Making daylighting work
Learning from failures to improve the design and implementation process

Prasad Vaidya
The Weidt Group
1625B Walnut Street, Berkeley CA 94709

Tom McDougall, Jason Steinbock, James Douglas, David Eijadi
The Weidt Group

Keywords
Daylighting, Efficiency, Controls, Commercial Buildings, Guidelines, Implementation,

Abstract
Daylighting, hailed as a cornerstone of sustainable building design, is the primary passive solar design strategy in commercial buildings. It has the potential to significantly reduce lighting energy, which can be 40% or more of the energy cost of a commercial building. We have found that projects with daylighting often do not provide the expected energy savings. In a risk-averse construction industry, even limited failures can dramatically slow the advance of valid technologies. There are numerous reasons for failure: natural light sources are complex and vary through the day and year; implementation requires coordination between different building design and construction trades; the documentation and specification of the controls equipment is often inadequate; and calibration after installation is rarely done well and can be confusing and time consuming.

In this paper, we provide four case studies as representative examples where daylighting did not deliver the expected energy savings. We identify the primary modes of failure and provide a template for each mode for easier problem resolution in the future. Through a detailed analysis of the case studies, we identify problem areas in the design and implementation process; we propose a more generalized solution set for design steps, documentation requirements and implementation checks that increase the chances of success.

Introduction
Design analysis often shows daylighting control to be one of the most promising energy conservation strategies for commercial buildings. Energy savings through daylighting can be accomplished by counting daylight as a legitimate source and reducing the number of lighting fixtures installed in a space. Counting daylight as a source may imply that the building is used differently during the day and night. In commercial building lighting design this is often not considered an acceptable approach. Thus more often, artificial lighting systems will be designed to provide all the light required in a space, day and night, and usually to the same lighting levels, but with manual or automatic switching systems to turn down lights when daylight is available. This leads to a reliance on automatic control systems which are expected to provide more reliable energy savings than manual controls. Consequently, daylighting controls are more frequently installed.

In our energy design assistance work we have suggested daylighting as an energy conservation strategy in over 400 buildings, about a quarter of which commit to implement it through automatic daylighting controls. We generally provide architectural design assistance for developing the daylighting potential of a building and then analyze combinations of lighting and control options for their resultant energy savings. On most projects we review construction documents and verify the installation of the systems. When possible, we help with calibration of the control system and gather feedback from the occupants. This has given us the opportunity to observe variables in design and implementation processes including the performance of both design teams and technologies.

Automatic switching or dimming control systems do not provide the expected energy savings as often as we would like. The possible reasons for an unsuccessful implementation of daylighting controls are numerous. It seems prudent to look for object lessons for success and failure from the set of early adopters. If energy efficiency through daylighting controls is to proliferate as a strategy its success rate needs to be improved.[1] Though there are successes, our intention here is to throw light on the weak areas so that future research and development on improving the process can be more focused.

In our earlier work (Vaidya 2004) we had covered eight case studies that did not meet the initial savings expectations. We found that savings from automatic daylighting control systems are often not realized fully when a building is turned over to the users. Where the controls do work, we are likely to find an involved and unusually committed owner. If controls are to be automatic, savings cannot depend solely on an owner or user's commitment. Many of these problems need to be solved during the design development and construction process.

Here, we offer four additional case studies. All case studies, including those from our earlier work, are analyzed for failure. Earlier, we had discussed the process of design and implementation and how daylighting systems in commercial buildings are developed. We identified the design decisions that typically could be made better with more attention to their effect on daylighting savings, and we identified construction documentation that is necessary but typically not included. Here we go into more detail and discuss the design decisions and construction documents. Through this discussion, we propose a more generalized solution that would increase the chances of success.

Case Studies

The following case studies are representative in nature. Some of the case studies here are of systems that simply did not work after the building was considered completed and ready for occupancy. In most cases the systems were made to work later, albeit with limited success after an owner, occupant, or building operator observed a problem and called for help.

While the case studies listed here are examples of problems encountered, there certainly are examples where daylighting is implemented as a successful strategy and energy savings are being realized as expected. In our experience however, the successful cases are the exception, not the rule.

