research MATTERS

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Daylight harvesting has the potential for significant energy savings by bringing daylight into buildings while dimming or shutting off electric lighting. The availability of daylight generally coincides with utility peak demand periods, making daylight harvesting a particularly valuable tool for peak electricity demand reduction. However, control systems to enable daylight harvesting have faced many barriers including expensive commissioning and unreliable operation. These barriers and initial research were discussed in depth in the LD+A "Research Matters" column in the April 2008 issue.

California Lighting Technology Center (CLTC) has continued research over the past year to develop and commercialize a next-generation daylight harvesting system with automatic commissioning and increased reliability through use of two photo sensors. CLTC is working with Wal-Mart to demonstrate the product prototype in a retail store and with Watt Stopper/Legrand to commercialize the system. This article presents the continuing research and demonstration results from the Wal-Mart test store in West Sacramento, CA.

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TRADITIONAL APPROACHES

Traditional daylight harvesting control approaches are categorized as closed loop or open loop (**Figure 1**). A closed-loop system measures the combination of electric light and daylight in the space and controls the electric light based on the sensor signal and programmed set points. An open-loop system measures only daylight outside the space. The electric lights are controlled based on a programmed relationship between the sensor signal and electric light level.

Closed-loop approach. The closed-loop system is advantageous because it evaluates light inside the space. However, the sensor signal is affected when the reflectance and geometry of the space changes. This is a common occurrence in retail stores with constantly changing displays. A closed-loop system requires recommissioning every time the space changes significantly, making it a costly and ineffective approach. In addition, the sensor signal may be affected by moving occupants. To combat this problem, closed-loop systems generally incorporate time delays. This is a reasonable approach for an on/off system but problematic for a dimming system that ideally should respond to daylight changes instantaneously.

Open-loop approach. The open-loop system measures light outside the space through a skylight or window, or on the exterior of the building. The sensor is not affected by interior space and occupant changes. The open-loop system requires initial commissioning to relate the sensor signal to the desired electric light level. Open-loop systems, which are currently used in all Wal-Mart stores with skylights, are generally more reliable and less expensive to maintain than closed-loop systems. However, the availability of daylight outside is not necessarily a good indication of the daylight inside the space, which is affected by sun angle and weather conditions. Open-loop systems lack the accuracy to maintain consistent light levels inside the space.

NEXT-GENERATION APPROACHES

CLTC has developed a new approach to daylighting controls by combining closed- and open-loop sensors into a dual photo sensor controller (**Figure 2**). The system features automatic, continuous commissioning and uses an intelligent algorithm to respond appropriately to daylighting changes despite occupant interference.

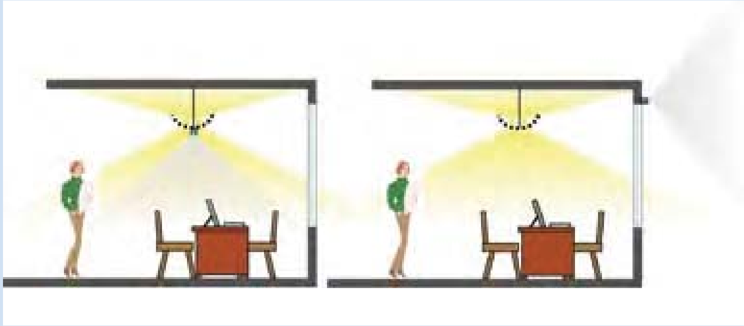

Figure 1. A closed-loop daylighting control system is affected by the electric lighting it controls (left), while an open loop is not affected by the electric lighting it controls (right).

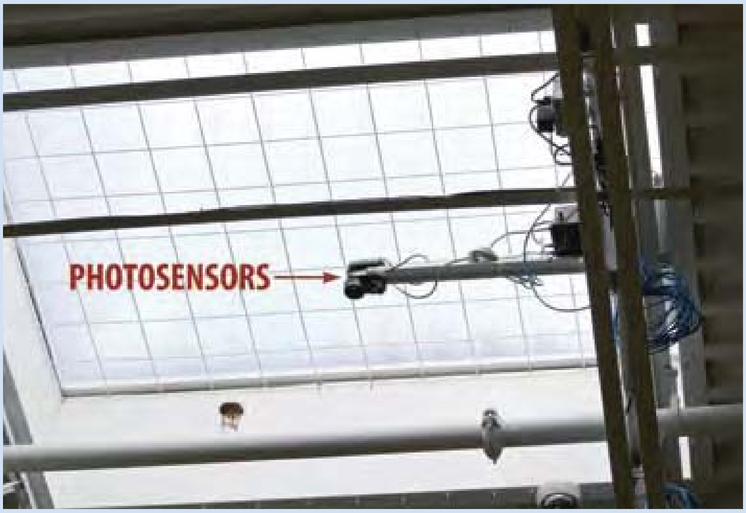

Figure 2 . Dual photo sensors installed in Wal-Mart skylight.

