Recommended Daylight Conditions for Photosensor System Calibration in a Small Office

Soo-Young Kim and Richard Mistrick

We generally rely on electric light to illuminate the interior of a commercial building. At the present time, however, there appears to be an increasing trend toward sustainable design, which means that daylight will likely play a more important role in the lighting of commercial buildings in the future. With daylight responsive control systems, it is projected that approximately 20-40 percent of a building’s lighting system energy consumption can be eliminated.\(^1\) One way to reduce the electric lighting energy in the perimeter of a building is to employ a photosensor-based dimming control system. Recently, a number of studies have performed detailed modeling or measurement of these systems, providing important information on both their performance and their design.\(^7\)

In a photosensor-controlled dimming system, the illuminance at the workplane is indirectly determined by the photosensor, and the electric lights are subsequently dimmed based on this sensor reading. To maximize energy efficiency and minimize occupant complaints, a photosensor dimming control system must properly control the electric lighting system, and, in particular, avoid situations where the workplane illuminance falls a significant amount below the target illuminance level.

Proper sensor location, control algorithms and photosensor calibration are necessary. Recent studies have shown the advantages of proper sensor placement and the impact of control algorithms on system performance. However, the optimum daylight condition at which to calibrate a photosensor dimming system to best maintain the target illuminance has received little attention. This paper expands on previous work, applying a wider range of daylight conditions to generate recommendations for field calibration of these systems. In this study, computer simulations were performed for a small office under a variety of daylight conditions for three commercially available photosensors.

Computer simulations

Simulation software

The simulation software used in this research is a series of computer programs written in FORTRAN, which is referred to as DayDim. DayDim determines workplane illuminance and computes the effective photosensor signal due to daylight and undimmed electric light. This analysis considers the spatial response and spectral response characteristics of three photosensors measured by Bierman, et al. Given a series of daylight conditions, the software determines an optimum calibration setting for a dimming system based on its control algorithm and the available calibration adjustments. The software can also be used to track the performance of the control system at a particular calibration setting over the course of a day. This software has been used in a number of previous studies and has been shown to agree reasonably well with real world performance.\(^3,7\)

Room, daylight and electric lighting conditions

The private office space considered in this study was \(3.6 \times 3.6 \times 2.7\text{ m} \) (12 ft wide \(\times\) 12 ft deep \(\times\) 9 ft). The reflectances of the ceiling, walls, and floor were assumed to be 0.8, 0.6 and 0.2, respectively, which are typical of most office spaces. Two 0.9 m (3 ft) wide by 1.5 m (5 ft) high windows were considered on the exterior wall. These windows were oriented toward both the north and the south in separate test conditions. For the north-facing space, the transmittance and reflectance of the windows were assumed to be 0.8 and 0.13, respectively, while for the south-facing space, they were 0.63 and 0.13, respectively. The transmittances were selected to study a wide variety of daylight conditions that resulted in a dimming level that was often above the minimum setting.

The surfaces of the room and windows were discretized into 0.15 m by 0.15 m (0.5 ft by 0.5 ft) elements for flux transfer purposes. A 0.9 m (3 ft) by 1.8 m (6 ft) desktop was located along the centerline of the space, with its geometric center 1.95 m (6.5 ft) from the window at a height of 0.75 m (2.5 ft). The reflectance of the desktop was 0.3. The desk’s top surface was the only interior object considered in the room flux transfer analysis. The sides of the desk were not considered. Figure 1 shows the dimensions of the space and the two photosensor positions used in this study.

The luminaire applied in this space is a common recessed 0.61 m (2 ft) by 0.591 m (2 ft) parabolic fluorescent troffer with a 3 in. louver. The luminaire had a 4x4 array of cells and two T8 "U" shaped lamps. The optical efficiency of the luminaire was 55.3 percent, and a light loss factor of 0.72 was assumed. The electric lighting system provided an average of 540 lx (50 fc) on the desktop.

