational?** *(Y/N)* | | | |
| **Does anyone know how to operate / maintain the control panels on-site?**<br>*If yes, note Name, Title and Phone number of the person* | | | |
| **Logger #***(s)* **installed** | | | |
| **Time installed** | | | |
| **Location of loggers** | | | |
| **Current reading (amps)** | | | |
| **Fedex Tracking #** | | | |
| **Notes:** | | | |

**Space # ___: ______________________________**

- *Occupancy:* ______________________________________________
- *Dimensions: Floor area:* ___________ sq. ft ***Ceiling Height:*** ________feet.
- *Surface Colors:*
  - ❑ Walls ______________________________________________
  - ❑ Roof/Ceiling ______________________________________________
  - ❑ Floor ______________________________________________
- *Lighting source:*
  - ❑ Fluorescent ______________________________________________
  - ❑ Metal Halide ______________________________________________
  - ❑ High pressure sodium ______________________________________
  - ❑ Other: ______________________________________________
- *Fixture type:*

  ❑ High bay ❑ Low bay ❑ Industrial strip ❑ Downlight ❑ Indirect
- *Fixture mounting height:* ________________________________ feet.
- *Lighting control:*

  ❑ on/off ❑ 1/2 off ❑ 2 level plus off ❑ 3 level plus off ❑ dimming
- *Design foot-candles:* ________________
- *Fixture count:* ______________ ***Wattage:*** ________________watts.
- *Lighting schedules:*
  - ❑ Weekday hours: ______________________________________
  - ❑ Weekend hours: ______________________________________
- *Shelving or rack height:* ________________feet ***Width*** ________________ feet
- *Aisle width:* ________________ feet
- *Number of skylights:* ________________
- *Skylight dimensions: Length*________________ feet ***Width***________________ feet
- *Skylight glazing type:* ❑ single glazed ❑ double glazed
- *Skylight glazing color:* ________________________________
- *Light well height:* ________________ feet ***Color*** ________________________________
- *Safety grate or insect screen Y/N:* ________________
- *Space heated? : (Y/N)* ________________
- *Heating system: (gas furnace, heat pump, etc.)* ________________________________
- *Space cooled? :* (Y/N) ________________
- Cooling System: (packaged rooftop, DX coils etc.) ________________________________

# PHOTOCONTROL GUIDELINES

# Photocontrol Systems

## *Design Guidelines*

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# 1. INTRODUCTION

This Guideline has been developed to assist in the design and deployment of photocontrol systems in skylit buildings. These are lighting control systems that reduce electric lighting in response to daylight from skylights. For many commercial buildings, where there are large, relatively open areas under a flat roof, this type of system can be used effectively to provide high quality lighting and cost-effective energy savings.

While the combination of skylights and photocontrols is relatively straightforward, field research has shown that these systems do not always function as effectively as desired. In some cases, the systems do not work to the occupants' satisfaction, and so the photocontrols are simply disabled and the lights are left on all the time resulting in lower energy savings, or the photocontrol system is disabled and the lights are left off most of the time often at the expense of lighting quality in the space. In other cases, the lighting provided by the skylighting system is inadequate. In still other cases, the photocontrols are not installed or calibrated properly, and so the savings are suboptimal.

However, over 2/3's of the systems we surveyed were operating well and overall the systems (in conjunction with manual switching) were saving 97% of the predicted amount of energy. This is in marked contrast to anecdotal reports of high failure rates for photocontrols used in conjunction with sidelighting; that is daylighting through windows. The difference between toplighting and sidelighting is that with diffusing skylights used for toplighting, only the magnitude of daylight changes whereas with clear windows used for sidelighting, the magnitude and the distribution of daylight changes depending upon sky conditions, sun angle, presence of snow or cars near windows etc. Thus the low success rate of photocontrols used with sidelighting through windows should not scare off designers from using photocontrols with diffusing skylights which have been proven to be successful.

The performance of a skylighting/photocontrol system is based upon a wide variety of factors including:

- Skylight spacing
- Skylight size
- Glazing type
- Light well geometry
- Light well reflectance
- Room geometry
- Surface reflectance
- Location of partitions or shelving
- Luminaire type
- Lamp/ballast type
- Circuiting
- Photocontrol type
- Sensor placement

Thus the design of successful toplighting systems is a multi-disciplinary effort that requires coordination between the architect, the lighting system designer, the photocontrol manufacturer, the interior designer, the space planner and the system installer. And to have sustained performance the maintenance personnel must be able to adjust the system to adapt to changes in space use or finishes.

A successful photocontrol system depends on the integration of many building design elements and operations. This Guideline offers advice to all the members of the design/construction team on how to contribute to the success of the system, and how to avoid mistakes that will prevent the building owner from reaping the full benefits of the system. We start at the most basic level – making sure that the building has adequate daylighting – and get progressively more detailed down to the level of guidance on how to calibrate the photocontrols. This final, and crucial, step is intended to complement the photocontrol installation instructions provided by the equipment manufacturer.

This Guideline is organized by trade or discipline, starting with the building designer and ending with the building operator. The priorities, in terms of actions for each discipline is–

1. Do no harm– i.e. don't do anything to the system that will interfere with the satisfaction or productivity of the building occupants.
2. Provide the basic functions such as lights turn off when sufficient daylight is available, override switches provide occupant control during short duration specialized tasks, time clocks turn off lights after hours.
3. Optimize the performance of the system for maximum occupant satisfaction and maximum energy savings. This is fine-tuning the system in response to occupant complaints or requests.

# 2. BUILDING DESIGNERS GUIDELINE

The building designer is the focal member of the design team and it is the building designers' responsibility to coordinate different aspects of the building systems and envelope design. To this end it is the building designer's responsibility to create a program that allows successful integration of the lighting and daylighting systems with the envelope design. Following are key considerations for designing an effective skylit building. This is a much larger topic than the design aspects we mention here, however. For a more complete discussion, please refer to the Skylighting Design Guidelines published through the Energy Design Resources (EDR) website. Also refer to the SkyCalc™ skylighting tool on the EDR website for information on estimating savings from skylighting.[1]

## 2.1 Skylight-to-Floor Area Ratio (SFR)

The SFR is defined as the ratio of gross skylight opening area to daylit floor area. The gross skylight opening area is determined by the amount of daylight needed in the space along with the energy tradeoffs on heating and cooling loads in the space. The general rule of thumb for large open spaces (such as warehouses, retail buildings, industrial work floors) is to have the gross skylight opening area within 3-6% of the daylit floor area. A good skylight design will provide adequate daylight in the space with the smallest skylight opening area in a cost effective manner. Excessive skylight area can lead to overheating and glare problems.

## 2.2 Skylight layout and spacing

While the SFR is a predictor of the total daylight entering the space, effective daylight distribution throughout the space depends on a good layout and sizing of the skylights. For special skylight applications such as lobbies and display areas, the skylight layout will be dictated by the design considerations of the space. For large open spaces (the main focus of this Guideline), the main concern is to provide uniform lighting throughout the space. Using the same SFR, the designer can choose either large sized skylights spaced wide apart or smaller skylights spaced closer. The former is easiest to install, but produces areas of brightness under the skylights with relatively dark spaces in between. The later produces more uniform daylighting and more energy savings, but costs more to install.

A general rule of thumb is to set the center-to-center spacing of the skylights at 1.0 to 1.5 times floor-to-ceiling height in a typical open space configuration with a

[1] Energy Design Resources website <http://www.energydesignresources.com>. Skylighting Design Guidelines under the publications tab, SkyCalc™ under the software tab. Website content and layout may be updated without notice.

flat roof (Figure 1). The spacing and the size of the typical skylight, therefore, increase with higher ceiling heights.

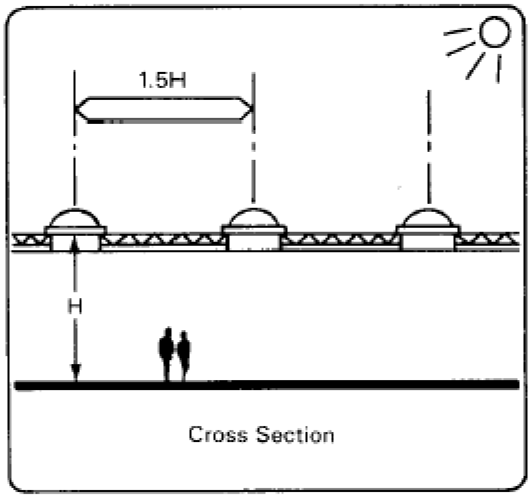



*Figure 1: Skylighting spacing rule of thumb*

For large open spaces with multiple skylights, the spacing of skylights should be coordinated with the structural support system to ensure that none of the structural members obstruct the skylight. A good layout will have the skylight curbs integrated in the structural system. In order to achieve good daylight distribution in the space, it is often essential to 'splay' the skylight well, and thus integrating the skylight well and the splay in the ceiling layout become critical to performance.

## 2.3 Skylight glazing type

Glazing is one of the most important factors in good skylight design. There are many alternatives and choices to consider, and careful selection is important to a successful design. The optical properties of the glazing materials influence daylighting quality and lighting savings. The two major types of skylight glazing are: transparent and translucent. Either of the two types can be: colorless, tinted or reflective. Furthermore, nearly any glazing can be mounted in single, double or even triple layers for greater thermal resistance.

For open spaces such as warehouses where uniform daylighting distribution is required, translucent glazing materials, frosty white in appearance are the best choice. These skylights diffuse the skylight and distribute it evenly over their coverage area even under direct sun conditions, and therefore do not require as much supplementary control from shades or other objects. If clear glazing is selected, then the light must be diffused by some other means within the space to prevent glare and spread the light more evenly through the space.

Another important glazing characteristic is overall light transmittance. As long as it is highly diffusing, the glazing should also have the highest practical transmittance, to admit the most light through the smallest opening.

Apart from the light transmitting properties, the skylight glazing also has thermal transmittance properties that affect the heat loss or gain through the skylight to the space below, and hence the heating and cooling loads on a space.

There are two properties that are important in determining the thermal performance of the skylight glazing: the relative proportion of the sun's radiant heat that is blocked by the glazing material, measured by solar heat gain coefficient (SHGC), and the overall conductivity of the skylight unit for all types of heat flow, measured by U-factor.