CASE STUDY A – RETAIL, GROCERY STORE

What was intended: This grocery store chain, with each store typically 8 000 m² in size, developed its concept for daylighting using lessons from one store to be implemented in the next. One store was built with extensive tall windows in the check-out area and the dining alcove. This store was lit exclusively with direct fluorescent fixtures, and all fixtures have dimming ballasts to enable adaptation compensation at night, and allow daylighting control during the day. The second store was built with the same lighting and front store windows, but it also included a side clerestory window and a north facing light monitor with a deep monitor well. The owner requested measurement of both stores to determine the performance of each.

What was built: The stores were built more or less as designed. The first store did not achieve much daylighting savings. The second store gets good savings from both daytime and night-time dimming, measured at about 300 000 kWh / year, of which about 140 000 kWh / year is due to dimming during the daylight hours. The north facing light-scoop, built with a very deep well, does not contribute towards measurable daylight savings.

Problem resolution: While there are no major problems, the owner has learnt through the performance measurement that the monitor needs to be redesigned. The owner has become more educated about daylighting controls in terms of real savings through detailed study of the operation and is evaluating additional glazing in the form of monitors, clerestories or skylights.

Comments on the process: This is one of the rare cases where dimming controls are in place before the decision to harvest daylight has been made. The dimming controls were used store-wide, independent of daylight for night-time dimming. This owner's commitment to reducing operating costs while improving the store environment with daylighting is a great example of how high performance buildings are achieved though iterative design, closing the loop from design to operation in each subsequent project. 'Big box' retailers with chains of stores have the opportunity to successively improve their energy performance.

CASE STUDY B – TECHNOLOGY COMPANY HEADQUARTERS BUILDING

What was intended: This headquarters building was designed primarily with daylighting and views in mind. Large glazed curtain walls on the perimeter atria and skylights above the interior atria provide daylight to the thin floor plates. Underfloor air delivery with personal environment modules and indirect electric lighting were part of the design to make for a high quality interior environment. Stepped daylighting controls were to control two perimeter rows of fixtures.

What was built: In many areas, the lights were wired such that the photosensors controlled the inner rows of fixtures that were not considered to be part of the daylight zone. When these lights were turned off by the controls, there was not much daylight to compensate for it. Meanwhile adjacent areas that were part of the daylight zone had daylight as well as electric light. The contrast between the two areas was significant.

1. For example, in the Skylighting Guidelines, Heschong et al describe a case of a newly constructed building with automatic daylighting controls, where the controls had been disabled by the occupants with tape over the sensor when they were not even wired to the lights. Since the controls were not functioning, they could not have been causing a problem. So did the occupants simply not trust an automatic lighting control system?

Problem resolution: The lights were rewired so that the photosensors controlled lights in the identified daylight zones.

Comments on the process: The daylighting control system was specified in the design documentation but without wiring diagrams. The controls manufacturer provided the shop drawings[2] that were not checked by the lighting designer. Thus, although the electrical contractor wired the system according to the shop drawings, the system did not work as intended.

CASE STUDY C – ENERGY COMPANY HEADQUARTERS BUILDING

What was intended: This was an existing warehouse building that was transformed to be an open office and conference room space for the energy company. The design added a number of modular Solatube skylights to provide daylight. Dimming daylighting controls were to control the direct light fixtures in the open office area and the two large conference rooms.

What was built: In the open office areas 1 photosensor was installed to control 6 different daylighting zones via a zone controller and dimming module. The photosensor type installed was open-loop, and was located between a Solatube skylight and an electric light fixture and positioned such that it could see both the electric light and the Solatube. The dimming module has 4 different "scenes" and changes between "scenes" based on the amount of daylight detected by the sensor. Since the sensor was open loop type and owing to its installed location, there was never enough daylight to dim the electric lights.

Problem resolution: This problem has not been resolved. The solution suggested is to move the photosensor into the tube of one of the Solatube Skylights so that it could only see daylight.

Comments on the process: The project was design build. The electrical contractor specified and located the daylighting controls on the drawings. The controls manufacturer provided the shop drawings. There was no one person on the project who had complete knowledge of both how the lights were intended to be controlled and how the control system worked. Thus, although the electrical contractor wired the system according to the shop drawings, the system did not work as intended.

CASE STUDY D – ARCHITECTURAL FIRM HEADQUARTERS BUILDING

What was intended: This was a historically significant beer brew-house that was remodelled as offices with new interior finishes and mechanical and lighting systems, reusing only the building structure and shell. The old building had large windows with high window heads that let in daylight; new glazing systems were introduced in to the window openings. The spaces are tall with over 6 m high ceilings, and stepped daylighting controls were envisioned to turn off lights in the daylight zones.