The dimming ballast used in this research has a dimming range of 17-100 percent of full electric light out-
put. The control signal voltage delivered to the dimming ballast is between 0-10 V, and the ballast responds to this voltage as shown in Figure 2.

The site for this building was assumed to be State College, PA (latitude: 40 degrees 50 ft, longitude: 77 degrees 50 ft). Clear, partly cloudy and overcast sky conditions were applied with a ground reflectance of 0.1. The window control conditions considered were no blinds (unobstructed clear glazing), and horizontal blinds oriented at 0 and 45 degrees applying the blind transmittance data of Klims. The days modeled were January 21, March 21 and May 21, and the times considered were hourly from 8:00 am to 5:00 pm (17:00). Table I summarizes the day, time, room orientation, blind and sky conditions assumed in this study.

Photosensors and control algorithms

Figure 3 shows the spatial response patterns of the three photosensors. These correspond to sensors 5, 6 and 8 in the Bierman study, but will be considered in this paper as sensors 1, 2 and 3, respectively. Sensor #1 has a medium-wide sensitivity distribution with symmetry in the horizontal plane. The maximum sensitivity of this sensor occurs at about 20 degrees from nadir. Sensor #2 has a wide distribution with a maximum sensitivity at approximately 25 degrees from nadir. Sensor #3 has a relatively wide distribution that is symmetrical about the photosensor’s principal axis. The control algorithm for these systems is closed-loop proportional control. Systems 1 and 3 are completely linear, while system 2’s algorithm provides a small amount of curvature. Sensors 1 and 2 were positioned in the center of the ceiling and aimed directly downward, while the maximum sensitivity for sensor 2 was directed into the room (away from the window). Sensor #3 was located 2.4 m (8 ft) into the room and tilted at a 45-degree angle toward the back wall, as directed by the manufacturer. Figure 1 shows the position of the photosensors in the room.

Optimizing the calibration settings

For the purpose of this study, the optimum calibration setting was the one that provided the best overall fit to the data (lowest sum of squares error), while not allowing the task illuminance to fall more than 10 percent below the target illuminance at any time. Task illuminance in this study was the average illuminance on the desk surface (determined using an array of points uniformly distributed across this surface).

The optimized calibration setting used in this research is defined as the setting that minimizes the error sum of squares (SSE) of the final dimming level (δ) from the ideal dimming level (δ_ideal), where the maximum permitted deviation below the target level is 10 percent. For a daylight condition where the average

<table>
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<th>Date</th>
<th>Time</th>
<th>Blind Conditions</th>
<th>Sky Types</th>
<th>Orientation</th>
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<tr>
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<td>08:00-17:00</td>
<td>No Blind</td>
<td>Clear</td>
<td>South</td>
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<tr>
<td>Mar. 21</td>
<td>08:00-17:00</td>
<td>45° Blind</td>
<td>Partly Cloudy</td>
<td>North</td>
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<td>08:00-17:00</td>
<td>Horizontal Blind (0°)</td>
<td>Overcast</td>
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Table 1—Daylighting conditions studied.
desktop illuminance from daylight is less than the target
desktop illuminance, the ideal dimming level is defined
as the level at which the resulting average desktop illu-
minance is equal to the target illuminance. For a daylight
condition where the sum of the average illuminance
from daylight and minimum electric light exceeds the
target illuminance, the ideal dimming level is defined as
the minimum dimming level. The definition of the ideal
dimming level is expressed in Equations 1 and 2.

\[ \delta_{\text{ideal}} = \begin{cases} \delta_{\text{min}} \\ 1 - \frac{E_{\text{wp-d}}}{E_{\text{wp-t}}} \end{cases} \]

(1)

( if, \( E_{\text{wp-d}} + E_{\text{wp-e}} > E_{\text{wp-t}} \) )

