Best Practices for Commissioning

Automatic Daylighting Controls

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Automatic daylighting control is an energy-savings strategy used with increasing frequency in high performance building design.[1] This type of control generally includes a photosensor that automatically dims or switches electric lighting to a lower energy state in response to natural daylight. Considerable effort is often expended on architectural and lighting design to bring in more natural light and give these systems high potential for performance. Unfortunately, the actual execution of the controls is often an afterthought.

Best practices suggest that proper execution of automatic daylighting controls goes well beyond basic installation, requiring a thorough commissioning effort, including calibration and functional testing to reach full energy-savings potential. The 2012 International Energy Conservation Code mandates commissioning of daylighting controls, though there are few specifics in the code regarding the steps involved, and enforcement is a potential problem. Additionally, anecdotal evidence, prior research,[2,3] and the research discussed in this article, shows that these necessary steps often are not completed.

In this article, we discuss the results of a study we undertook to monitor and commission several daylighting control systems in the Midwest to demonstrate the industry's current level of achievement.[4] We show that there is potential for economical energy savings from daylighting controls, but that challenges remain in reaching that potential. Finally, during the commissioning phase of our work we compiled guidelines and tips for successful execution, startup, and commissioning of daylighting control systems that practitioners can use.

Potential Solutions

Key steps can be taken to mitigate the problems that arise in executing a successful daylighting control strategy. Observations from the buildings that we studied reinforced the generally recommended—but not often followed—best practice that daylighting controls, like HVAC controls, require full calibration and commissioning for proper operation.

Controls commissioning ideally extends from predesign through occupancy. However, the most critical steps in the process for daylighting controls occur after installation—when the installation is verified, the system is started up and calibrated, and functional testing is complete. It is best to have a single person—a third-party agent or a member of the construction team—responsible for verifying completion of these steps in accordance with design, manufacturer specifications and owner requirements.[5]

These and other commissioning tasks should be included in that person's contract, along with a line item in someone's budget to complete the tasks. The

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commissioning authority should also ensure proper training of the building owner or operator to ensure persistent savings. User interfaces, calibration steps and *equipment locations* must all be taught and well documented to the operator during this training step, allowing them to make ongoing adjustments for occupant complaints and building modifications.

Calibration and functional testing controls are steps in this commissioning process that are critical to successful implementation and energy savings.[6] Calibration is sometimes blended into the functional testing task, though ideally the calibration would be finished and then separate functional tests completed to ensure steps from installation to calibration were done correctly.[7] In an ideal process, the contractor would complete start-up and calibration, and a commissioning authority would simply verify that the calibration and necessary illumination tests had occurred. In practice, it is most important that *somebody* at the very least calibrates the system.

Most of the system problems that we encountered could be solved if this process was completed. In fact, as part of our study we went back to each system and recommissioned them to measure the impact on performance. Primarily, we followed the recommended calibration processes to adjust the daylight sensor and controller settings to achieve adequate light levels at the critical work plane* with minimum possible energy consumed. This process aims to optimize the settings in *Table 1.* All that is needed for the process is knowledge of the controls (including locations), design illumination targets, and a light meter for determining that design illumination is met.

Our study found that with these steps in place these systems save substantial energy, and can be economically justified. More importantly, the study showed that these key commissioning steps were critical to making the technology justifiable.

What We Did

The Spaces

We began our study by locating buildings throughout Minnesota and Wisconsin that used daylighting controls. Of a larger sample set that included a range of building types, we chose 20 spaces for in-depth study. The spaces were chosen to be significantly different in orientation, usage, and perceived level of commissioning in an attempt to achieve a diverse sampling of spaces.

TABLE 1 Six key items to be adjusted during daylighting control calibration.