The skylights should help in reducing heat loss from the space in cold weather by using lower U-factor, and reduce heat gains in sunny, hot weather by using lower SHGC. This is especially true for more extreme climates. The trade-off is that the features that reduce U-factor and SHGC, such as dual or triple glazing, often tend to reduce light transmittance. In most jurisdictions, energy codes require that skylights over conditioned spaces at least be double-glazed.

## 2.4 Coordination with the interior layout

A good skylight layout is aligned with the interior layout. Locating skylights between tall wide stacks in warehouses prevents the light from being blocked by the stacks. Often, the interior layout in a space is not known at the time of design of the space. In such cases, the skylights should be laid out on a standard grid in order to ensure that there is uniform distribution of light in the space. For special conditions such as lobbies and display areas however, the skylighting design is a function of the aesthetic requirements, and hence the layout may be customized to generate the right 'moods' in the space.

## 2.5 Coordination with electric lighting system

The building designer needs to coordinate with the lighting system designer to ensure optimal lighting coverage in the space (for more information see section 3). If designed correctly, the electric lighting layout complements the daylighting from skylights by covering areas between skylights that might not receive adequate light. At the same time the electric light layout should be able to provide adequate lighting throughout the space during night and when the daylight is not adequate. Coordinating the daylighting and electric lighting also makes controlling the electric lighting systems more effective.

## 2.6 Coordination with photocontrol system

The photocontrol system marries the skylights with the electrical lighting system and enhances the ability to conserve energy. To achieve optimal savings it is essential to devise a control scheme that switches or dims light fixtures in a timely fashion while maintaining uniform illuminance throughout the space. The control system should be designed such that it dims or switches light fixtures in areas with adequate daylight, while keeping the light fixtures in areas without daylight at the design output. This will ensure that there is adequate light throughout the space, and reduces the risk of over-rides to the control sequence. See section 4 for more information on this important coordination issue.

## 2.7 Consideration of user and building operator needs

The best of the designer's intent can be laid to waste if the design does not satisfy the user's needs. One of the major reasons the users complain about the photocontrol system often, resulting in the building operators overriding the photocontrol system is that the system does not maintain adequate light levels in the space or that it does not control the lights when the users need them to be controlled.

In order to keep the users happy about their photocontrol system, they need to have a feeling of control over their lighting conditions. One way of ensuring this is to make the daylighting and photocontrol layout user friendly and capable of adapting to changes in the space configuration. The easier it is for the building operators to change the control settings, the longer the control system will be operational at peak performance potential. It is important to locate the control system in an easily accessible location within the space controlled.

## 2.8 Reference: Skylighting guidelines – energy design resources

The Skylighting Design Guidelines available on the Energy Design Resources (EDR) website are excellent reference material for architects and engineers for using skylights to maximum advantage in commercial and industrial buildings. These guidelines:

- Describe opportunities for energy savings and good lighting design
- Explain how to integrate skylights with other building elements
- Show how to estimate energy and dollar savings
- Help designers avoid costly mistakes

The guidelines can be viewed online and downloaded from the following URL:

<http://www.energydesignresources.com/resource/140/>

## 2.9 Reference: SkyCalc analysis tool

SkyCalc™ Skylighting Tool for California: This Microsoft Excel™ spreadsheet application helps building designers determine the optimum skylighting strategy that will achieve maximum lighting and HVAC energy savings for a building.

SkyCalc operates at three levels of detail:

- The first level requires little information from the user; instead relying on extensive defaults to describe the user's skylighting system and building operation.
- The second level allows the user to modify any default in order to describe the situation more precisely.
- The third level allows the user to enter detailed information about products and schedules (such as performance data for specific products or detailed building operation information).

SkyCalc also can take into account a variety of climate conditions in California. The user selects a particular climate zone, and SkyCalc calculates the energy impacts from skylights on an hourly basis throughout the year. (See Figure 2.)

Effective Aperture = 2.50%, Skylight to Floor Ratio (SFR) = 5.00%

**Average daylight foot-candles**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 19 | 32 | 42 | 45 | 39 | 27 | 14 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 14 | 29 | 47 | 55 | 57 | 55 | 45 | 27 | 11 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mar | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 9 | 25 | 42 | 57 | 66 | 70 | 67 | 59 | 41 | 20 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Apr | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 20 | 45 | 65 | 79 | 88 | 90 | 84 | 70 | 55 | 29 | 11 | 3 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 3 | 12 | 33 | 56 | 75 | 89 | 98 | 99 | 93 | 85 | 63 | 39 | 17 | 5 | 0 | 0 | 0 | 0 | 0 |
| Jun | 0 | 0 | 0 | 0 | 0 | 4 | 14 | 32 | 55 | 75 | 93 | 103 | 107 | 102 | 89 | 71 | 46 | 22 | 8 | 0 | 0 | 0 | 0 | 0 |
| Jul | 0 | 0 | 0 | 0 | 0 | 3 | 11 | 31 | 57 | 81 | 98 | 110 | 113 | 108 | 95 | 75 | 50 | 23 | 9 | 1 | 0 | 0 | 0 | 0 |
| Aug | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 22 | 46 | 68 | 90 | 101 | 105 | 101 | 85 | 64 | 39 | 16 | 5 | 0 | 0 | 0 | 0 | 0 |
| Sep | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 17 | 41 | 64 | 84 | 93 | 96 | 88 | 72 | 50 | 23 | 8 | 1 | 0 | 0 | 0 | 0 | 0 |
| Oct | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 10 | 29 | 46 | 64 | 69 | 71 | 63 | 47 | 26 | 10 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 15 | 29 | 42 | 48 | 48 | 42 | 26 | 12 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 18 | 29 | 40 | 39 | 33 | 22 | 11 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Design Illuminance = 50 fc

< 5 fc; < 25 fc; < 50 fc; > 50 fc;

*Figure 2: SkyCalc™ daylight illumination chart*

This sample SkyCalc daylight illumination chart illustrates average hourly room illumination (in foot candles) that would result from a given skylighting design for a particular climate.

SkyCalc also includes an optimization feature that helps designers identify where the energy performance of a particular design falls among a range of possible designs. (See Figure 3.)

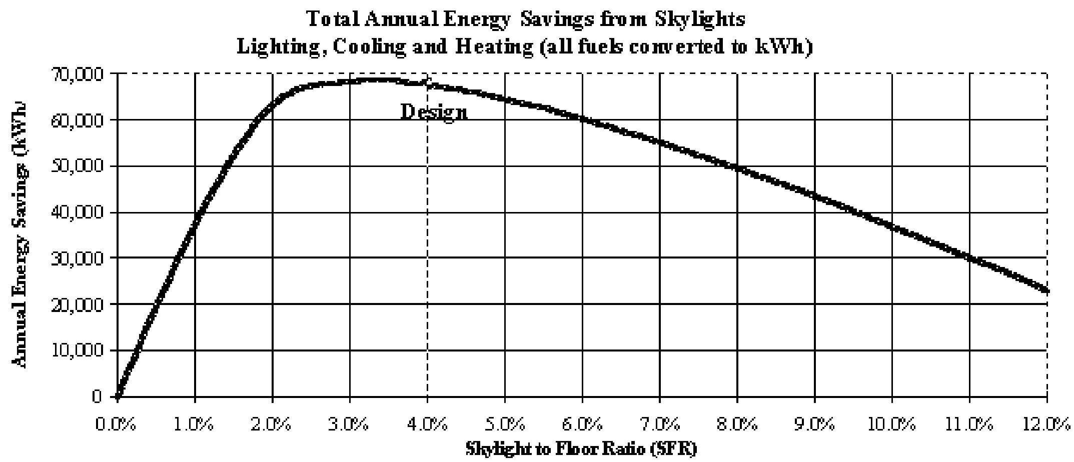



*Figure 3: SkyCalc™ optimization curve*

The above graph is a SkyCalc optimization curve generated for a grocery store located in Bakersfield. The store is equipped with dimming controls on the electric lighting system and has daylighting through single-glazed, white acrylic skylights that cover five percent of its gross roof area. This graph indicates that although this particular design will save significant energy at the designed 4% SFR, the skylight area is not optimized to achieve maximum energy savings, and that reducing the skylight area slightly would actually benefit the overall energy savings in this particular case.

All SkyCalc reports can be printed easily. In addition, the user can adjust the basic spreadsheet and save new Excel templates for different building projects and/or climate zones. Since the program is installed as an Excel template, new copies can be saved for different building projects and/or climate zones.

SkyCalc can be used in conjunction with the Skylighting Guidelines (refer Section 2.8) to help designers select the best skylighting system for a given building.

SkyCalc™ can be downloaded free of charge from the Energy Design resources website at the following URL:

< http://www.energydesignresources.com/resource/129/>

A version of SkyCalc that has weather files for cities outside of California can be downloaded from: [www.h-m-g.com](http://www.h-m-g.com).

# 3. LIGHTING SYSTEM DESIGNERS GUIDELINE

The lighting system designer is responsible for balancing the user's need for illumination with the appropriate lighting system. The lighting designer must work in coordination with the building designer and the building controls designer to incorporate daylighting into the lighting design.

The lighting system designer is responsible for selecting the lamp/ballast type, layout of the lamps in the space, circuiting the layout to achieve the objectives of the control system (see following section on controls design), and daylight integration.

## 3.1 Choice of lamp/ballast type

The lighting designer must, of course, consider all of the usual aspects of lighting system design and selection to meet the needs of the space and its occupants. Selecting the lamp color temperature is an important criterion when using a combination of daylighting and electric lighting in a space. Using warm color temperatures (below 3500 K) tend to make lamps look more pink or orange as compared to daylight, while selecting cool color temperatures (above 4100 K) makes the lamps look bluer than daylight.