( if, \( E_{\text{wp-d}} < E_{\text{wp-t}} \) )

where,

\( E_{\text{wp-d}} \): Workplane Illuminance due to Daylight

\( E_{\text{wp-e}} \): Minimum Workplane Illuminance due to

Electric Light

\( E_{\text{wp-t}} \): Workplane Illuminance due to Daylight and

Electric Light

\( \delta_{\text{ideal}} \): Ideal Dimming Level

\( \delta_{\text{min}} \): Minimum Dimming Level

The SSE of the final dimming level with respect to the
ideal dimming level was calculated using Equation 3, which
considers a weighting factor that accounts for the relative
frequency of a particular sky condition at the test site.

\[ \text{SSE} = \sum \frac{N}{c} \left( \delta_{c} - \delta_{c, \text{ideal}} \right) \times W_{c} \]

(3)
where,

\[ N = \text{total number of sampled daylight conditions for each window orientation (i.e. north-facing or south-facing)} \]
\[ c = \text{Index for the N daylight conditions.} \]
\[ \delta_{\text{act}} = \text{Actual dimming level} \]
\[ \delta_{\text{ideal}} = \text{Ideal dimming level} \]
\[ W_c = \text{Weighting factor, proportional to the percent occurrence of daylight condition } c. \]

### Simulation Results

**Development of calibration guidelines for each system**

Graphs of system performance are provided for each of the three photosensors for each of the three time conditions and room orientations in Figures 4-9. On these graphs, the individual points represent dimming levels that would provide an illuminance equal to the target level and the corresponding photosensor signal. The optimum photosensor system calibration condition that addresses performance across all three test dates for each sensor and room orientation is also shown on these graphs.

Using these graphs of system performance and the optimum dimming lines, calibration guidelines were determined. For the purpose of this study, we decided that a suitable daylight calibration condition must provide at least 40 percent of the target illuminance, and provide performance similar to that of the optimum dimming curve. The daylighting conditions (time of year, sky and blind conditions) were then classified into the following categories: Best, Good, Not Recommended and Insufficient Daylight — in terms of their suitability for use as the system calibration condition. This classification was done using visual evaluation.

The “Best” calibration conditions are those points that lie very close to the optimum calibration line with light output settings of 17-60 percent of the target illuminance. Calibration conditions that were positioned slightly below or above the optimum line and fell within this dimming range were considered as “Good” conditions. Points that fell well below the criterion line, through which an established system dimming line would undershoot the target illuminance much of the time, and points where the target illuminance was exceeded are “Not Recommended.” Finally, conditions that provided insufficient daylight on the workplace (requiring light output greater than 60 percent of the target) are noted.

**Table 2** presents a summary of these calibration guidelines. In general, horizontal blind conditions with clear and partly cloudy skies provide either the best or good conditions on most days of the year (when direct sunlight penetration does not occur). The partly cloudy conditions are generally closer to the optimum calibration condition than are those for the clear sky. The 45-degree blind orientation only provides sufficient daylight for the May daylight condition and a few others, when the ground receives high illuminance, and is generally acceptable under these conditions. The no-blind conditions provide the worst possible calibration conditions and are not recommended under any sky condition when blinds are present on the windows and are likely to be applied. Calibration under a no-blind condition will result in the electric lighting system not meeting the target illuminance when blinds are then applied.

**Discussion of calibration guidelines**

The calibration guidelines proposed in this study are valid for the single room geometry condition considered here. These results are in general agreement with the results obtained by others (in particular, Lee, et al.).

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Figure 5—System performance and optimum calibration condition for System #1, South-facing; January 21 (top), March 21 (middle), and May 21 (bottom).

Figure 6—System performance and optimum calibration condition for System #2, North-facing; January 21 (top), March 21 (middle), and May 21 (bottom).

Based on the results of Lee, it is likely that blind angles between 0 and 45 degrees will provide acceptable results if daylight levels are sufficiently high.