What was built: The lighting designers lit the space with compact fluorescent high bay systems with a dual level switching system. Each level provided about 70-80 Lux of electric light with the total electric illumination at about 150 Lux. No daylighting controls were included; they were added after the fact. But calibration could not be accomplished since open loop type controls were added high up on the ceiling far away from the windows. The sensors never saw enough light from their location to turn any lights off.

Problem resolution: This problem has not been resolved.

Comments on the process: The electric lighting was designed with very low lighting levels. Further lighting reduction could have been achieved but the sensors needed to be placed at the windows looking outside. The building operators and contractors who added the controls did not realize the impact of the high ceilings and placed the sensors in the wrong location.

SUMMARY OF PROBLEMS

In many cases, we find that calibration of the controls was not done before the occupants moved in. While calibration itself can be easily done after construction is completed, other problems revealed by calibration cannot be corrected later. Once contractors have left the site, some reprogramming can be attempted, but rewiring is difficult to accomplish afterwards, window sizes, furnishings, and lighting fixtures will almost never be changed after construction is completed.

Daylighting systems failed due to a lack of coordination between the design disciplines - architectural, interior and space planning, mechanical and lighting. Designers seemed to be unaware of how the decisions they make can affect the performance of a daylighting control system. Sensors were blocked by other equipment and were located so as to be inaccessible for calibration. The location of daylighting controls is as much a spatial decision as the location of windows to bring in the daylight. Not many lighting designers realize this or create documents to reflect it.

In general, it seems that the usual checks of the design documentation were not in place for daylighting controls. Shop drawings made by the contractors that detail the daylighting system were not checked, or lighting designers simply did not know what to check for.

When a daylighting system performs poorly, the investigation or the compromises done later are not documented and taken back to the designer to complete the feedback loop.

Installations that are not calibrated do not perform well. The failure mode of under-dimming is typically not noticed nor reported. If on the other hand, the failure is over-dimming the occupant's performance may be hindered, the occupant will complain or simply sabotage the control system. The result of this is that a daylighting system that does not save energy goes unnoticed, and a daylighting system that saves energy more aggressively than it should, gets disabled.

2. In the case of complex building systems, a contractor will respond to an incomplete set of construction drawings by preparing a set of drawings called shop drawings that are sent to the designers for review; these drawings are also called production drawings in some countries. The system finally gets built to fulfill the approved set of shop drawings.

Case Study	1	2	3	4	A	C
Space type	College Dining Hall	College Classrooms	Office Building	Office Building	Grocery Stores	Office Building
Failure mode	**Under-dimming**	**Under-dimming**	**Over-dimming**	**Under-dimming**	**Under-dimming**	**Under-dimming**
Effects of Failure	Reduced energy savings	Reduced energy savings	Reduced energy savings	Reduced energy savings	Reduced energy savings	Reduced energy savings
Root Cause	Not wired correctly	System not calibrated	Calibrated aggressively	System not calibrated	Not enough windows	Sensor location improper for open loop control
Additional Causes	System not calibrated	Windows smaller than expected	Occupants have history of higher lighting levels	Too many sensors installed, calibration not feasible	Not calibrated initially	Not calibrated initially
		Sensor sees indirect lights	Dark furnishings create dark space			
Action to correct situation	Re-wire sensors to control dimming light sources	Proper calibration	Continue to test the ability of the occupants to accept some lighting control	Remove sensors from the daylighting system, control lights with 1 sensor per orientation	Continue calibration and evaluation	Relocate the sensors to the skylight
	Calibrate system	Educate operator		Proper calibration of remaining sensor		
	Educate operator	Educate user		Educate operator and user		

