Beyond Advanced Lighting Controls: Reaching Net Zero with Integrated Building Controls

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ABSTRACT

Many manufacturers offer proven ALC systems that network conventional lighting controls (schedules, occupancy, daylight harvesting, dimming, etc.) into an integrated front end, providing facility managers with an unprecedented level of monitoring data and control. ALC systems are capable of sophisticated lighting control strategies that enable deep lighting energy savings that are greater than the sum of the stand-alone control components.

Besides capturing significant lighting energy savings, the sensors in these systems provide the capability to make significant improvements in the efficiency of HVAC systems and control of plug loads. Combining the lighting and HVAC benefits of these systems offers customers the greatest return on their investment without sacrificing the comfort, safety, and control of the occupants. This integrated approach also provides non-energy benefits to building owners and operators by providing improved feedback on facility operation that was previously not available.

This paper identifies and describes the potential non-lighting energy and operational benefits associated with advanced lighting controls (ALCs) and provides decision makers with a justification to specify integrated building systems. The authors include a discussion of ALC system network topologies and associated, enabled lighting efficiency measures. The paper will provides an in-depth analysis of control strategies that provide non-lighting energy savings in new construction and existing buildings applications.

Introduction

Lighting and lighting controls have been a historic target for improved building efficiency for both energy professionals and energy codes since the wide-spread advent of demand-side load management. Benchmarking studies support this emphasis on lighting as a source of curtailment by routinely finding lighting consuming nearly a third of the energy used in buildings (EIA, 2008). As a result, the market has developed increasingly sophisticated control solutions to help reduce unnecessary lighting loads.

Originally, these control solutions were simple, stand-alone devices – switch replacement occupancy sensors, mechanical timeclocks, and open loop photocells. The lighting control industry continues to iterate with lighting control devices, coming up with increasingly accurate and easier to install devices. Energy codes, lighting designers, electrical engineers, and utilities have embraced these technologies and now they can be found in high performance buildings across the nation.

The lighting controls industry continues to innovate and iterate, developing new and improving existing technologies. Lighting controls have evolved from simple, individual devices to networked control systems rivaling the best heating, ventilation, and air conditioning (HVAC) controls for their depth of reach into buildings. These advanced lighting control (ALC) systems are the next step in the growing sophistication of existing lighting control technologies.

This paper proposes integrating any ALC system with the existing facility building automation system (BAS) and acting on the new influx of lighting control data to modify HVAC sequences and yield energy savings. An advanced lighting control system for the purposes of this paper is a networked lighting system providing "granular" control of light fixtures (either circuit- or individual fixture-based) with a series of networked control devices (occupancy sensors, photocells, time-based schedules, etc.). The network infrastructure can be either wired or wireless. ALC systems fill the same control niche as their standalone counter parts, but relay the control status (i.e. on, off, dimmed, etc.) and control variables (i.e. occupied, daylight contribution, etc.) back to a centralized lighting control system.

The basic structure of ALC systems uses existing sensor technologies for both occupancy and daylighting, passing that information via a network to a control panel or interface device. The control panel then responds by turning on, dimming, or turning off a controlled lighting circuit or fixture. The exact process varies by manufacturer and the selected configuration of the lighting controls. There are more than eight large ALC manufacturers whose product offerings offer several different configurations and lighting control components.

Unlike stand-alone lighting control systems, ALC systems provide an ecosystem that enables a number of additional control options:

- Task-Tuning: When the overhead lighting provides more light than necessary, an ALC operator can specify a maximum light output less than 100%.
- Occupant-Enabled Controls: In large areas with many users, an ALC system can give individual occupants control via a website on the intranet, internet, or via a phone app. The ALC operator can specify a maximum and even a minimum, giving occupants some level of control without affecting overall uniformity.
- Distributed Override Controls: ALC control systems can be set up with multiple override settings rather than relying on a single hardware switch. For example, the ALC system may give the janitorial overrides only 30% of design light output for cleaning tasks and safe navigation of the space. Normal occupants working late or on weekends would receive design light output when using telephone or web overrides.
- Dimming Schedules: In large areas with variable occupancy, ALC systems can dim the lights over individual cubes when occupants are not at their desk without leaving dark spots.
- Demand Responsive Controls: With the increased reach of individual circuit and fixture control, ALC systems can shed load uniformly throughout a building. This load shedding capability can be used for demand response or day-to-day load management.

The biggest barrier to wider adoption is cost. The current lighting control solutions available that leverage network-based controls are more expensive than the stand-alone devices currently saturating the market. To reduce the financial payback, the market is responding by delivering lower prices as the scale of manufacturing increases. The controls industry is also participating in and fostering contractor training programs to educate the workforce and transform the marketplace. It is up to designers & engineers to increase the value of ALC systems in buildings, thereby improving the overall payback proposition. This paper proposes integrating any ALC system with the existing facility building automation system (BAS) and acting on the new influx of lighting control data to modify HVAC sequences and yield energy savings.