Lee appropriately states that calibration should be performed under stable daylight conditions, and indicates that such conditions can be achieved under a clear or overcast sky. In this space, an overcast sky did not provide acceptable results, either providing too little daylight when the blinds are applied, or a poor photosensor to task illuminance ratio when no blinds are used. Lee’s study did not consider the no-blind condition. Lee recommends against partly cloudy sky conditions because such skies can produce significant variation in daylight over a short time period. If partly cloudy conditions are present and the daylight is relatively stable over the time it takes to calibrate a system, the resulting calibration would appear to be acceptable. Lee also suggests that the range in the gain for a particular calibration condition should be determined by adjusting the Venetian blind over its full range of tilt angle, and that a blind angle of 20-45 degrees is a good condition at which to commission the system, which appears to be a reasonable approach. In this study, the horizontal condition fared slightly better than the 45-degree condition in most cases, but the results are quite similar and agree very well with the measurements performed by Lee.

Lee also recommends that the daylight illuminance on the workplane should be at least 100 lx, which, in a space designed for 500 lx, represents 20 percent of the target value. In this study, we have selected a minimum value that is 40 percent of the target level to reduce the magnitude of errors that may result from extrapolating the dimming line through a calibration point that is very near the no-daylight condition. It is not clear exactly where this lower cutoff level should be set, but a higher minimum daylight level is likely to provide better results.
Figure 7—System performance and optimum calibration condition for System #2, South-facing; January 21 (top), March 21 (middle), and May 21 (bottom).

Correlation between photosensor signal and workplane illuminance

The position of a photosensor and its spatial response impact system performance since they affect the relationship between the photosensor signal and the target illuminance.

In this research, the correlation between the signal generated by the photosensors and the workplane illuminance due to daylight were studied for each of the three photosensors. $R^2$ values were determined for a linear fit between these two quantities. Table 3 shows the correlation between photosensor signal due to daylight and workplane illuminance due to daylight, where $R^2$ values range from 0.63-0.91. The north-facing room yields slightly higher $R^2$ values than the south-facing room, which is consistent with past research. In the south-facing room, all no-blind (clear window) conditions that admitted direct sunlight were eliminated from this analysis.

System #3 had the best correlation while system #2 showed the weakest correlation among the three systems. These differences likely result from the photosensors’ different spatial sensitivity characteristics. Sensor #3 was aimed toward the back wall and therefore is impacted least by direct light arriving from the window. System #2 likely receives the most direct light from the window. Sensor #2 appears to track the daylight quite well when blinds are used, which is consistent with the results of a previous study that did not assess the no-blind condition. In that study, this sensor provided the best overall correlation. However, since the no-blind conditions provide a very different sensor reading to workplane illuminance ratio, the $R^2$ value for this sensor is lower when...

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calibration condition for the range of sky conditions studied. A blind condition was selected for each daylight condition that provided the most daylight without exceeding the target illuminance level. The results of this analysis (shown in Table 4) indicate that the difference in energy savings is small between the three different photosensor systems. As expected, clear skies provide the most energy savings, while overcast skies provide the least; South-facing windows provide more energy savings than north-facing windows, and horizontal blinds provide more energy savings than does a 45-degree blind condition.

Conclusions

In this study, computer simulations were performed in a small office for three photosensors under a variety of daylighting conditions. Optimum dimming curves were developed using each photosensor’s control algorithm, which were then used to develop calibration guidelines for these sensors. A summary of these guidelines and other general findings of this study are as follows:

1. Calibration of small offices equipped with horizontal blinds should be performed with the blinds lowered under clear or partly cloudy sky conditions if the blinds will be used when the space is occupied. If partly cloudy conditions are present at calibration time, the setting should be acceptable, provided daylight levels are stable during the calibration process. In this study, the 0-degrees blind condition provided an appropriate setting most of the time, while the 45-degree blind setting provided too little daylight much of the time. Although only 0-degree and 45-degree blind conditions were considered, it appears that a blind angle between 0 (horizontal) and 45 degrees should also provide good calibration conditions if sufficient daylight levels are provided.

2. The fact that relatively similar results were obtained for the three sensors, which have characteristically different spatial response functions, indicates that these findings are likely to be generally applicable to most photosensor systems applied in small offices.

3. In offices where blinds are likely to be used, calibration should not be performed with the blinds retracted (in the full “up” position) since this will result in the electric lighting system being dimmed excessively when the blinds are in use.