Case Study	5	6	7	8	B	D
Space type	College Classrooms	Big Box Retail	Office Building	Recreation Center - Pool	Office Building	Office Building
Failure mode	**Cycles**	**Over-dimming**	**Lights on at night**	**Under-dimming**	**Over-dimming**	**Under-dimming**
Effects of Failure	User irritation	Concern for store revenue to be reduced	Reduced energy savings	Reduced energy savings	User irritation	Reduced energy savings
Root Cause	Faulty controller	Calibrated aggressively	Night-time over-ride not available	Sensor location does not detect enough light	Incorrect set of lights being controlled	No controls installed during construction
Additional Causes	Photosensor and controller incompatible	3 daylight zones makes calibration a more complex task to do accurately.	Wrong sensor type installed	System not calibrated		
		Daylight is not uniform in the space				
Action to correct situation	Change programming in EMS system to set delay for dimming by the photosensor	New owner needs to understand system and become convinced to try re-calibration	Change sensor type and relocate sensor	Remove poorly located and not working sensors from the system.	Rewire the lights	Relocate the sensors to the windows- not done
				Control fewer fixtures with the working sensor		

Figure 1. *Failure analysis of case studies*.*

*Vaidya 2004. Case studies numbered 1 through 8 have been described in detail in our earlier work, but they are included here in the failure analysis. The failure analysis method applied here is based on the Failure Mode and Effect Analysis prescribed by the Failure Information Center.

Failure Analysis and Future Process Controls

In our earlier work we identified and described four common failure modes for daylighting systems; under-dimming, over-dimming, cycling, and cases where the lights are turned on and stay on through the night. We propose that a daylighting system that is found to be not working can be approached by considering and identifying the type of failure. Once a failure mode is identified, the failure mode template (Figure 2) can be referred to for further understanding, investigation and action. The template shows the effects, severity level, and potential consequences. It recommends a temporary action as an immediate response; it suggests potential causes. This list of potential causes can be used to identify the root cause of the failure which in turn would suggest a corrective action.

Based on the observations from the case studies and the potential causes listed in the failure templates, we propose a set of actions below that may act as future process controls.

Coordinating between design disciplines

Coordinate with the users so that the frequency of lighting change that will occur with controls is acceptable to them. Ensure that the parameters used in initial daylighting calculations are still valid. The parameters include window sizes, glazing, shading, partitions and other obstructions, surface reflectances etc. Ensure through coordination that the photosensor's view is not blocked by other equipment.

Developing a lighting control narrative

Prepare a written description of how the controls are expected to operate. Describe how daylight controlled lighting interacts with other controls such as manual switching, occupancy sensors and building-wide programmable controls. This allows other disciplines, commissioning agents, contractors, building operators and even users to understand the control system. It allows the control manufacturer to propose equipment that may better suit the narrative.

Failure mode	Under-dimming	Cycles	Over-dimming	Lights on at night
Effects of Failure	Reduced energy savings	User irritation	User irritation	Reduced energy savings
Severity	Major	Catastrophic	Critical	Major
Potential consequences	Savings loss	Disabled sensor, zero savings	Disabled sensor, zero savings	Savings loss
Reccommended Immediate Action	Call commissioning agent	Call commissioning agent and disable sensor/ controller	Call commissioning agent and disable sensor/ controller	Call commissioning agent
Potential causes	System not calibrated Sensor location does not detect enough light Not wired correctly Faulty sensor Not enough windows in room Sun-glare issues, users draw shades Dark furnishings, sensor sees dark surfaces	Delay not set Not calibrated Faulty controller	System not calibrated Sensor location sees electric light Sensor location sees excess daylight Wrong sensor type installed	No night-time over-ride set Night-time over-ride not available
Identify Root Cause				
Identify Additional Causes				
Action to correct situation				

Figure 2. *Daylighting Failure Mode Templates.*

Reviewing construction documents

Review the construction documents with a specific focus on the daylighting system.

- Ensure that the parameters used in initial daylighting calculations are still valid and that other disciplines have not compromised the daylight quantities or sensor's view.
- Ensure that the sensor is located appropriately for maintenance access, and to avoid direct exposure to sunlight or electric light.
- Ensure that the controller is located appropriately for easy access for calibration and maintenance. Check to see that photosensor type, range, field of view, control algorithm, fade rate delay, setpoint and deadband have been specified.
- Ensure that light fixtures and lamps to be controlled have been identified and grouped correctly and assigned to the appropriate photosensor control.
- Ensure that the electric light source to be controlled is compatible with the daylighting controls and sequences.
- Ensure that a controls narrative is included in the specification.
- Check to see that calibration and short term system monitoring is specified. Calibration is to be typically required as per the manufacturer's recommendation. Short term monitoring of light levels, power draw of the controlled circuit, and exterior light levels should be recorded every five minutes for a minimum of one week.