SENSOR LOCATION	Sensor Should be Located Over a Workplane
SENSOR ORIENTATION	Sensor Should See Reflective, Representative Space
SENSOR SHIELDING	Sensor Should Not Receive Direct Light
GAIN	Tune to Design Light Level + Lumen Depreciation
FADE RATE	Fade Rate Should be Long (~1 Minute)
DEADBAND (IF STEPPED)	Deadband Should be Long (Several Minutes)

Data Collection

We collected data over three separate periods of time to demonstrate the effect of commissioning. In Period 1, the control system was monitored in its as-found state. In Period 2, the daylighting controls were disabled (other lighting controls remained functional) such that the system would behave as if it never had daylighting controls. Then, prior to Period 3, we completed a basic recommissioning of the system, with the help of knowledgeable technicians. This process included calibration of the key items discussed previously, and listed in *Table 1*.

In each space we installed continuous monitoring equipment to collect several data points across all periods, beginning on Jan. 13, 2012, and concluding at the end of Period 3 on July 10, 2012. For more information regarding our monitored spaces and data points, refer to our full report.[4]

Methodology and Analysis

Two different savings metrics were key outcomes of this study: the energy savings from a typical daylighting control system (measured in Period 1) and the energy savings from a fully commissioned system (Period 3). We calculated each metric for the luminaires *controlled by* the daylighting control system. The measured lighting energy power was calculated using monitored electrical current, along with spot measurements of voltage and power factor. This calculation is represented in *Figure 1,* in which the energy usage of Period 1 and Period 3 is shown in yellow, while the energy savings is shown in orange. Recall that the energy savings in Period 3 includes additional savings realized by full commissioning.

But the primary goal of our study was not to look at the architectural or lighting design impacts on daylighting

*The critical work plane is the location that receives the least daylight within the zone of controlled light.

but rather to focus specifically on the performance of the control system itself. With this goal in mind, lighting energy savings is not the best metric because savings is impacted heavily by the architectural (glazing size, furniture, finishes) and lighting design (lighting power density, layout) aspects of the space. As a result, we created a metric called "controls effectiveness," here represented as ε:

$$\varepsilon = \frac{\text{Actual Savings}}{\text{Ideal Achievable Savings}} \quad (1)$$

The effectiveness ranges from one when the actual energy usage is equal to the ideal energy usage (perfect control), to zero when the actual energy usage is equivalent to that with no photo controls at all (no control). In order to calculate controls effectiveness, you need both actual energy savings and ideal achievable savings.

We calculated actual savings from our measured data. We calculated ideal achievable savings by adjusting the measured current to a level that would deliver the target illuminance (the illuminance that the designer intended) for each timestep in the period. In this way, we created a set of ideal current data that represented a system that was operating perfectly.

Figure 2 illustrates a set of measured current and the corresponding idealized current for one of the spaces in the study. The area highlighted in blue is essentially the energy savings of the system. The area highlighted in green is the additional savings had the photocontrol been operating ideally.

Effectiveness was most useful when we encountered under or overly daylit spaces. One such space had a daylighting zone that was too deep, and contained dark, obstructing furniture. The savings from daylighting controls in such a space was generally low. But the effectiveness was quite high, indicating that the controls were properly installed, started up, and calibrated.

This left us with four key metrics for each space: the energy savings both before commissioning (Period 1) and after (Period 3), as well as the controls' effectiveness

FIGURE 1 Measured current in a given space over the three periods and approximated energy usage and energy savings.