4. When the three photosensors were calibrated at their optimum calibration condition, reasonable energy saving levels were achieved in the private office, even when blinds were utilized. All three sensors provided similar levels of total energy savings under the tested sky conditions.

5. For the photosensors studied, the correlation between photosensor signal and work plane illuminance due to daylight was best for the photosensor that was...
<table>
<thead>
<tr>
<th>Mon</th>
<th>C-C</th>
<th>North-facing Room</th>
<th>South-facing Room</th>
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<tr>
<td></td>
<td></td>
<td>System #1</td>
<td>System #2</td>
</tr>
<tr>
<td>Jan</td>
<td>Best</td>
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<td>Good</td>
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<td>Ho</td>
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<td>P/C</td>
<td>Ho</td>
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where,  
C : Clear Sky  
P/C : Partly Cloudy Sky  
O/C : Overcast Sky  
Mon : Month  

Table 2—Calibration Guidelines for each Photosensor System

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<thead>
<tr>
<th>System</th>
<th>North-Facing</th>
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<tr>
<td># 1</td>
<td>0.87</td>
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<tr>
<td># 2</td>
<td>0.74</td>
<td>0.65</td>
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<td># 3</td>
<td>0.91</td>
<td>0.85</td>
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</table>

Table 3—Correlation ($R^2$) between photosensor signal due to daylight and workplane illumination due to daylight

angled to receive light from the wall opposite the window. The lowest correlation occurred in the system whose spatial response provided it with the largest direct light contribution from the window.

Future work  
A field study would help to further validate these recommendations, but could not be performed as part of this study due to the lack of a suitable space, the cost of such a study and the amount of time required. Based on JOURNAL of the Illuminating Engineering Society Summer 2001
### Table 4—Percent electric lighting energy savings per day

<table>
<thead>
<tr>
<th>Month</th>
<th>Sky</th>
<th>Blind</th>
<th>North-facing #1</th>
<th>North-facing #2</th>
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<td>34.6</td>
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<td>61.1</td>
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Where,
- C : Clear Sky
- P/C : Partly Cloudy Sky
- O/C : Overcast Sky
- Hor : Horizontal Blind
- 45 : 45° Blind
- : No Blind
- : Not shown since direct sunlight is admitted

Previous work, however, the findings of these simulations should agree reasonably well with real world results. The algorithms applied in this study are designed to model all aspects of a control system's operation, as it would occur in a real installation.

Additional work is needed to study blind conditions between 0 and 45 degrees. This study applied actual bidirectional transmittance data for blinds, which was only available for the two blind angles tested. Further study will be possible with advancements in analysis software that are currently under development.

Additional studies should be performed to determine if these calibration guidelines could be applied to different window configurations and room types. No overhang or other exterior or interior obstructions were considered in this research, which may have some impact on the results. A similar study is currently underway for a large open space (a classroom). Similar work could also be performed for open plan offices where furniture and partitions are present. The results of this study suggest that the presence and the angle of the blinds are critical factors that affect photosensor control system performance.
Acknowledgments
We would like to thank Pacific Gas & Electric Company for permission to apply the photosensor performance data gathered under a previous research funded by them in this research effort.

References

Discussions
The work of this research team has provided another important piece of daylight system modeling. The results of this work will hopefully lead to improved methods for accurately calibrating and commissioning daylight-controlled dimming systems. The paper provides useful information and guidance. The incorporation of blinds and shading criteria as part of this research is particularly useful. Further research and empirical verification in this area will hopefully continue. Of particular interest is the work in larger spaces such as classrooms. The following are questions raised about the study.

1. Please provide a brief overview of the DayDim program, or is there more information available elsewhere?
2. What effect on system performance, calibration settings and energy will there be with ballasts that dim to one percent and five percent?
3. What are the R² values and their relevance to the study?
4. In actual use, occupants may tend to use blinds on south-facing but not north-facing windows. Am I correct in reading the percent energy savings chart, in that it shows improved savings on the north side under these conditions?
5. Do you have any thoughts on how to get this information into general use to provide improved calibration and commissioning of actual systems being installed.