Selecting the right type of ballast and lamp combination is also critical to effective operations of the photo control system, which will be automatically controlling the electric lighting system in response to available daylight, for the purpose of saving energy. Fluorescent lighting is more compatible with lighting controls than HID (high intensity discharge) lighting. Fluorescent fixtures can be easily switched or dimmed and respond almost instantaneously to control signals. HID lamps require 5 to15 minutes to cool down before they can be turned on again (re-strike time) and therefore are not as well suited for On-OFF type controls. The choice of lamp/ballast type, therefore, must be coordinated with the design of the photocontrol system. Additional considerations:

### 3.1.1 High Intensity Discharge (HID) Lamps/Ballasts:

These include metal halide and high-pressure sodium sources, which are frequently used for large, high bay spaces. In addition to problems associated with re-strike time, HID lamp life is more affected by cycling lamps on and off than is fluorescent. To mitigate the problems associated with HID lamp life and re-strike times, high/low switching is occasionally used as a method of reducing energy consumption. High/low switching drops light output to 20% to 50% instead of turning lamps off; this eliminates the re-strike problem and reduces lamp life concerns. However at 20% light output, the lamp/ballast consumes 50% of the rated power consumption. Another alternative is to have on/off control of lamps but to leave some fraction of the lamps on. In general, well-designed switching controls will save more energy than high/low switching.

To minimize the re-strike and cycling problems for HID switching controls often the time delay is set longer than what is used for fluorescent lighting systems. Some lighting controls also include an astronomical time clock that estimates the time the lights are off so that if the photosensor calls for turning the lights off but there is only a little more time in the day that the lights would be off, the control keeps the lights on at the end of the day instead of allowing them to be turned off for only a few more minutes.

If the design of the lighting system is still under consideration, fluorescent lighting should be considered as an alternative to HID lighting. In general fluorescent lighting has a greater maintained efficacy than HID lighting ad as described above, is easier to control. "Aisle-lighter" fixtures with T-5 high output lamps are an energy efficient alternative to high bay fixtures. Since the fluorescent fixtures typically have multiple lamps per fixture, even reduction of light output can be easily accomplished by switching off alternate lamps or by dimming lamps.

### 3.1.2 Fluorescent Lamps/Ballasts:

Fluorescent lamps can be easily dimmed or switched, and do not have the long re-strike times of HID lamps, making them easier to use along with photocontrols. In many large open spaces, T8 or T5 fluorescent lamps can replace HID lamps. The advantages are instant response to control signal, longer lamp life and lower energy consumption when controlled well. Unlike HID lamps, light output of fluorescent lamps is almost proportional to their energy consumption, and they can easily dim or switch to the OFF state.

Multi-step switching strategies work well with fluorescents, as many fixture types include two or more lamps. As long as the circuiting is done correctly, it is relatively easy to switch off lamps in the fixtures one at a time in order to achieve multiple levels of control. Fluorescent dimming is becoming more common but dimming ballasts are still relatively expensive. Special dimming ballasts are required to implement a dimming control strategy.

## 3.2 Layout of lighting fixtures

The lighting system designer needs to coordinate with the building designer to ensure optimal lighting coverage in the space. If designed correctly, the electric lighting layout complements the daylighting from skylights by covering areas between skylights that might not receive adequate light. At the same time the electric light layout should be able to provide adequate lighting throughout the space during night and when the daylight is not adequate.

Equally important is the layout of the lighting system in relation to the tasks and furniture in the space. The lighting system designer needs to coordinate with the building designer to ensure that none of the light fixtures are partially or completely obstructed by high partitions, stacks or machinery. The lighting grid should be coordinated with the structural grid and with the furniture layout grid to allow for rearrangement of the space.

## 3.3 Circuiting of lighting for controls

To achieve the desired control of light fixtures it is critical that the lighting system is circuited per the control designers' specifications. Often the control strategy is defeated by the inability of the circuiting to provide the needed level of control. Following are a few suggestions for achieving good control through circuiting –

- Circuiting must match daylight availability and task lighting requirements
  - Circuiting should be segregated by task illuminance requirements.
  - Areas close to skylights circuited separately from areas further away from skylights
  - Lighting over spaces with different geometries (such as open areas versus stacks) should be separately circuited.
- Specify a detailed circuiting layout to the installers, and confirm the execution of the layout. Keep it simple but ensure desired performance.
  - Do not accept the wiring of the lighting system until each circuit of lights has been switched on and off to show that the circuiting is installed as designed. This is very expensive to fix after the acceptance date has expired.
- The shortest and easiest route for wiring fixtures is often not the best option for good control, and the installer must be aware that the circuiting layout must be as specified.
- In large spaces, subdivide the space into different sectors and circuit each sector independently to ensure flexibility in operation.
- Generally the more circuits per layout, the greater the control options. However, a circuiting done without attention to the architectural elements and interior layout is ineffective.

# 4. LIGHTING CONTROLS DESIGNER GUIDELINE

The lighting controls designer is the specialist dealing with the selection, calibration and commissioning of the photocontrol system. In some cases the lighting system designer may also be the lighting controls designer. The lighting control designer needs to work in close coordination with the lighting system designer and the building designer in devising a control strategy that both satisfies the performance needs and achieves desired savings without causing discomfort to the users.

## 4.1 Consideration for the user and building operator needs

Above all the other factors the control scheme needs to be sensitive to the user needs and perceptions. Often the control schemes are over-ridden by the building operators because the users feel there is too much or too little light in their space and complain about it. In some cases, users become dissatisfied because lights are switching on and off without apparent reason, so satisfaction is also related to training and understanding of the role of the photocontrol system.

The control scheme needs to be easy to use and easy to change with the occupants' needs over time. Most of the control systems are maintained by staff not trained for controls operations, therefore it is important to devise control schemes that are intuitive and easy to learn (or at least well documented and straightforward to maintain).

Some clients have controls experts within their company but not necessarily on-site. These clients typically have multiple sites and are use to controlling a variety of control parameters remotely. The desirability of networked controls should be explored with these clients.

Change is inevitable in the long-term operation of any space, and the control scheme needs to be modified periodically to maintain desired performance. It is essential that building operators be able to easily modify the control scheme.

## 4.2 Selection of control strategy

The primary photocontrol design consideration is related to the placement of the photosensor, and how the control circuitry uses the photosensor signal to modify the light output of the lighting system. There are two main photocontrol strategies from which the controls designer can choose:

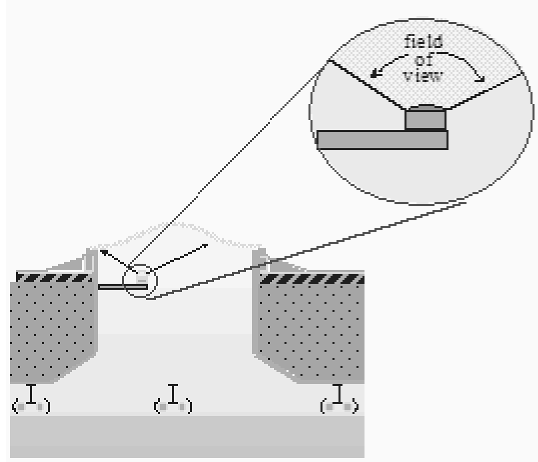


*Figure 4: Open loop photosensor mounting*

- Open loop control – In this control scheme the photosensor accepts inputs from (or "sees") only the external daylight source and adjusts interior light levels based upon a preset control profile. An open loop control for skylighting can be straightforward – the photosensor looks up at the skylight sees only the diffuse light entering through the skylight, which can be the result of both beam sunlight and diffuse light from the sky. An open loop control system assumes that the available daylight in the space is a simple, linear function of the amount of light entering the skylight. This assumption is reasonable for skylighting, although it may not always be so for sidelighting through windows.

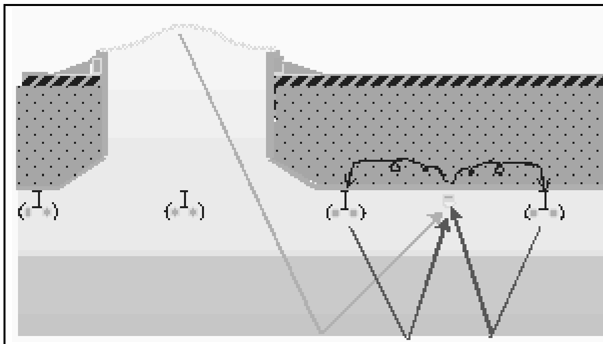


*Figure 5: Closed loop photocontrol*

- Closed loop control – In this control scheme the sensor 'sees' both daylight and electrical light in the space, and adjusts the electrical lights output based on the total illumination from both sources. Typically, the photosensor looks down on a work surface or some other surface that represents the uses in the space. Since the control scheme is dependent on interior lighting conditions, any changes in lighting due to reflections or glare on the sensor, or to changes in the reflectance of the reference surface (such as putting white papers on a dark desktop) can trigger a false response and provide unnecessary control of the lights and excessive cycling.

Selecting the right control strategy depends upon the space type, lighting system type and source of daylight. Skylighting systems lend themselves especially well to open loop controls, as all of the skylights in the space are typically looking up at the same sky conditions, and the delivered daylight down at floor level is usually directly proportional to the amount of light entering at the skylight.

## 4.3 Coordination with lighting system

The viability of the photocontrol strategy is dependent upon the lighting system it is controlling. Whether using an open loop or a closed loop strategy, the controls designer can select any of the following control options

- Stepped switching – The lamps are turned OFF or switched to a minimum light output in a series of discrete steps per the available daylight. Some of the popular options used are – ON/OFF, two levels plus off, ON-1/2, three levels plus off and ON-2/3's-1/3 light output. The On-1/2 and ON-2/3's-1/3 controls leave some fraction of the lights ON at the minimum light control level. This is especially advantageous for retail, where all the lights off give the consumer the incorrect message that they are closed. Controls that leave some of the lights ON are also a benefit for HID lighting systems in that the space is not entirely dark while waiting for the re-strike time to expire. The choice of steps in a switching strategy will determine how the lamps are circuited within and between fixtures.