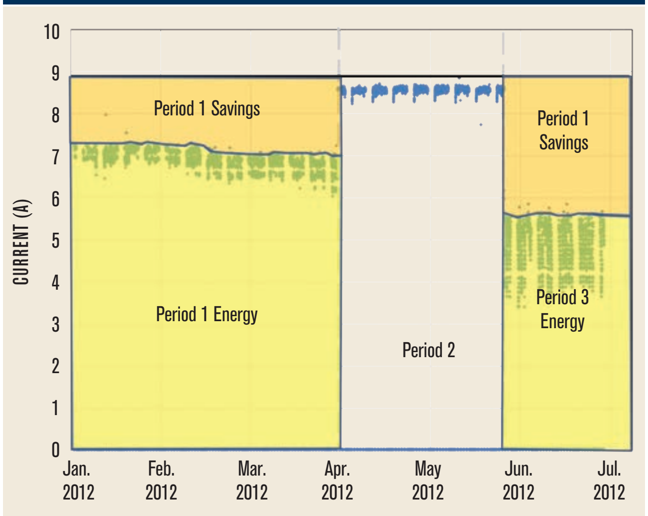
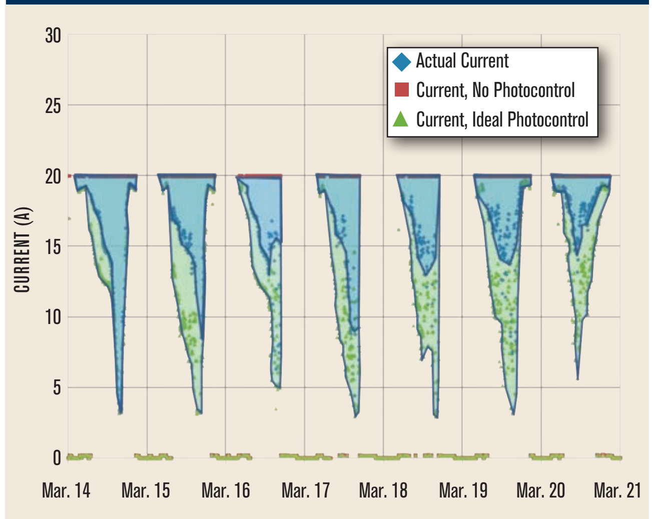


FIGURE 2 Actual and ideal energy savings for one space over a week of the study.



before commissioning and after. As in any multi-period energy study, we normalized all of these for weather effects (e.g., available daylight) between these periods, with the ultimate results representative of a Typical Meteorological Year.

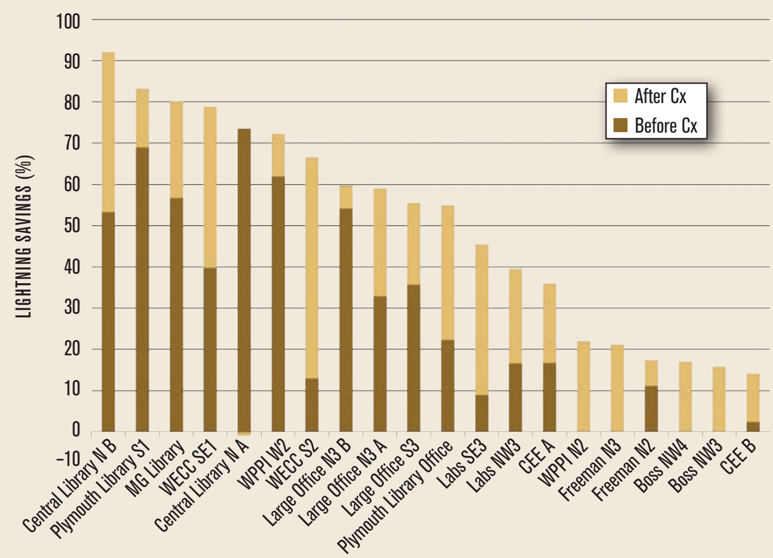
Results of Our Study

Before and After Results

The primary metrics we used to describe energy savings were electricity savings per kW of controlled lighting in units of kWh/kW (MJ/kW) and the percentage of

energy saved for the controlled lighting. Our data for Period 1 shows that the median automatic daylighting control system in a population represented by our sample would save approximately 809 kWh for every kW (2912 MJ/kW) of lighting that is controlled by the system, or about 20%† of the controlled lighting energy. This number increases to 915 kWh per kW (3294 MJ/kW) or 23% if we include the savings in associated HVAC energy. If we look at the units of kWh/kW, this essentially simplifies to the number of equivalent hours in a year for which the lights would be fully off. If a typical commercial space operates for 3,500 hours per year, it seems reasonable that a typical daylighting control system could keep the lights at or near off for a quarter of that time. On an area basis, for a typical commercial space lit with 1 W/ft^2 (11 W/m^2), this savings equates to 0.9 kWh/ft^2 (9.7 kWh/m^2).

FIGURE 3 Lighting savings for each space both before and after our commissioning effort.