What are your future plans for larger spaces? Also, will you do any actual measurements to verify these conclusions?

James Yorgey
Lutron Electronics
Coopersburg, PA

This research takes an invaluable step toward understanding how and where to place a photosensor and when to commission a daylighting photoelectric control system to achieve reliable control. This lack of understanding is a critical barrier within the daylighting industry. Historically, improperly installed and commissioned daylighting systems have resulted in occupant complaints of insufficient light, intervention measures and system disuse. This research develops a useful method, based on actual measured data of commercially-available products, which could be automated to yield design and commissioning guidelines for a variety of space types, daylighting systems (e.g. windows, skylights, shading systems, and light-redirecting systems), and climates or to develop improved control system products.

Clarification is needed on a few items:
— Basis for deciding which days of the year to model.
— Length-to-depth ratio of the Venetian blinds. This is useful in helping the reader to determine which days and hours will be affected by direct sun, particularly for sensors #1 and #2.
— Method for determining the effective photosensor illuminance and percent light output (shown as point symbols on Figures 4-9).
— The source of data to determine the relative frequency of a sky condition.
— Basis for deciding if suitable daylight conditions for calibration guidelines must provide at least 40 percent of the target illuminance (216 lx). Very low photosensor input can yield noise, but it appears that the point

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data (on Figures 4-9) within 10–40 percent of the target illuminance are not affected by signal noise.

— Commissioning typically takes 5-30 minutes per space. Did the authors note any time-of-day trends that indicate which times are better for commissioning than others; e.g. solar position relative to the window?

Separately, we monitored photosensor response with 1) a partially-retracted Venetian blinds with different tilt angles and 2) an unshaded window with different levels of glazing transmission in a subsequent full-scale test room study. This work (unpublished) agreed with your simulation data: The no-blind condition yields noisy data and should not be used for commissioning a system if blinds will be used in the space.

Can the authors comment on whether design tools or design guidelines will be developed in the near future based on the methods developed in this work?

Eleanor Lee
Lawrence Berkeley National Laboratory
Berkeley, CA.

This paper demonstrates the advances in understanding photosensor performance and the practical application information that can be garnered when photosensor systems are systematically analyzed according to their control algorithm responses. The graphs showing light output as a function of effective photosensor illuminance reveal the exact system response (solid line) as well as the ideal system response needed to maintain constant task illuminance under the different time and sky conditions (symbols). How well these two match characterizes how closely the system maintains workplane illuminance. This type of system analysis leads directly to the conclusions and useful recommendations given by the authors. For this reason, the paper is very valuable for helping people effectively use photosensors. Recommendations for calibrating photosensors that are based on solid analysis is sorely needed by the lighting controls industry, and the authors do a fine job of distilling the data down to useful conclusions and recommendations.

Because I feel that this type of analysis is so important to understanding photosensor performance, I would like to see more of an explanation of the graphs in Figures 4-9. I am concerned that the authors’ explanation is too brief and that the graphs may not be understood well by readers who are not familiar with this type of analysis. Further explanation of what is plotted on the graphs and how to interpret it would help ease my concerns that this type of analysis is appreciated.

Beyond calibration issues, the graphs also provide insight to the limitations of present-day photosensor technology. Specifically, it appears that the systems cannot respond adequately to both situations of blinds and no blinds using the same calibration settings. Do the authors view this as an important limitation to the usefulness of photosensor control and user acceptance, or are the differences with and without blinds rarely seen in practice? If it is a limitation, can integration of window blind control with photosensor operation overcome it in a practical manner?

The calculated energy savings presented in the paper are for the “optimum calibration setting.” While this is a useful benchmark for assessing product performance, how realistic is it? In other words, how sensitive are the energy savings to differences in the calibration settings done under the different sky conditions or different times of day? In a similar vein, the correlation between photosensor signal due to daylight and workplane illuminance due to daylight is dependent on the calibration setting as well. The authors state that the key to overall performance (for the systems tested) is achieving the proper calibration setting. A sensitivity analysis on how the calibration setting affects system performance would be interesting.