Requiring and checking shop drawings

Follow review procedures outlined for the construction documents.

Instructions for user/ operator

Building operators need to be made aware of the system, and how it is expected to work. This can be done by explaining the lighting controls narrative. In addition, the building operators have to be given a failure mode instructions; make building operators aware of how to temporarily disable system; give them contact information to call in case the lighting controls do not work as expected.

Issues with the overall design and construction process

Quality of design decisions that affect daylighting savings: Success of a daylighting system in a building depends on a series of design decisions. Figure 3 lists the types of decisions that are made on a typical daylit building. Against this list of decisions we list the primary design discipline responsible for making the decision and documenting it in the drawings or specifications. The same trade is also responsible for checking the shop drawings to determine if the design intent is being followed there. In our earlier work we subjectively scored the decisions for the way they get made and how they eventually affect the savings of a daylighting system. In general, decisions made by the architect are made reasonably well but the lighting energy savings are not always realized. Even when buildings are designed to harvest daylight aggressively, the energy savings due to lighting energy reduc-

		The quality of this decision		Documentation (adequate or inadequate currently)					
				Design		Construction		Commissioning/ Calibration	Post Occupancy
Decisions that affect daylighting	Primary Trade	Could be better	reduces/eliminates daylighting savings	Drawings	Specifications	Shop Drawings	Contractor Submittal	Report	Report
Building Orientation	AR	Y	R	A					
Building Shape	AR	Y	R	A					
Ceiling height	AR	N	ok	A					
Window Area	AR	N	ok	A					
Window location	AR	N	ok	A					
Glazing type	AR/ ME	N	ok		A		A		
Exterior Shading	AR	N	ok	A	A		A		
Interior Shading	AR/ ID	Y	R		I		I		
Interior space planning	ID	Y	R	A					
Interior partitions	ID	Y	R	A		A	A		
Interior Colors	ID	Y	R		A		A		
Lighting Illuminance	LD	N	ok		A				
Lighting Fixture type	LD	N	ok	A	A		A		
Lighting Lamp type	LD	N	ok	A	A		A		
Lights to be controlled	LD	Y	R	I		I			
Control Sequence	LD	Y	E		I		I		
Lighting Switch/ Dim control	LD	N	ok	A					
Ballast type	LD	N	ok		I		I		
Photosensor type	LD	Y	E		I		I		
Photosensor location	LD	Y	RE	I	I	I	I		
Photosensor, number of	LD	Y	R	A		I			
Controller dials available	LD	Y	RE		I		I		
Controller location	LD	Y	RE	I		I			
Calibration	LD	Y	RE		I		I	I	
Relamping - Burning in guidelines	LD	Y	RE		I			I	
Building operator education	CA	Y	RE		I		I	I	I
User awareness education	CA	Y	E		I				I
Problem reporting protocol	CA	Y	E		I				I
Performance monitoring	CA	Y	R		I				I
Performance reporting	CA	Y	R		I				I

AR = Architect, ID= Interior Designer, ME = Mechanical Engineer, LD = Lighting Designer, CA = Commissioning Agent
R = Reduces, E = Eliminates, RE = Reduces and could eliminate, A = Adequate, I = Inadequate

Figure 3. *Decisions and Documentation Quality.*

tion are not fully realized. Some of the daylighting potential created by the architectural design is reduced due to interior design decisions, but a large part of the savings is lost simply because the lighting controls do not function well. The commissioning agent's work include tasks that go beyond the simple checking of the system; we associate the commissioning agent with building operator and user education and for continued performance monitoring. These tasks are not routinely incorporated into a commissioning agent's scope of work.

Design documentation issues that reduce daylighting savings: The architect's and interior designer's documentation related to making daylighting work is passive in nature[3] and is usually done adequately. In the lighting designer's scope of work, lighting fixture design is documented well, but lighting controls for daylighting are often documented only at a conceptual level. A commissioning agent's documentation fares even worse. All design disciplines care equally about the work they produce – the lack of adequate documentation is in no way due to a lack of intent, rather it is due to a lack of training on how to do it.