Savings for this as-found condition ranged from as high as 74% or 2,463 kWh/kW (8867 MJ/kW) for controlled lighting on a fully glazed north façade, to as low as zero. In fact, four of the 20 systems that we studied were essentially not saving energy as they were found. And, in at least one case, the owner assumed they were saving substantial energy.

But after the spaces underwent recommissioning, savings changed substantially. *Figure 3* shows the lighting savings on a percent basis both before and after commissioning for each space in our study. The median savings increased to approximately 1,762 kWh for every kW (6343 MJ/kW) of lighting controlled by the system, or about 55% of the controlled lighting energy.‡ These savings numbers can be as high as 4,220 kWh per kW (15 192 MJ/kW) and 92% savings including HVAC energy. More importantly, the *minimum* savings has increased from 0% prior to commissioning, to 14% after commissioning. And, if we include the savings in HVAC energy, median savings increased to approximately 1,976 kWh per kW (7081 MJ/kW), or 63% savings. For an average space at 1 W/ft^2 (11 W/m^2), this equates to 2 kWh/ft^2 (21.5 kWh/m^2).

Next, we can examine the difference in controls effectiveness. Again, controls effectiveness normalizes for light level in the space, and, therefore, measures just the performance of the control itself. Initially, we found the average controls effectiveness in the as-found condition to be 51% (with a median of 66%). However, the spaces in our study displayed a wide range of performance. Four did not work at all, showing an effectiveness of zero. On the other end of our spectrum, over half of the spaces had effectivenesses of more than 60%.

After our commissioning effort, controls effectiveness increased (on average) from 51% to more than 75%, or a 50% improvement. This additional savings results solely from improving controls operation, not from any change to glazing design, blinds operation, furniture, or ballast minimum power—all more difficult or expensive items to modify. *Figure 4* shows, for each of the 20 spaces, the correlation between effectiveness both before and after our commissioning effort. Note that in all but one of the spaces effectiveness improved after commissioning, and some dramatically so.

Table 2 summarizes key results for both *before* and *after* conditions in our study.

Impacts on Heating and Cooling

Results were presented previously for either 1) lighting only or 2) the combination of lighting and HVAC impacts. Daylighting controls generally reduce cooling loads and increase heating loads in the space due to reduced light energy. We found that most of the spaces

† With a range of performances selected, with some systems working and others not, the standard deviation of these values based on our sample size is 1250 kWh and 27%.

‡ Though these savings values have nearly doubled from the pre-commissioning case, the absolute standard deviation remains similar at 1,260 kWh (4536 MJ)and 25%; there is considerably less (relative) variation in results when systems are all commissioned.

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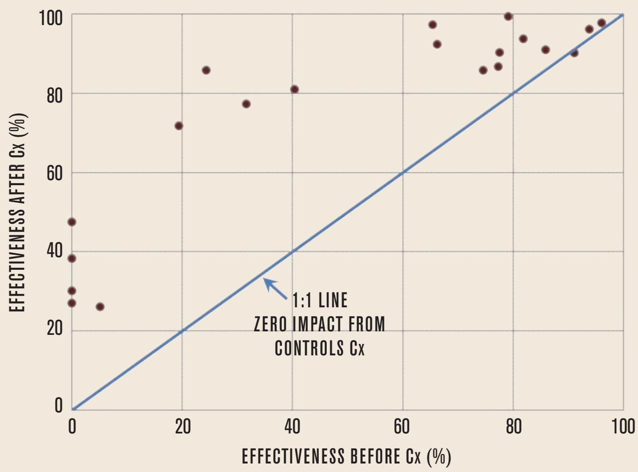
FIGURE 4 Controls effectiveness before commissioning versus controls effectiveness after commissioning.



studied were in cooling mode during the majority of the daylight hours. Therefore, there was generally additional savings to HVAC, even in the cold Minnesota climate. We averaged this savings across the spaces studied, normalizing for a Typical Meteorological Year, and found 13% additional savings due to HVAC.

TABLE 2 Summary of energy savings and controls effectiveness results.