I agree that a field validation of the results obtained here would be nice to see, although I would not expect any significant differences in the conclusions reached. Nevertheless, validation of the simulation program and analysis methods is needed to fully establish these methods and increase people’s confidence in using photosensors and the tools for applying them.

Andrew Bierman
Lighting Research Center
Troy, NY

This paper presents a new recommendation on optimum calibration conditions for a photosensor-controlled dimming system for electric lighting systems in private offices.

Could the authors provide additional information to the following points?
1. Was clear glass the only glass type used for this investigation?
2. The presented data in Figures 4-6 system #2 position 1,7 system #3 position 2 show the best fit is to the PC or OVC sky conditions in most cases and in the case of the clear sky with blinds at Horizontal or 45-degree position, the results do not have a good fit. Why is this condition occurring? One would think the only time to use the blinds would be during the clear day for south or in case of external reflected component from north (e.g., high-rise buildings in Chicago along the waterfront).
3. Were any internal shields or baffles used within the interior photosensors modeling? (e.g., see your References 2 and 10).
4. What are the best indicators to be used for field validation of this work?

Mojtaba Navasab
The University of Michigan,
College of Architecture and Urban Planning
Ann Arbor, MI

The recommendation for blind position during calibration does not differentiate between north and south orientations of the window, regardless of the time of year. This seems surprising for the January condition, when the sun is near the horizon for much of the day (maximum solar altitude about 26 degrees for Pennsylvania). In fact, sunlight would likely penetrate horizontal blinds. At more northern latitudes, this effect would be even more pronounced. Could the authors comment on the effect this has on the illumination received by the spaces and by the detector?

Are there any positions at which the 45-degree tilted blind slats would re-direct sunlight to the detector? How would this affect the relationship between detector input and light received? At the workplace?

James A. Love, ArchD, P. Eng., LC, MRAIC
University of Calgary
Calgary, Alberta, Canada

Author's response

To James Yorgey

The DayDim program is described in more detail in reference #7.

With regard to ballasts that provide lower minimum light output levels, calibration and commissioning should not be significant affected; however, energy savings should be improved.

The R² values are provided to show a general goodness of fit between the calibration line and scattered optimum performance points. The improved savings on the north side are the result of the blind setting conditions used in this study. The daylight levels were not permitted to exceed the target level, even if no sunlight was admitted into the space. In reality, occupants could set their blinds to provide higher daylight levels and energy savings.

We believe that a tool such as DayDim would be very valuable for manufacturers of photosensor equipment. It would also be helpful to designers and specifiers of these systems. Of course, a user-friendly interface is important for any software to be easily applied. DayDim is a research tool, and does not have such an interface at the present time.

To Eleanor Lee

In response to Lee's questions, we decided to model the selected days because they represent roughly the center of three two-month periods for the purpose of conducting an energy analysis. In addition, the winter solstice is not that much different than the sky conditions on January 21 and the summer solstice is not that different than the conditions on May 21, so we considered a very wide range of sky conditions.

The blind conditions consider a standard 30 percent overlap (15 percent at each of the two adjacent blinds). The individual points on the graphs represent the effective photosensor illuminance that results from the daylight condition, and the dimmed electric lighting, that provides a workplace illuminance equal to the target illuminance level. If the dimming system worked perfectly, it would operate at each of these conditions. In reality, its performance must lie on a line that is fitted to these "optimum" performance points.

The weather conditions that were used were for the closest National Weather Service site for which the average number of clear, partly cloudy and overcast conditions in each month are available. For State College, PA, this location was Williamsport, PA, which is located about 55 miles away.

The decision to only accept daylight conditions that provide at least 40 percent of the target illuminance was a judgment decision. It may be possible to calibrate at lower values, but small deviations in these settings or readings would have a larger impact on the resulting system performance.