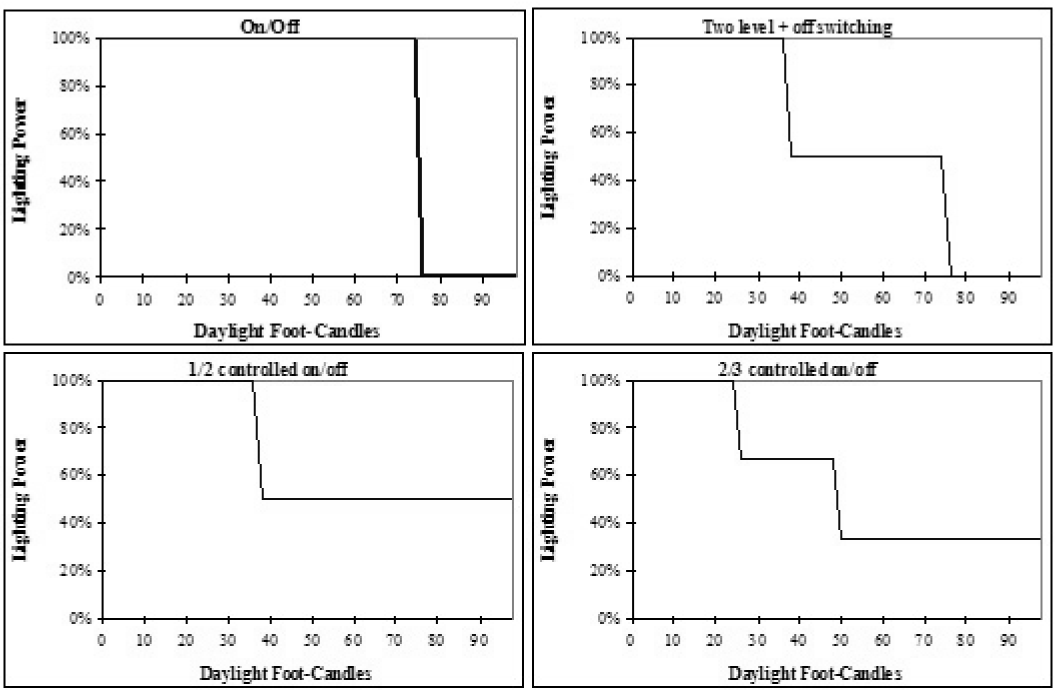
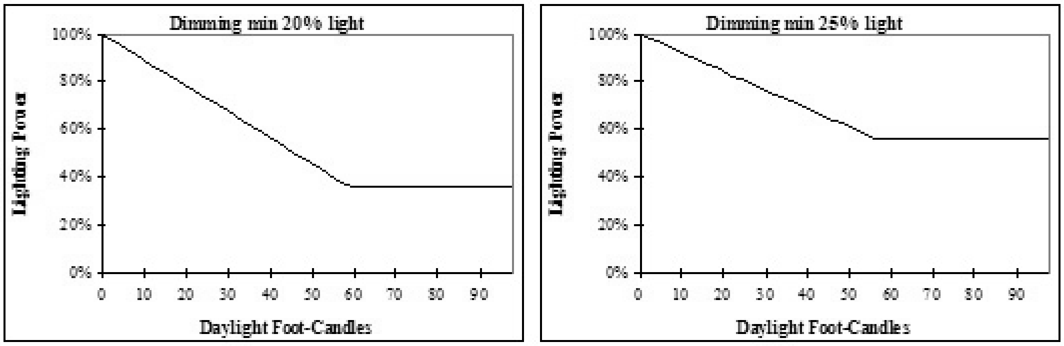



*Figure 6: Switching Control Strategies*

- Continuous Dimming – The light output is gradually dimmed to an OFF state or to a minimum light level based upon the available daylight. Fluorescent lamps respond better to continuous dimming than HID lamps due to their faster response. While HID lamps can be dimmed energy savings are relatively low and color quality is diminished.

  When dimming ballasts are used, the circuiting is continuous for all fixtures in a given control zone, but there is usually separate control wiring. For retrofit applications where a separate control circuit is undesirable, dimming ballasts and controls can use PLC (power line carrier) or triac based controls to send the dimming signal in the current carrying conductors.



a) Fluorescent dimming b) HID dimming

*Figure 7: Dimming control strategies*

## 4.4 Placement of photosensor

The importance of correctly placing and orienting the photosensor cannot be overstated. The control algorithms are governed by the photosensor outputs, which in turn are dependent on what the photosensor 'sees'. Following are recommendations for the placement of photosensor, depending on the control strategy.

- For sky-lit buildings with open loop control it is best to locate the photosensor directly underneath a representative skylight facing up towards the skylight well. If some of the skylights are smoke vents it is worthwhile to consider placing the sensor under the smoke vent, as it is easier to access the sensor for cleaning from the roof. The sensor should have a wide angle of view, so that it averages the brightness of the entire skylight dome. This strategy assumes a diffusing, rather than a clear, skylight glazing. Clear glazing would not work well here, because at times the photosensor would be looking at beam sunlight, at other times it would see blue sky (which is not bright) and at other times it would see overcast sky. With diffusing glazing, the photosensor sees an 'averaged' sky luminance, which will be proportional to the illuminance on the task surfaces below.
- For sky-lit buildings with closed loop control it is best to locate the photosensor facing a vertical surface (internal wall) that is equally distant from the skylights and electric lighting at a height sufficient to avoid shading from any furniture or equipment. In this strategy, the target surface and the other room surfaces are assumed to receive, diffuse and reflect the typical daylight and electric lighting, and so to represent the

general light levels throughout the space. The photocontrol will use the light level reading from this surface to raise or lower the electric lighting to maintain a constant level of illuminance, and so the target surface must respond to both kinds of lighting in a way that is similar to the rest of the space. The surface must be protected from excessive shading and from extraneous light sources (such as reflections off of surfaces outside the space), which would send the wrong signal to the photocontrol system and inappropriately dim electric lighting.

As implied in the previous two recommendations, there are several ways to get the photosensor placement wrong. The most basic mistake is to place the photosensor in a location that does not receive illumination representative of the task areas. If the photosensor receives extra light that is not typical of the space, then it will turn down the lights excessively. If it does not receive as much light (or a proportional amount of light) as the rest of the space, then the electric lights will be controlled brighter than necessary. The former case could lead to dissatisfied occupants; the latter case to lost lighting savings. Another mistake is to place the photosensor in a location where it can be easily damaged, where it will become excessively dirty, or where it can be blocked by occupants or objects.

Fortunately, in skylighting systems, these problems are easily avoided because the photosensor can be placed high up in the space and out of the way of hazards or unusual light sources/blockages.

## 4.5 Selection of controller features and algorithms

There are numerous options when implementing any control scheme and it is important to select the right components to meet all the performance needs. Following are the critical characteristics of the control scheme -

- Control setpoints – setpoints are triggers set at specified daylight levels to control the lights. It is critical to select setpoints that allow the users to perform their tasks without discomfort. Selecting a setpoint too high for turning OFF the lights will waste energy while selecting too low of a setpoint may result in excessively low light levels. The actual value of the setpoints will depend on what the photosensor 'sees'. If it is looking up at the skylight, it will be responding to high light levels, much higher than the design illuminance levels within the space. If it is looking into the space, it may actually be seeing lower illuminance levels than the design levels. The setpoints in both these cases are analogues for the design illuminance levels that the control system seeks to maintain inside the space, and they must be established empirically during the commissioning of the photocontrol system (see Section 5.)
- Deadband settings – the deadband setting ensures that the lights do not cycle through the control stages too frequently and cause user discomfort. There are two settings to a deadband, based on the photosensor

readings: the upper setting turns off the electric lights when the daylight level exceeds the upper limit, while the lower setting turns the electric lights back on when the daylight level falls below the lower limit.

For open loop controls if there were no deadband, the electric lights would cycle on and off whenever the daylight levels were near the set point and the daylight levels fluctuated even slightly. Deadband is significantly more important for closed loop controls since the control senses the combination of electric lighting and daylight. Without sufficient deadband in a closed loop system, the cycling of the lamps on and off will be limited only by the time delay. The deadband for closed loop controls should be slightly greater than difference in light levels between the lights being ON and OFF as measured by the photosensor.

- Ease of changing setpoints and deadband settings – The space usage and interior coverings often change and necessitate changes to the setpoints and deadband settings. It is critical that the controller allow the user to change the settings easily and without extensive training. It is also important, of course, that the controller be physically located in a location to make the adjustment process convenient.
- Display of control settings and results – it is essential that the user be provided a visual confirmation of the control settings by the controller. It is also desirable to have a readout on the resultant lighting energy savings. This may be achieved in a variety of ways including but not limited to a digital readout of the sensor reading, the wattage consumed by the lighting system, and the setpoints and deadband settings. The easier it is for the user to understand and adjust the photocontrol system, the more likely it is that the system will continue to operate satisfactorily over time.

## 4.6 Establishing target savings

It is a good design practice to set performance criteria for the control system in terms of energy savings during the design stage. The performance criteria will vary slightly depending on the individual site situation and user needs. In some cases it may be more important to maximize peak savings, while in other cases it may be important to minimize the variability in illumination levels (potentially reducing the savings potential). By establishing the performance criteria for the system, the designer creates a target for system performance that the installers and operators can use in the future to assess whether or not the system is performing to expectations. These criteria also provide a basis for adjusting the system operation should the needs or uses of the space change over time.

## 4.7 Installation and commissioning

Surveys of skylighted buildings in the field[1] show that the majority of photocontrol systems that fail to achieve desired performance goals do so because of installation and commissioning problems. In most cases, the system commissioning procedures described in this report were not followed or were not available and the users did not have knowledge how to adjust the control settings for correct system operation.

It is critical for a good installation that –

- The control designer provide the installers/contractors detailed guidelines on installing and commissioning the control system.
- The users are properly trained in the operation of the system and in the methods of changing setpoints if system performance needs tuning.
- The commissioning process includes onsite adjustments for a specific time period to ensure long-term applicability. Rarely do the initial setpoints and deadbands satisfy users needs completely.

The survey results also show that systems that were set up to work well at the time of installation have continued to operate successfully over time.

[1] Conducted by the Heschong Mahone Group, Inc. for Southern California Edison, '*Photocontrols Field Study Report'* 2003

# 5. PHOTOCONTROL INSTALLERS/COMMISSIONERS GUIDELINES

The purpose of this section is to give guidance to the photocontrol manufacturers on the type of information that is needed to help an installer calibrate their control. As such the instructions would be less generic and more specific to the configuration of their control. In addition, it is hoped that better understanding of the calibration process by manufacturers may lead to control designs that are easier to calibrate.