	BEFORE Cx	AFTER Cx
MEDIAN ENERGY SAVINGS	809 kWh/kW	1762 kWh/kW
	20%	55%
MEDIAN ENERGY SAVINGS INCLUDING HVAC	915 kWh/kW	1976 kWh/kW
	23%	63%
AVERAGE CONTROLS EFFECTIVENESS	51%	75%

Economics

Daylighting controls come with significant additional upfront costs, ranging anywhere from \$0.75 to \$3 per square foot (\$8 to \$32 per square meter), depending on the complexity and flexibility of the system. It is not obvious on most projects whether this first cost increase is justifiable based on energy savings. We conducted life-cycle cost (LCC) analysis in accordance with the procedures in the Federal Energy Management Program, and assumed Minnesota's average electrical utility rate, which is \$0.093/kWh (\$0.026/MJ). Because the costs of these systems can vary depending on the space in question, we found it most

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useful to use traditional LCC tools to calculate a *breakeven cost*: if the control system can be purchased and installed for less than this cost, it is the right financial choice.

Based on the energy savings that we observed for typical systems (prior to our recommissioning), for every 1 kW of luminaires controlled, an owner should spend, at most, $1,000 for controls. If the system undergoes a full commissioning process, including optimization at startup, the results show that an owner can afford to spend $2,200 for a 1 kW system. The cost of the basic steps of commissioning required should easily fit under that $1,200/kW difference. Per square foot, these costs depend on the installed wattage, which for commercial buildings is often 0.6 to 1.4 W/ft^2 (6.5 to 15 W/m^2). We also calculated simple payback and found paybacks of between six to 11 years for fully commission control systems. A more thorough treatment of the economics of commissioning is included in our full report.

Steps to More Effective Daylighting Control

As we completed the monitoring and recommissioning of all these spaces, we characterized the operational problems with each system that we encountered. Aside from calibration of the sensor gain and other setpoints, improper zoning was the most common commissioning issue. Zoning is best dealt with in design. Zone sizes should be kept to a minimum, with even smaller zones used for stepped control than continuous dimming. If addressable ballasts are used, zoning can be adjusted at startup, but guidance from the designer can still be vital, especially if installing personnel do not have significant experience.

Sensor position and orientation was another observed deficiency, one that is also best initially dealt with in design.

But these and other control problems were observed to be much less common than improper calibration. We observed everything from controls that needed only a slight adjustment in gain, to systems that had undergone no calibration whatsoever. In working through all of these issues, it was clear that full commissioning would have solved most problems. In addition, we compiled the following conclusions regarding process:

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• Calibration should be performed after furniture, or even occupants, are in the space. Sensor location or orientation should be adjusted based on final interior design.

• Calibrate at a time of moderate brightness in the space; check at a second time if possible.

• Do not assume that initial nighttime light levels equal the design-intended illuminance.

• To save time, shorten the fade rate and deadband settings prior to calibration for immediate controls response. Reset (to longer rates for occupant comfort) and test these values prior to completion.

• Your body will interfere with light levels. Use a remote, or step away from the sensor and light meter for a time before taking illuminance readings.

• Using an ammeter to observe the circuit's electrical current during calibration can provide useful feedback, and ensure minimal power levels are reached.

• If the system uses stepped control, the deadband absolutely needs calibration. Set to at least several minutes to ensure occupant comfort, and follow up to see if different solar/weather conditions cause problematic switching.

• Your manufacturer should either offer a simple user interface so that building managers and contractors can startup, commission, and maintain systems themselves, or include these steps in the product cost. This is not always true with some of today's complex systems.

Conclusion

In studying a variety of daylighting control systems, we have demonstrated that established commissioning procedures (especially calibration and functional testing) are required to achieve energy-savings potential. If these procedures are in place, these control systems have substantial potential to improve energy performance and the economics of building operation.

Several resources exist for more guidance in executing these procedures. In addition to the references throughout this article, the full report from our study contains substantial additional detail: www.ecw.org/mndaylighting. For more control commissioning guidance, refer to Illuminating Engineering Society Design Guide 29. Finally, for general daylighting control information see Lawrence Berkeley National Laboratory's "Tips for Daylighting with Windows," available at http://tinyurl.com/p5y6m58.

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