We did not investigate time of day trends. It appears, however, that the major condition that influences the interior daylight conditions is the blind angle. Still I would recommend conducting calibrations at higher solar angles, such as between 9:00 a.m. and 3:00 p.m (1500), to best represent the solar conditions over the course of a typical day.

We hope that manufacturers and other government agencies who are interested in promoting these systems will continue to study the key issues related to these systems, such as control algorithms, system calibration and occupant satisfaction. In the past few years, we have learned many important details related to the performance of these systems that now need to be transferred to the design and application of these systems. This should take the form of design guides, improved products and possibly analysis software.

To Andrew Biernack

With a control system that monitors and/or controls the blinds, it would be possible to improve performance and save additional energy by applying two calibration conditions: one with no blinds, and a second for an appropriate
blind setting. Energy would be saved in applying a no-blind calibration curve when the blinds are retracted, since the workplane would receive more than the required electric lighting levels if the system were calibrated with the blinds in place. Without such differentiation, the resulting illuminance levels will be higher than the target level under a no-blind condition, resulting in higher energy consumption. Differences between blind and no-blind conditions are expected, given that the blinds will alter the distribution of the daylight passing through a window.

System performance at other calibration settings is relatively easy to derive from the graphs. Calibration at a single daylight condition will result in a system performance curve that passes through the selected point. Points that lie to the right and above this performance graph will receive less than the target illuminance at those daylight conditions. This is because the points on this graph depict the dimming level required to maintain the target illuminance at each daylight condition (with the resulting sensor signal at this electric lighting condition due to both daylight and electric light recorded on the abscissa).

Meanwhile, the calibration line represents how the system will actually perform for each sensor signal condition for a single calibration condition. The distance that the calibration line lies below any point is a rough indication of how far below the target illuminance the resulting workplane illuminance will fall. It is a rough indication, because the sensor signal — due to daylight and the dimmed electric lighting condition — provides less than the target illuminance level, and will result in a signal that is slightly less than that at the corresponding point.

The actual energy savings is somewhat difficult to determine since it will be impacted by occupant control decisions. The values provided in the paper assume that the blinds are set at an angle where the resulting daylight illuminance will not exceed the target level; however, it is possible that the occupants will adjust the blinds so that higher illuminance levels are maintained, resulting in more energy savings than predicted. At times, the reverse may also be true. The occupants may fail to adjust the blinds to enhance daylight penetration as the available daylight declines, resulting in lower savings than predicted. Information on how occupants typically control their window blinds is needed to better predict the level of energy savings that may occur.

To Mojaba Navab

The glazing was clear for all cases (and blinds were used at an appropriate angle setting to block direct sunlight). If blinds will not be used on a north-facing exposure, then the calibration setting would be very different. However, if blinds are present and will be used, it is important to calibrate the system under an active blind condition, unless you want to force the occupants to open the blinds to achieve the desired workplane illuminance. (This would be necessary since the control system will provide less the required workplane illuminance if it has been calibrated under no-blind conditions and blinds are then applied).

Internal shields or baffles on the sensors were not necessary — these are commercially available products that are designed with a limited field of view or a directional response that faces away from the window in a small office application.

Since this work is designed to model all aspects of system performance, field validation of the work would compare the resulting dimming level in a real space with the dimming level determined by the software at the same daylight condition. This requires consideration of identical calibration settings in both the real and the modeled environments. Workplane illuminance values and photosensor signals should also be compared in both the real space and in the model.

To James Love

The blind conditions should not permit direct sunlight to enter the space on the south side of a building. A blind angle setting of 45 degrees will block direct sunlight at a solar profile angle of 13 degrees, therefore the elimination of direct sunlight should not be too difficult. Further studies may be necessary at higher site latitudes than the 40-degree latitude considered in this study.

A blind angle where mirror-like reflections of direct sunlight are directed to the photosensor from the blinds would not be a good calibration condition, and may result in over-dimming of the lamps if it occurs during standard system operation. This special situation is worth investigating in more detail to determine its relative impact on system performance. Such a reflection would have a more significant impact on a system with a wider spatial sensitivity.

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