The photocontrols installer is responsible for the physical installation of the photocontrol system and the calibration of the control system to the manufacturers' and photocontrol designer's specifications.

You may have heard horror stories on how difficult it is to calibrate daylighting controls. If your control system is to be used to control lighting under diffusing skylights -- don't worry, it is much simpler than daylighting controls for spaces that are daylit with windows. Here is why:

- If the skylights are truly diffusing, the ratio of illuminance in the light well to that at a given location in the space is virtually constant under all sky conditions. Thus once you have identified this ratio you can figure out the daylight contribution quite easily. This makes "open loop" controls where the photosensor is in the light well under the skylight "looking" up easy to adjust. This is the method of choice if you have a switching control system that switches lights or lamps off in response to daylight.
    - When skylights are truly diffusing, their distribution of light is similar to that of the electric lighting system. Thus the ratio of light at the task to that received by a "closed loop" photosensor on the ceiling looking down at reflected light is the same for both the skylight and the electric light. This makes it relatively easy to adjust "closed loop" controls for continuously dimming systems.

While specific product characteristics vary among manufacturers, the calibration process nevertheless shares some commonalties, which are described below. Specifics may vary according to manufacturers' directions.

## 5.1 Switching controls overview

The first thing to do is be clear on the basic functions of the photocontroller, they all work approximately the same way but how these functions are described and how adjustments affect these functions vary between manufacturers and models of equipment.

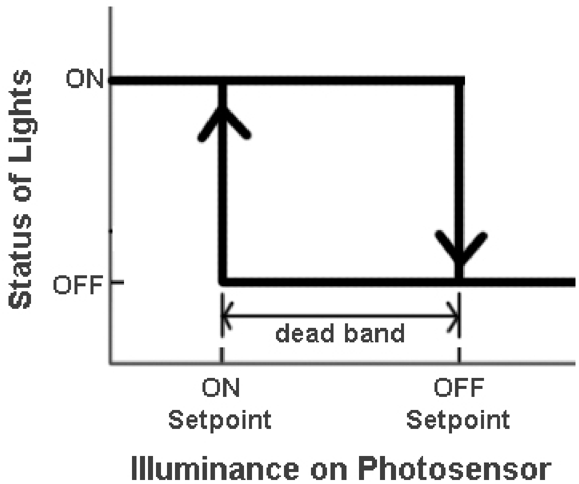



*Figure 8: Photocontrol Control Diagram*

Figure 8 illustrates the control function for switching controls. The status of the control (Lights ON or Lights OFF) is a function of the control status and the illuminance on the photosensor. Lights stay ON until the light level on the photosensor exceed the OFF Setpoint, then the lights turn off. Lights stay OFF until the light level on the photosensor is less than the ON setpoint. The DEADBAND is the light level difference on the photosensor between the ON Setpoint and the OFF Setpoint.

Almost all switching controls will refer to an illuminance setpoint, but this could refer to the ON Setpoint the OFF Setpoint, and in some cases, midway between the ON Setpoint and the OFF Setpoint. Thus it is important to ask the manufacturer to define how both the ON Setpoint and the OFF Setpoint are adjusted. However, they are all related by the following simple relations:

- OFF Setpoint = On Setpoint + Deadband
- Deadband = OFF Setpoint - On Setpoint
- ON Setpoint = OFF setpoint - Deadband

Most switching controls have an adjustable time delay. This time delay prevents lights from cycling on and off on partly cloudy days when daylight footcandles can jump around.

With a time delay, when the photosensor footcandles drop below the ON Setpoint, the lights do not immediately turn on. Instead the control starts a timer and if the photosensor footcandles remain below the ON Setpoint for the duration of the time delay, then the lights are switched on. Since maintaining light levels above a desired minimum footcandles is more important than immediately turning off lights when there is sufficient daylight, some controllers have separate time delay ON adjustments from time delay OFF adjustments.

## 5.2 Commissioning protocol for open loop switching controls

This protocol makes the following assumptions –

- The space is lit with top lighting from skylights with diffusing glazing. If you can see images through the glazing, it is not diffusing. The skylight should be casting a broadly spread blob of light not a shaft of light that creates a distinct image on the floor.
- The photosensor is located in the skylight well facing up towards the skylight glazing. This sensor should have a wide angle of view (typically 120 degrees) and should be mounted in 8" from the edge of the light well on a standoff and be at least 12" below the sky

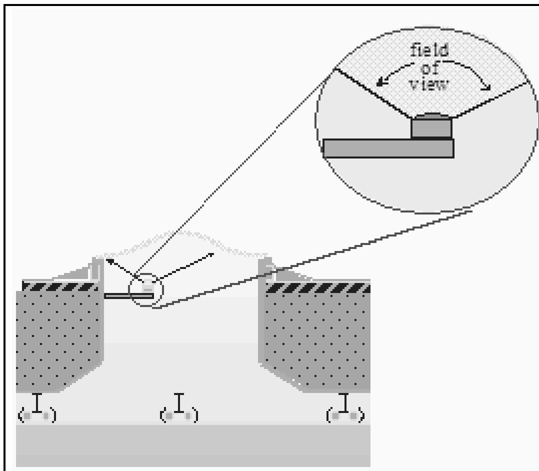


*Figure 9: Open loop photosensor mounting*

- The control algorithm uses a switching strategy (ON/OFF or multi-level switching)
- If multi-level circuiting is used, circuiting is organized so that lights closest to skylights are on a separate circuit from those that are further away from skylights. Also circuiting is on a regular pattern so that lights on one stage of control alternate with lights on another stage of control.

Once the photosensor is mounted in the skylight well, the photocontroller needs to be calibrated. The purpose of the calibration is to assure that no location in the room is less than the design illuminance and that the lights do not cycle on and off due to temporary cloud cover. Correct design illuminance is accomplished by adjusting the ON Setpoint and minimizing cycling is accomplished by adjusting the deadband and time delay.

Ideally the location where control adjustments are made is remote from the photosensor and is easily accessible (unobstructed and accessible without needing an ladder or lift). If the designer has specified a control where the calibration adjustments are made on the photosensor, try to make the adjustments so that you are shielding the sensor as little as possible.

### 5.2.1 Required tools

1. Light meter (to check light levels at task locations in the space).
2. Small screwdriver or other tool for turning adjustment screws or controls

3. Method of communicating with person taking light level readings. In larger spaces this may require a radio or cell phone.
4. Ladder or lift if control settings are located up in light well with sensor (not recommended).

### 5.2.2 Identify Daylight Task Footcandles (DTF)

The purpose of this calibration is to adjust the control so that all task areas have at least the design task footcandles at all times while saving as much energy as possible by turning off lamps as soon as there is sufficient daylight.

1) This procedure is best performed at times when interior daylight is near the design illuminance, if this is not known then calibration at mid-day (noon) is best to ensure the maximum amount of daylight available.

2) Identify the location of minimum task illuminance in the zone where the lights are being controlled. This task location should NOT be directly under a skylight or under a light fixture. This is the location where we shall measure task footcandles (TF).

3) If there are another set of lights that are also controlled by the photocontrol system and this circuit is designed to be turned off at the same time of at a lower daylight footcandles than the circuit you are calibrating turn them off.

4) Extra task lighting is any light source that provides a significant amount of light to the task in the controlled lighting zone and is:

- Not controlled by the photocontrol (such as emergency lighting) or
- A stage of lighting control that requires HIGHER levels of daylight before it is turned OFF

The light from extra lighting on the task reduces the amount of daylight needed at the task and is measured as follows
Extra footcandles (EF) = ($TF_{EON}$ - $TF_{EOFF)}$
where,
$TF_{EON}$ = task footcandles with extra lights ON
$TF_{EOFF}$ = task footcandles with extra lights OFF (all or almost all of this light should be from the skylight)

5) (DTF) the daylight task footcandles is the amount of daylight needed at the task in addition to the extra footcandles (EF) to turn off the controlled lighting in the zone. Daylight task footcandles, DTF, is:
DTF = Design footcandles - EF

6) If you do not have a feel for what the design footcandles should be, turn on and off all the lights and record the difference in light levels at the same point where the task light level (TF) measurements are taken.
Design Footcandles = $TF_{ON}$- $TF_{OFF}$
where,

$TF_{ON}$ = task footcandles with ALL lights ON
$TF_{OFF}$ = task footcandles with ALL lights OFF

7) Record task footcandles with all electric lighting turned off, $TF_{OFF}$. This is the amount of daylight footcandles at the task.

### 5.2.3 Calibration adjustments

1) Start the procedure by minimizing the time delay and the deadband settings (set to zero if possible).
2) If the controlled lights are on in the space reduce the setpoint until the lights go out.
3) Record the sensor footcandles (SF) measured by the control photosensor in the skylight well either from an electronic readout from the photocontroller or by increasing the ON Setpoint until the lights turn ON. Record the value of sensor footcandles (SF) as:
    a) Display of sensor footcandles or voltage.
    b) Dial or slider – note the angle of the dial or position of slider with respect to the OFF position, or by manufacturers designated setpoint indicators (numbers or letters by the adjustment).
    c) LED's – note the number of LEDs lit -for one manufacturer you have to count number of times a button is pushed between LED's turning on.
4) Identify if reading is on a linear scale. Some manufacturers use a logarithmic scale for setpoint adjustment and you must use a look-up table or a graph to translate what a certain number means on their control.
5) Calculate the photosensor footcandles to task daylight footcandles ratio (STR).
   $STR = (SF)/(TF_{OFF})$
6) Define your desired control setpoint (DCS) by the following:
   DCS = (STR) x (DTF)
   where,
   DTF = minimum daylight footcandles on task needed so that overall task footcandles with controlled lights OFF are above design footcandles. Minimum daylight task footcandles are calculated in the section above.
7) Follow the manufacturers instructions to set the desired control setpoint (DCS) calculated above. Be sure so identify how the control settings relate to each other. Some control settings are linear and it is easy to make the adjustment. In other cases the setpoint is non-linear and you must use a look-up table or graph to estimate how to make the adjustment.
8) Once the setpoint is set, change the time delay back to the manufacturer's recommendations. Typically the ON time delay is set to a low value to ensure immediate response when the daylight is inadequate, while the OFF time delay is set to a higher value to prevent lamp cycling due to

sudden changes in daylight levels (such as clouds passing overhead). The OFF time delay is typically 5 minutes.