A daylighting control changes the nature of a lighting system from a static to a dynamic one. Lighting designers, unlike HVAC designers, are currently not skilled at designing dynamic systems. They do not have the experience and do not know how to make documentation required for dynamic systems. Many lack sufficient familiarity with the controls and do not have a clear process for proper implementation. Lighting designers, like all design professionals, rely on a repository of design experiences and published guidelines. The Illumination Engineering Society of North America (IESNA) is a professional organization that takes the lead on developing guidelines and standards for design. IESNA publishes Recommended Practices and Design Guides to be used as references. Lighting design in terms of the source photometric data, availability of resultant light and its distribution is well documented and supported in the guidelines and software tools. On the controls side, however, neither the IESNA publications nor any software tools seem to do justice to the topic. Lighting designers claim that since control products vary across manufacturers, their best option is to seek the documentation provided by the manufacturer (Hunt 2004). They design and prepare documentation based on the guidelines provided by the manufacturers (Hunt 2004; Nielson 2004; Reese 2004). Manufacturers' information is often inadequately presented and inconsistent within the industry.

3. Architects have been designing and getting windows and window treatments built for centuries. If a window shape or design needs to be changed for daylighting from what is normal, they still know how to get it built. Thus window openings, glazing types and window treatments are typically well documented and implemented.

Features	Open Loop Switching	Open Loop Dimming	Closed Loop Switching	Closed Loop Dimming
Gain/ sensitivity adjustment	-	MH	-	MH
Deadband adjustment	HD	-	HD	-
Setpoint adjustment	MH	O	MH	MH
Time delay adjustment	HD	O	HD	O
Speed of reponse adjustment	O	O	O	O
Remote adjustment	O	O	O	O
Easily accessible, clearly labeled controls for calibration	HD	HD	HD	HD
Graduated indicators for all controls adjustments	HD	HD	HD	HD
Manual override	O	O	O	O

MH = Must Have, HD = Highly Desirable, O = Optional

Figure 4. *Control Features Checklist.**

*This matrix was developed by The Lighting Research Center for the Daylighting Controls Practicum, 2004.

Of the inadequacies apparent in the decisions and documentation quality matrix, we choose to focus here on the suggested process improvements that concern lighting control design.

Process Improvement Suggestions

Improved documentation from the lighting control manufacturers: Our survey of documentation provided by 3 lighting control manufacturers showed an inconsistency in the information that is provided by each manufacturer about their controls (Vaidya 2004). A consistency in the documentation would mean that each manufacturer provide, at a minimum, the following information for each daylighting control product:

- Range of illumination response that the sensor is capable of.
- Spectral response of the photosensor.
- Control algorithm type, such as open or closed loop.
- List of features: Gain/ sensitivity adjustment, deadband adjustment, setpoint adjustment, time delay adjustment, speed of response adjustment, remote adjustment, labelled controls for calibration, graduated indicators for controls adjustments, manual override.
- Working temperature and humidity range.
- List of compatible ballasts and components.
- Power requirements for the control.
- Number of ballasts the device can control.
- Application guide by common spacetypes.
- Sample wiring diagrams.
- Sample control sequence narrative.
- Specification guidelines and samples.
- Installation guidelines.
- Calibration guidelines.

Process improvement for design and documentation: The Lawrence Berkeley National Laboratory has published *Tips for Daylighting with Windows*. Section 8 of this document discusses the considerations during design of a lighting control system. Electric Power Research Institute's Lighting Controls Patterns for Design is another definitive guide to be used during the design process. Despite the availability of such resources, their adoption and use by lighting design professionals is rare. The Lighting Research Center has started to conduct training workshops specifically designed for daylighting controls. A lot more work for dissemination of this knowledge is necessary. Currently available guidelines and workshops are focused on educating the designer about the controls and helping them select the right equipment. As yet, there have been no guidelines written on preparing the documentation that will convey the design intent adequately to the contractor. We offer the following comments as a take-off point towards the development of such a documentation guideline.

- Based on the architectural elements of the design, do a daylight simulation that produces daylight isolux plans; use these plans when designing the lighting system and its controls.
- Prepare plans that document the expected daylight zones for the building while breaking up areas that require control independent of each other as a result of window conditions, or pattern of use.
- Locate the daylight sensor on the reflected ceiling plans and interior elevations.
- If the controller is separate from the sensor, locate the controller on plans and interior elevations.
- Identify lighting fixtures that are controlled by individual sensors or controllers. This can be done through lighting fixture and control schedules or through single line circuit diagrams.
- List compatible ballasts in the specifications.
- Prepare a controls narrative to be included in the specifications. The narrative should mention the times and sky conditions when adequate levels of daylight are expected to activate daylighting controls. It should describe how

the controller will respond as daylight illumination levels increase, how fast the controller will respond to abrupt changes in daylight levels, and how the controller will respond as the day progresses towards night and daylight levels reduce. The narrative is to address how daylight controlled lighting interacts with other controls such as manual switching, occupancy sensors and building-wide programmable controls.