The automatic commissioning selects a closed-loop set point by measuring the closed-loop photo sensor signal from the electric light only. At the installation, this is measured automatically by turning the lights from on to off and calculating the difference. This electric light value is the closed-loop set point. The West Sacramento Wal-Mart is open 24 hours a day. In this store, the set point is updated every night when the lights are on. CLTC installed the demonstration system during the seasonal area to characterize the change in the closed-loop sensor signal from changing displays. In December, the closed-loop sensor was predominately affected by the light reflected off of the red and green holiday items. The measured electric light value was 4.75 (**Figure 3, left**). In January, the store removed the holiday items and stocked white storage boxes on the shelves under the sensors (**Figure 3, right**).

The electric light value increased to 6.97, a change of +47 percent. A traditional closed-loop system would have over-dimmed the lights significantly due to the increased reflectance of the displays. However, the dual-loop system updated the set point nightly to keep the lighting functioning at an appropriate level.

The dual photo sensor approach complements the automatic, continuous commissioning closed-loop system by adding an open-loop photo sensor to provide additional information about daylight fluctuations. This additional sensor provides information on the available daylight when the closed-loop signal is disturbed by moving occupants. For example, a pallet with merchandise moving under the sensor would temporarily affect the closed-loop signal. This is problematic for a closed-loop continuous dimming system as the electric lighting changes based on these events. The dual-sensor system addresses this issue by comparing the signal change over a short time interval of the closed-loop sensor to the open-loop sensor and determining if the change in the closed-loop signal is from a change in daylight. The electric lights promptly respond to daylight changes and do not respond to transient changes caused by occupant interference.

Figure 3. Seasonal shelves at Wal-Mart in December (left) and January (right).

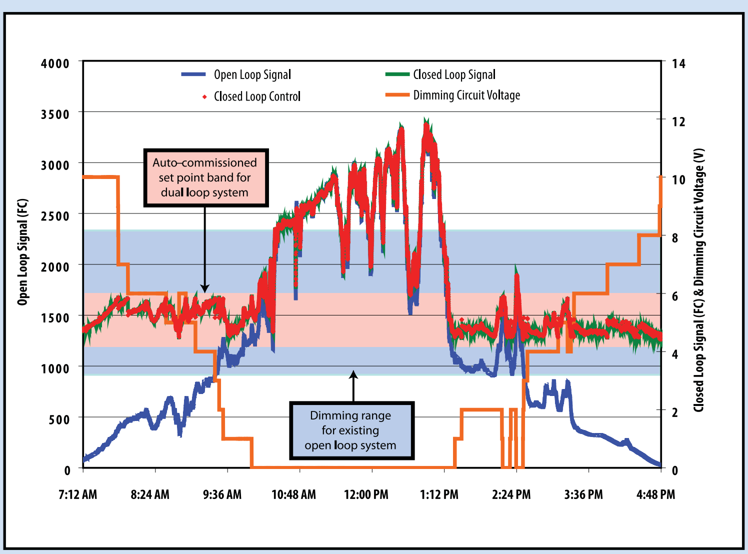

Figure 4. Comparison of open-loop to dual-loop operation during a partly cloudy day.

INITIAL RESULTS

The operation of the dual-loop system compared to the existing open-loop system at the Wal-Mart test site has yielded promising results. The data collected during a partly cloudy day are particularly interesting because the quickly fluctuating daylight levels are a challenge for control systems (**Figure 4**).

In Figure 4, the closed-loop control value is shown in red. The dual-loop system maintains the closed-loop control value within the auto-commissioned red set point band by adjusting the electric lights. The dual-loop system:

- Started to dim down lighting at 7:30 a.m. and shut off the lights at 10:00 a.m.
- Started to increase lighting at 1:15 p.m. and reached full brightness at 4:45 p.m.
- Did not need to turn on the lights midday even with severe daylight fluctuations. The system determined the daylight in the store was adequate because the closed-loop control value stayed above the bottom of the red band.

In Figure 4, the open-loop signal is also recorded in blue. The baseline open-loop control system following the existing Wal-Mart logic adjusts the electric lights between an open-loop signal of 900 and 2,300 footcandles (blue band). Had the system been functioning as an open-loop control system, the electric lights would have:

- Started to dim down lighting at 9:30 a.m. and shut off the lights at 10:30 a.m.
- Started to increase lighting at 1:00 p.m. and reached full brightness at 2:30 p.m.
- Turned on and adjusted the electric lighting midday as clouds passed over and the open-loop signal dipped back into the blue band.

The dual-loop system has shown several benefits over the existing open-loop system including automatic, continuous commissioning and more accurate adjustment of the electric lighting during early morning and late afternoon hours, and during partly cloudy skies.

FUTURE WORK

This study will continue to gather approximately six months of data between November 2008-May 2009. Further analysis will compare the baseline open-loop control system to the dual photo sensor system. Consistency of the lighting, energy use and user satisfaction will all be considered in the final analysis. CLTC will continue to work with Watt Stopper/Legrand to commercialize both stepped switching closed-loop and dimming dual photo sensor automatic commissioning products. Continuing research on dual loop-photo sensor control for daylight harvesting is supported by the Public Interest Energy Research (PIER) Program of the California Energy Commission.


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