9) Change or reset the deadband to the manufacturer's specifications. In an open loop configuration this is typically 10% of the desired control setpoint (DCS).

If there are any complaints on the operation of the system, investigate the reason. If the complaint is that the task light level is too low, measure the light level and if indeed it is too dark then increase the desired control setpoint up by an appropriate fraction. If the complaints are about the lights cycling on and off, increase the deadband or the time delay.

### *Multi-level switching controls*

If you have multiple stages of control on the same set of lights, first calibrate the circuit(s) of lights that are furthest away from the skylights as described above. This is the circuit of lights that will be turned OFF last by the photocontrol as daylight levels increase. Thus all of the other stages of the control should be turned OFF during calibration this control stage and are NOT included as part of the extra lighting calculated in Extra Footcandles, EF, (see Section 5.2.2 Identify Daylight Task Footcandles (DTF) step 4).

Then calibrate the circuit(s) of lights that are second furthest away from the skylights. This is calibrated as described above EXCEPT

- The location where task footcandles (TF) is measured is moved in closer to the skylights because the circuit controlled is closer to the skylights (this changes the calculation of the photosensor footcandles to task daylight footcandles ratio (STR); and
- If the task area is receiving more than 10% light from the lighting controlled by previous stage of control, then include these lights as part of the extra lighting calculated in Extra Footcandles, EF, (see Section 5.2.2 Identify Daylight Task Footcandles (DTF) step 4).

Additional levels of control are calibrated similar to the lights that are second furthest away from the skylights. The only difference is that all the previous stages of lighting can be considered to be part of the extra lighting calculated in Extra Footcandles, EF, (see Section 5.2.2 Identify Daylight Task Footcandles (DTF) step 4).

### *Different Tasks or Different Geometry of Space*

**If you have more than one zone on the same (multi-channel) control,** the characteristics of the other zone may be such that the sensor to task footcandles ratio (STR) may be different. An example of this phenomenon is a warehouse like that shown in

Figure 10 that has both an open receiving area and an area with high stacks. The sensor to task ratio, STR, in the stack area will be higher than the open area because the stacks intercept more of the light and thus there is less daylight at the task level in the stacks. Thus, lights over the stacks should be separately circuited and have separate channels (or photocontrols) from lights over the open areas. The stacks may have different desired minimum task footcandles (DTF) and will definitely have a different sensor to task footcandles ratio (STR) than the open area.

*Figure 10: Warehouse with tall racks and open loading area*

## 5.3 Commissioning protocol for closed loop switching controls

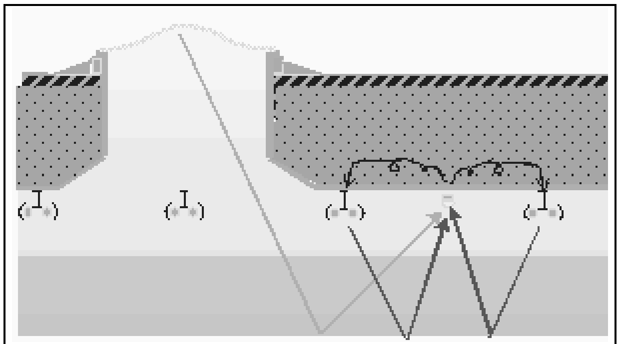


*Figure 11: Closed loop photocontrol*

As shown in Figure 11, closed loop controls have the photosensor in the space that "sees" both light from skylights and from the electric lighting system. Since the sensor is affected by the lights it is controlling and these lights have discrete "jumps" in output corresponding to lamps being turned ON, setting the deadband becomes very important. If the deadband is too small, the control will cycle on and off limited only by the time delay. If the deadband is too large, the control will not be saving as much energy as is possible.

The sensor can be looking down at the task surface or a floor but can be just as likely be pointed at a wall. In general the closed loop sensor is receiving reflected light from both the electric light and the skylight. Thus it is important to place the sensor looking at something that is not likely to have its reflectance change. If the sensor is pointed down, it is better to place the sensor over a circulation area rather than over a task area and to use a moderately broad acceptance angle (such as 60°) sensor so that the change in reflectance is averaged out by other surfaces in the space.

### 5.3.1 Required tools

1. Light meter (to check light levels at task locations in the space).
2. Small screwdriver or other tool for turning adjustment screws or controls
3. Method of communicating with person taking light level readings. In larger spaces this may require a radio or cell phone.
4. Ladder or lift if control settings are located up in light well with sensor (not recommended).

### 5.3.2 Measuring Task Footcandles (TF)

The purpose of this calibration is to adjust the control so that all task areas have at least the design task footcandles at all times while saving as much energy as possible by turning off lamps as soon as there is sufficient daylight.

1) This procedure is best performed at times when interior daylight is near the design illuminance, if this is not known then calibration at mid-day (noon) is best to ensure the maximum amount of daylight available.

2) Identify the location of minimum task illuminance in the zone where the lights are being controlled. This task location should NOT be directly under a skylight or under a light fixture. This is the location where we shall measure task footcandles (TF).

3) If there are another set of lights that are also controlled by the photocontrol system and this circuit is designed to be turned off at the same time of at a lower daylight footcandles than the circuit you are calibrating turn them off.

4) Extra task lighting is any light source that provides a significant amount of light to the task in the controlled lighting zone and is:

   - Not controlled by the photocontrol (such as emergency lighting) or
   - A stage of lighting control that requires HIGHER levels of daylight before it is turned OFF

5) If you do not have a feel for what the design footcandles should be, turn on and off all the lights and record the difference in light levels at the same point where the task light level (TF) measurements are taken.
   Design Footcandles =
   [task footcandles with ALL lights ON] - [task footcandles with ALL lights OFF]

### 5.3.3 Calibration adjustments

1) Extra lighting that is normally on when this stage of lighting being calibrated is ON (as described above) should be turned on. Other controlled lighting that would normally be OFF (such as lighting that is turned on at higher daylight levels) should be turned off.

2) Start off with time delay set to minimum, ON setpoint high and:

   a) If control has OFF setpoint set to maximum

   b) If control has deadband adjustment set to maximum

3) Record $TF_{OFF}$, task footcandles with this stage of lighting turned OFF.

4) Gradually decrease ON setpoint until lights turn ON. Record ON control setpoint measured during calibration, $CSON_{meas}$.

5) Let electric lighting warm-up (5 minutes for fluorescent, 10 minutes for HID lighting) and measure task footcandles with lights ON, $TF_{ON}$.

6) Gradually decrease OFF setpoint or deadband control until lights turn off and then increase value slightly to prevent cycling. Record task footcandles with this stage of lighting control turned OFF, $TF_{OFF}$; it should be close to the $TF_{OFF}$ as measured in step 3. If not, start over from step 2.

   a) If the controller uses OFF setpoint control, record OFF control setpoint measured during calibration, $CSOFF_{meas}$. and then increase OFF setpoint control to maximum.

   b) If the controller uses deadband control, record deadband setting measured during calibration, $DEADBAND_{meas.}$

7) Calculate $CSON_{SET}$, the desired ON control setpoint as follows:

   $CSON_{SET} = CSON_{meas}.x\ TF_{SET} / TF_{OFF}$

   where,
   TFOFF = desired (or design) footcandles

8) Adjust the ON control setpoint to the desired setting, $CSON_{SET}$. You must confirm with the manufacturer how control setpoints relate to the markings on the adjustment control. If the adjustment is linear, you can apply $CSON_{SET}$ directly, otherwise use the manufacturer's look-up table or graph.

9) If the controller uses a deadband control you can leave the deadband as calibrated earlier.

10) If the controller uses an OFF setpoint control, the footcandle is increased by the same amount as for the ON setpoint control. Calculate $CSOFF_{SET}$, the desired OFF control setpoint as follows:

   $CSOFF_{SET} = CSOFF_{meas}.+ [CSON_{SET} - CSON_{meas}]$

11) Adjust the OFF control setpoint to the desired setting, $CSOFF_{SET}$. You must confirm with the manufacturer how control setpoints relate to the markings on the adjustment control. If the adjustment is linear, you can apply $CSOFF_{SET}$ directly, otherwise use the manufacturer's look-up table or graph.

12) Once the setpoint is set, change the time delay back to the manufacturer's recommendations. Typically the ON time delay is set to a low value to ensure immediate response when the daylight is inadequate, while the OFF time delay is set to a higher value to prevent lamp cycling due to sudden changes in daylight levels (such as clouds passing overhead). The OFF time delay is typically 5 minutes.

If there are any complaints on the operation of the system, investigate the reason. If the complaint is that the task light level is too low, measure the light level and if indeed it is too dark then increase the desired control setpoint up by an appropriate fraction. If the complaints are about the lights cycling on and off, increase the deadband or the time delay.

### *Multi-level switching controls*

If you have multiple stages of control on the same set of lights, first calibrate the circuit(s) of lights that are furthest away from the skylights as described above. This is the circuit of lights that will be turned OFF last by the photocontrol as daylight levels increase. Thus all of the other stages of the control should be turned OFF during calibration this control stage and are NOT included as part of the extra lighting (see Section 5.3.2 Measuring Task Footcandles (TF) step 4).

Then calibrate the circuit(s) of lights that are second furthest away from the skylights. This is calibrated as described above EXCEPT

- The location where task footcandles (TF) is measured is moved in closer to the skylights and
- If the task area is receiving more than 10% light from the lighting controlled by previous stage of control, then include these lights as part of the extra lighting (see Section 5.3.2 Measuring Task Footcandles (TF) step 4).

Additional levels of control are calibrated similar to the lights that are second furthest away from the skylights. The only difference is that all the previous stages of lighting can be considered to be part of the extra lighting (see Section 5.3.2 Measuring Task Footcandles (TF) step 4).

## 5.4 Dimming controls overview

Dimming controls provide a control signal to a special dimming ballast. Some ballasts are configured to receive 0-10 VDC, 4-20 mA, low voltage signals and others use the power conductors to receive PLC (power line carrier) or conduction angle signals typified by triac based wall dimmers. Also some companies are releasing ballasts that make use of digital signaling such as DALI (Digital Addressable Lighting Interface). Currently the majority of fluorescent dimming ballasts use a 0-10 VDC control signal. The concepts described here can be used for ballasts that use other communication protocols.