- For the photosensor and control equipment, each desirable feature should be specified. The checklist in Figure 4, developed by The Lighting Research Center, helps identify equipment features based on type of control and control algorithm.
- Require the contractor to submit shop drawings based on the design documents and the control narrative. Review the shop drawings.
- Include the requirement for calibration of the daylighting controls in the specifications. The calibration must be done by an authorized representative of the controls manufacturer. Require calibration logs to be submitted as part of contractor submittals.
- Include a requirement for building operator training on the daylighting controls by an authorized representative of the controls manufacturer.
- Include a requirement for short term performance monitoring of light levels, power draw of the controlled circuit and exterior light levels, to be recorded every five minutes for a minimum of one week after the building is occupied. Ask the building operator to prepare a brief report of user interviews on daylighting controls, and review performance monitoring results and user interviews with an authorized representative of the controls manufacturer and energy consultant.

Conclusion

Daylighting systems often fail due a number of reasons. Common amongst these is the lack of coordination between design disciplines to ensure that initial parameters with which daylighting savings are predicted are not compromised later. Many lighting designers currently do not possess adequate knowledge of daylighting controls. Manufacturers of daylighting controls do not provide adequate and consistent product information. There is a lack of training on how to provide appropriate documentation get the daylighting control system implemented right.

In this paper we have suggested controls and checks in the overall design and construction process to increase the likelihood of success. We have identified the typical inadequacies in the design documentation. We suggest a minimum level of information that manufacturers of daylighting control systems should provide and we have compiled a guideline for documentation that designers need to provide to contractors so that the design intent may be fully conveyed. This guideline needs to be developed further especially by professional organizations such as the IESNA.

References

Bullough, J, Wolsey, R. 1998. Specifier Report: Photosensors. National Lighting Product Information Program Specifier Reports V6,1. The Lighting research Center.

CHPS Inc. 2002. CHPS Best Practices Manual 2002 Volume II—Design Daylighting Collaborative. www.daylighting.org. Last Accessed February 12, 2004.

Electric Power Research Institute. 1996. Lighting Controls Patterns for Design.

Electric Power Research Institute. 1997. Daylighting Design Smart and Simple.

FMECA.COM www.fmeca.com/ffmethod/fmeaproc.htm. Last Accessed February 12, 2004.

Herzog, P. 2004. Building operation consultant. Personal communication. February 25.

Heschong Mahone Group. 1998. Skylighting Guidelines

Hunt, P. 2004. Lighting designer. Personal communication. January 16.

Lutron. www.lutron.com. Last accessed March 10, 2004.

Munton, B. 2004. Controls manufacturer representative. Personal communication. February 18.

New Buildings Institute, 2003. Advanced Lighting Guidelines

Nielsen, E. 2004. Lighting designer. Personal communication. January 20.

O'Connor, J, Lee, ES, Rubinstein, F, Selkowitz, S. 1997. Tips for daylighting with windows: Sensors and controls (pages 8-1 to 8-7). Lawrence Berkeley National Laboratory.

Pacific Gas and Electric Company. 1999. Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance.

PLC-Multipoint, Inc. www.plcmultipoint.com. Last accessed March 10, 2004.

Reese, J. 2004. Lighting designer. Personal communication. January 20.

Spectrum Associates Market Research. 2003. Daylighting Dividends Focus Group Report. The Lighting Research Center.

The Watt Stopper, Inc. www.wattstopper.com. Last accessed March 15, 2004.

The Watt Stopper. 2003. Classroom Photosensor Control System Performance Specification. PIER Lighting Research Program

The Watt Stopper. 2003. State of the Art Photocell: Final Report. PIER Lighting Research Program

Vaidya, P, McDougall, T, Steinbock, T, Douglas J, Eijadi, D. 2004. Where It Goes Wrong and How Users Respond to Failure. In Proceedings of ACEEE 2004 Summer Study.