The ballast light output response to control signal is usually pretty linear. However, most ballast do not dim over the entire 0 to 10 volt range. Figure 12 shows a 20% dimming ballast that changes light output only when the control voltage is between 8 and 2 volts. Thus knowing at what control voltage dimming begins and ends is an important calibration consideration.

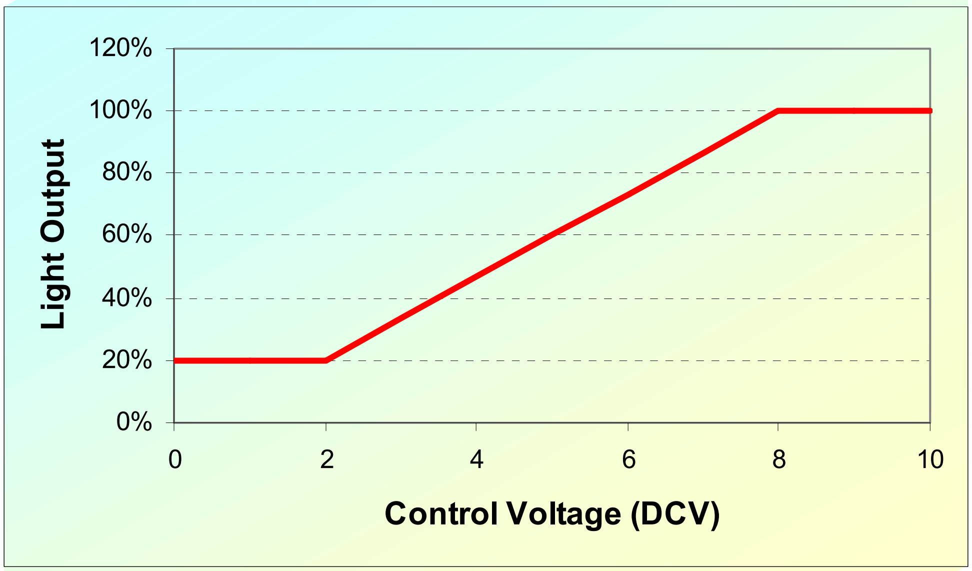



*Figure 12: Typical dimming ballast light output response to control voltage*

Depending upon whether the configuration of the controller is open loop (photosensor is looking up into light well and is sensing only daylight) or closed loop (photosensor is looking down into the space and is sensing the combination of daylight and electric light) there are different calibration requirements. In addition, oftentimes controls made for sidelighting are applied to toplighting - thus the manufacture's calibration instructions may not be written for your application.

There are but a few types of calibration adjustments for dimming controls. The affect that most of these calibration adjustments have on the dimming ballast control signal is visualized in the control function graphs in Figure 13. These adjustments include:

a) Offset Adjustment - this tells the controller how much light must fall on the photosensor before the control will start dimming the ballast. The offset adjustment is needed for closed loop controls because photosensor "sees" light from the electric lighting system. Without an offset, the control would dim the lights even at night time

b) Sensitivity Adjustment - this defines the slope of the dimming curve in terms of dimming percentage per footcandle of light received by the photosensor. A high sensitivity means that it takes a little light to dim the lights a lot where a low sensitivity requires more light for the same amount of dimming.

c) Min/Max Voltage Output Adjustment - a maximum voltage adjustment is used when one wants to "tune" the lighting system. Tuning can be used to exactly match the electric lighting output to the desired design footcandles. The minimum voltage adjustment is to prevent electric lighting levels to fall beneath a given value. Using the minimum output adjustment reduces the energy savings of the control.

d) Typical closed loop adjustment (for skylighting systems) shows an offset that is equal to the footcandles on the photosensor at the desired task footcandles. The sensitivity of the response is set high as photosensor footcandles should remain around the amount defined by the offset. The control should respond to increased daylight footcandles on the photosensor by dimming the electric lighting until the total photosensor illuminance has dropped close to the offset value.

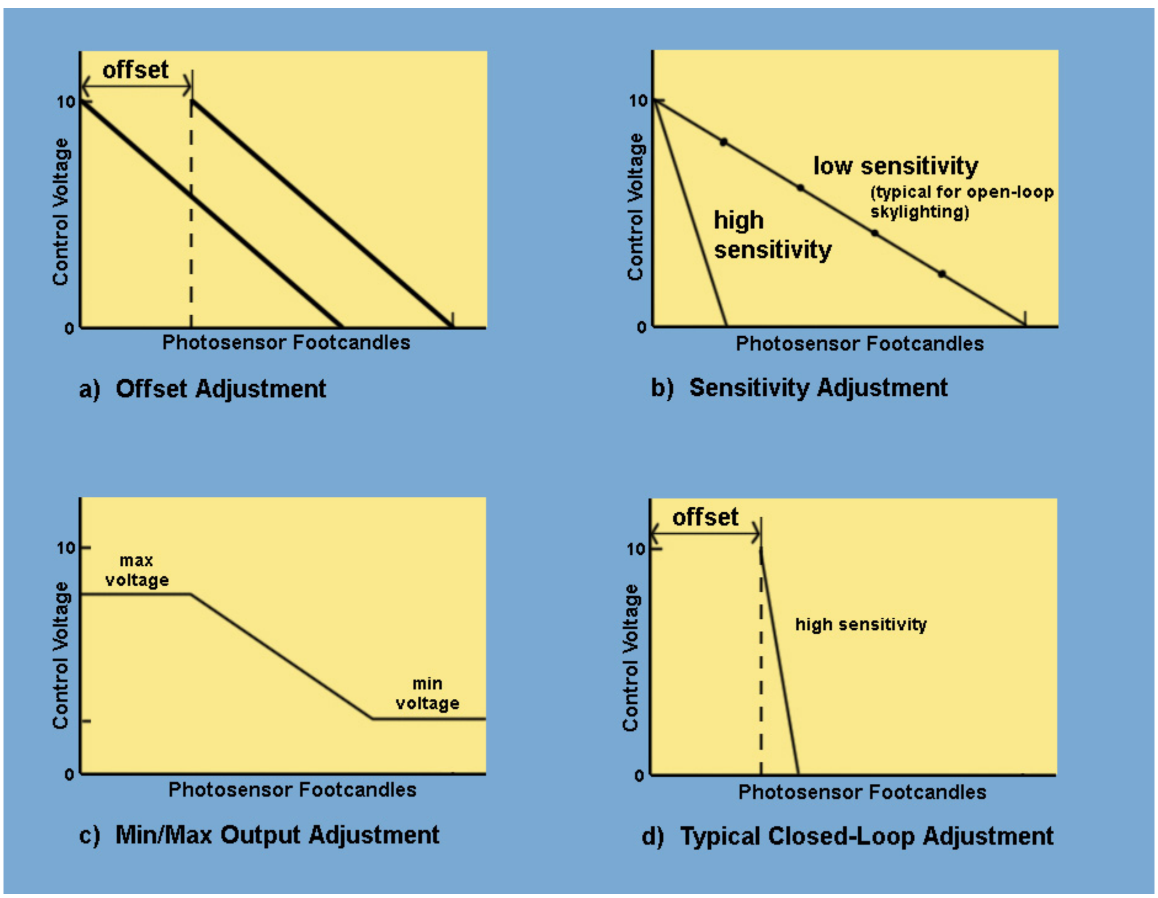



*Figure 13: Dimming control adjustment functions*

Similar to the time delay functions for switching controls, we don't want the dimming control to be fluctuating at such a rate that is distracting. Thus dimming controls have either a built-in or adjustable ramp and fade rate.

- Ramp rate adjustment - this defines how quickly (in seconds) the control will ramp up the electric lighting levels in response to lower photosensor footcandles. Since we don't want to leave people in the dark this is usually set relatively fast. Typical values are around 15 seconds.
- Fade rate adjustment - this defines how quickly the control will dim electric lighting in response to increases in photosensor footcandles. Since having too much electric light is not as distracting as too little, often the fade rate is slower than the ramp rate. Typical values are 60 seconds, which has minimal impact on energy savings.

## 5.5 Calibrating closed loop dimming controls

- Calibrate at night
- Identify the location of minimum task illuminance in the zone where the lights are being controlled. This task location should NOT be directly under a skylight or under a light fixture. This is the location where we shall measure task footcandles (TF).
- Set ramp and fade to 0
- Set sensitivity to maximum
- Set offset high and then reduce offset until lights start to dim - then back off a hair
- If controller has adjustments for fade and ramp set the ramp rate to 15 sec and fade to 60 seconds. Adjust in response to comments or observations that lights are responding to quickly or too slowly.
- During day when daylight contribution is close but below desired footcandles refine sensitivity if needed. Set ramp and fade 0 while refining sensitivity. Then restore ramp and fade values after making adjustments to sensitivity.

## 5.6 Calibrating open loop dimming controls

Most dimming controls do not allow you to define range of control voltages over which ballasts vary their output; it is usually some small portion of the 0 to 10 VDC range. As a result, we can only approximate the appropriate control response via a sensitivity adjustment. The protocol described below errs on the side of providing too much electric lighting. This is considered preferable to maximizing energy savings but providing inadequate illuminance some of the time. And certainly preferable to receiving callbacks due to complaints!

If we try to simply adjust the sensitivity of the control so that there is enough total light in the room at the time of calibration, we could end up with the problem shown in Figure 14. In this situation, the control is OK for that one daylighting condition, but would be too dark whenever there was more sunlight.

This process is more complex than it has to be because most control manufacturers do not provide an adjustment that identifies the control voltage when the ballast starts to dim. Such an adjustment would set the control voltage at this amount at 0 sensed footcandles and increases in sensed footcandles would result in proportional reduction in control voltage based solely on the sensitivity setting.

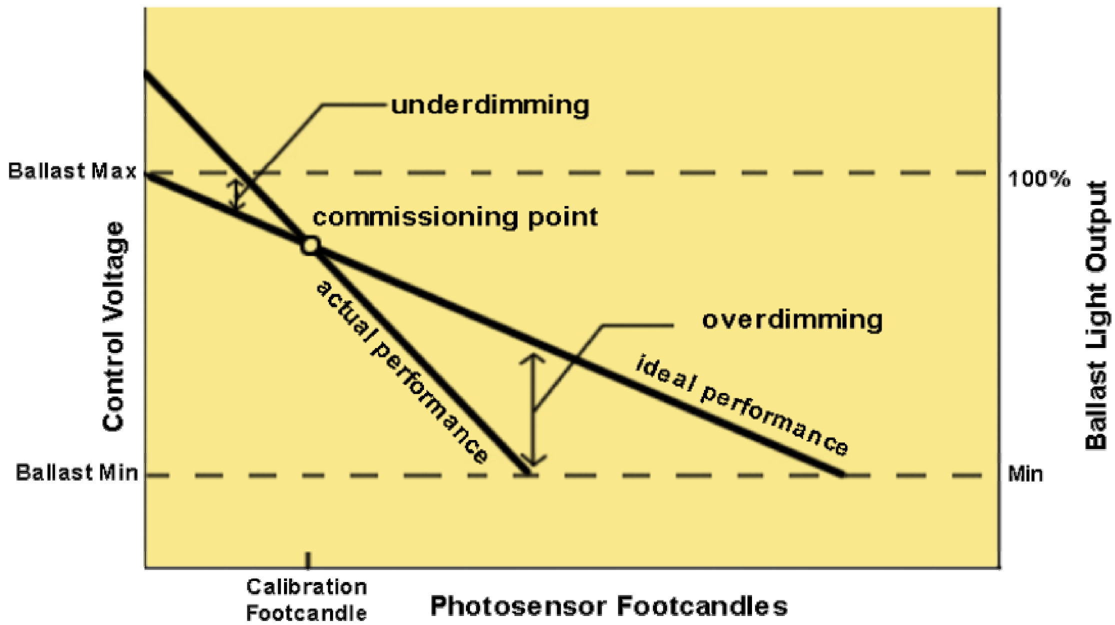



*Figure 14: Open loop dimming - single point calibration*

If we calibrate when the interior daylight footcandles is just below desired (design) footcandles, then we have the situation that energy savings are maximized while assuring that the total light levels are at or above the desired (design) footcandles. However, there is a short time window when interior daylight footcandles is just below the desired (design) footcandles.

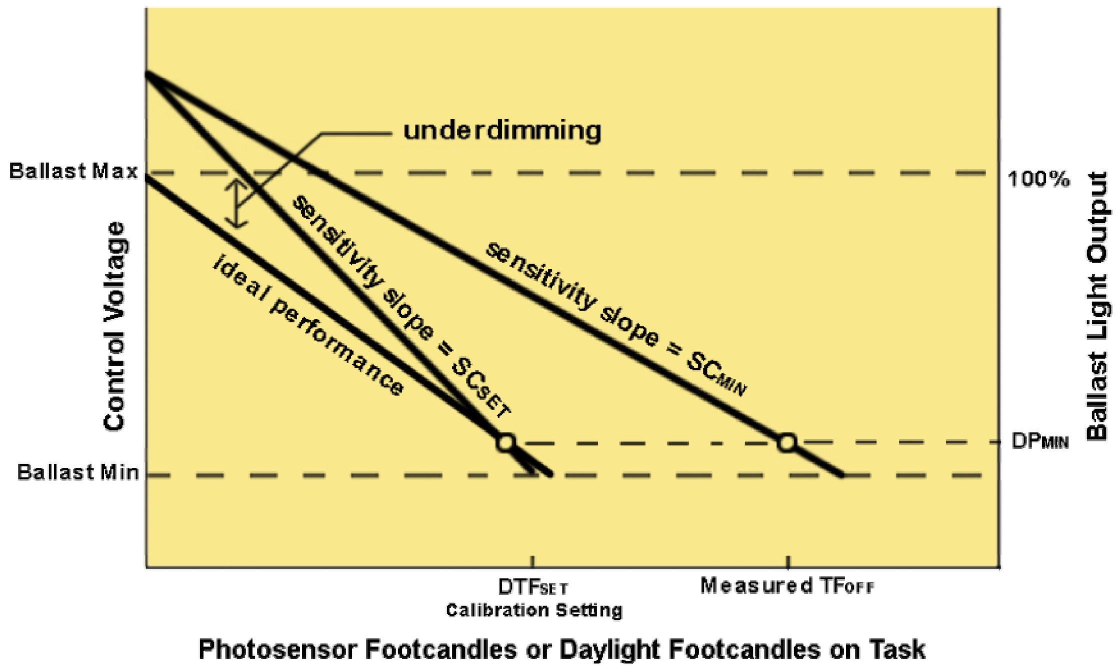



*Figure 15: Open loop dimming - sensitivity slope ratio method*

The calibration description below describes how to adjust the photocontrol sensitivity based on the minimum electric lighting light output regardless of the actual interior daylight footcandles. This dimming method identifies the sensitivity setting to dim the ballast to just above its minimum light output while simultaneously measuring the interior daylight footcandles. By calculating interior daylight footcandles that should correspond to ballast minimum light output, one can then develop a sensitivity adjustment ratio that is the ratio of the design interior footcandles for minimum ballast output to the interior daylight footcandles at the time of calibration.

- One must perform this calibration during daytime hours. It is desirable but not necessary to calibrate when daylight contribution is close to but below desired design footcandles.
- Identify the location of minimum task illuminance in the zone where the lights are being controlled. This task location should NOT be directly under a skylight or under a light fixture. This is the location where we shall measure task footcandles (TF).
- Set ramp and fade to 0
- Set offset to 0
- Measure task footcandles with electric lighting at full output, $TF_{ON}$. (Ask controls manufacturer how to do this - it may be as simple as turning sensitivity all the way down or may involve removing a lead from the controller.

- Adjust sensitivity until lamps are dimmed to their minimum output, and then back off on sensitivity just a hair until you see the task footcandles rise slightly. Measure this task footcandles at minimum electric lighting output, $TF_{MIN}$, and also make note of value of the sensitivity control $SC_{MIN}$.
- Turn off electric lighting - measure daylight on task $TF_{OFF}$
- Full output electric lighting task footcandles, $EF_{ON}$, are:
  $EF_{ON} = TF_{ON} - TF_{OFF}$
- Minimum output electric lighting task footcandles, $EF_{MIN}$, are:
  $EF_{MIN} = TF_{MIN} - TF_{OFF}$
- The electric lighting dimming percentage at minimum light output, $DP_{MIN}$, is:
  $DP_{MIN} = [1 - (EF_{MIN}/ EF_{ON})] \times 100\%$
- The dimming percentage ratio measured, $DPR_{MEAS}$, is the ratio of the percent dimming per footcandle of light at the task:
  $DPR_{MEAS} = DP_{MIN} / TF_{OFF}$
- Define the desired dimming percentage ratio, $DPR_{SET}$, the dimming percentage at minimum light output to the appropriate daylight task footcandles, $DTF_{SET}$.
  $DPR_{SET} = DP_{MIN} / DTF_{SET}$
  where,
  $DTF_{SET} = EFON - EF_{MIN}$
- The desired sensitivity control setpoint, $SC_{SET}$, is the value that the photocontroller should be adjusted for the desired performance.
  $SC_{SET} = DPR_{SET} / DPR_{MEAS} \times SC_{MIN}$
- Turn lighting back on
- Make adjustment to sensitivity - verify scale of sensitivity setting. Some controllers have a non-linear sensitivity scale. Make sure to ask them how they scale sensitivity to the adjustment gradations on their controller.
- After lighting has warmed up take measurements to validate that the measured task footcandles are at or above design (desired) footcandles.
- If controller has adjustments for fade and ramp set the ramp rate to 15 sec and fade to 60 seconds. Adjust in response to comments or observations that lights are responding to quickly or too slowly.

# 6. BUILDING OPERATORS GUIDELINE

All the above actors play a role in the design, installation and commissioning of the photo control system, but none have as much vested in the system's performance as the building operators. It is the building operators responsibility to monitor the photo control system for adequate performance and to perform regular maintenance. In certain cases the manufacturers and/or the controls designer will assume a role in maintaining and monitoring the system performance, but even these require some building operator participation. It is therefore essential for the building operators to understand how the system works, how to improve its operation and what to do when the system fails.

## 6.1 Understanding how the controls are supposed to work

The building operator must be a participant of the controls design and implementation process. If the building operator is aware of the control system capabilities and how the control system is set up it is easier to monitor the system for intended operation. Few considerations in this regard are –

- A training session for the building operators must be scheduled after the system is installed and commissioned. This training should include explanation of the system capabilities, and instructions on how to change the control variables.
- A user manual for the control system and all associated components must be maintained onsite in an easy to access and safe location.
- Contact information for the designers and manufacturers should be readily available to the building operator in case of future troubleshooting.

## 6.2 Optimizing operation for energy savings

Despite the designers and manufacturers best intentions it is possible that the system does not perform to its optimal performance. The personnel best suited for judging day-to-day performance of the system is the building operator. A properly designed system will allow the building operator to change the setpoints and the control features after the initial training.

While it is advisable not to make changes to the control system that might be detrimental to the system performance, fine-tuning of the operation is critical to ensure user satisfaction and adequate savings. This may also be necessary due to a number of variables such as changing peak demand savings targets, changes in interior layout etc.

A diligent building operator can increase the savings yield of the photocontrol system while improving the comfort of the building users.

## 6.3 What to do in case of failure

The first step in case of failure is the ability to detect failure. Often the photo control systems are not operational, but the failure is not apparent because the lights are ON. The building operator therefore needs to keep track of the lighting system operation and confirm that the system is controlling the lights as expected.

If the system has failed –

- It is critical for troubleshooting to record the exact nature of the failure and any set of events that contributed to the failure. These could be
  - Recent additions or changes to the building envelope
  - Recent additions to the control scheme
  - Equipment failure
  - User discontent with the system causing local overrides
- In case of performance contracts, the building operator should contact the service provider for immediate repairs and maintenance
- Where there are no performance contracts, the operator can troubleshoot the system based upon the manufacturers literature and the control designers' guidelines.
- The operator can hire external consultants to recommission the control system, or use in house personnel trained to undertake recommissioning activities.
- The building operator should always maintain a current list of phone numbers for the manufacturers and controls designers for troubleshooting.