Integrating ALC Data to Save HVAC Energy

There are two key means of integrating ALC system information into the BAS. The primary integration methodology uses the ALC system components to provide information to the BAS. Most manufacturers support this integration with a gateway or other network connectivity device, providing a connection to and from the ALC system and BAS. The second potential integration technique uses the ALC network infrastructure to bring in additional HVAC signals (duct pressure, dampers, etc.). At this time, fewer manufacturers support adding HVAC control points to their ALC networks.

The HVAC energy saving potential with an ALC system is entirely dependent on the existing HVAC BAS. At a minimum, a building needs functional, fully-programmable DDC control at each air handler. Depending on the zone-level controls, there are ALC-enabled HVAC measures for either pneumatic or direct-digital control (DDC) systems.

Pneumatic-Zone Control HVAC Integration Measures

Lighting manufacturers are finding it increasingly cost effective to integrate multiple sensors together into a single device. There are at least two manufacturers that also include temperature sensors with their occupancy and photocell sensor offerings. Pneumatic controls rely on air pressure signals between 0 and 15 psig, provided by a network of pressurized pneumatic lines. As much as 70% of existing buildings still use pneumatic controls (Pacific Gas and Electric Company 2013) and one of the key limitations for HVAC controls with pneumatic-zone controls is the lack of feedback from the occupied areas of the building. Replacing pneumatic zone controls in existing buildings with DDC zone controls is an expensive capital improvement involving potentially intrusive hardware modifications. Adding an ALC system to a building with pneumatic zone controls provides an integration opportunity that yields new insight into the existing HVAC operations. With the greater visibility into a building’s operation, greater energy savings and comfort can be simultaneously achieved.

The next sections detail potential energy saving control strategies using an ALC system when constrained by pneumatic zone controls.

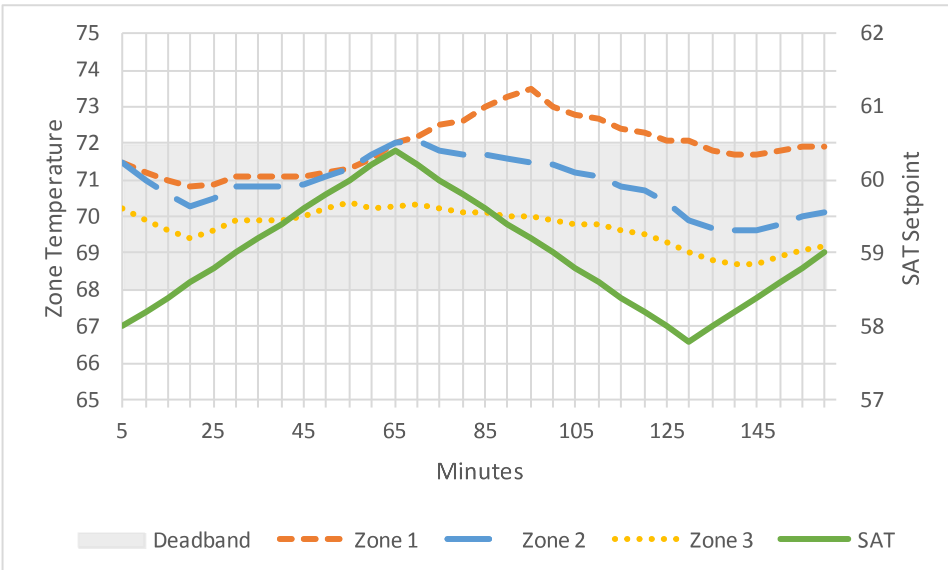
Supply Air Temperature Reset

Using sensor data from lighting control systems with on-board temperature sensing capabilities, an ALC control system provides granular data back to the building automation system to enable a demand-based supply air temperature reset. This type of reset is most valuable for air handlers serving multiple zones with single-duct or dual-duct terminal boxes and applies to both constant air volume (CAV) and variable air volume (VAV) zone control.

Occupancy sensors with integral temperature sensors are often installed on the ceiling, in which case the temperature reported to the BAS is not the occupied zone temperature, but the ceiling temperature. Unlike a zone-level DDC system, that measures zone temperature at the thermostat typically 4 to 5 feet above the floor, this strategy will require an offset to accurately measure the temperature in each zone. Depending on the stratification in the space, this difference can be fairly substantial. An offset between the actual zone temperature and the sensor reading should be established during the commissioning process by measuring the difference for a few representative zones.

In this control strategy, the building automation system would monitor the zone temperatures. When the zone temperatures are less than the zone temperature setpoint (defined by the BAS or DDC controller, not by the local pneumatic thermostat), the BAS will raise the supply air temperature by a small increment, usually less than 1ºF, every 5 to 10 minutes. This will continue until either the maximum allowed supply air temperature is reached or until one of the monitored zones exceeds the zone temperature setpoint. In response to a zone temperature setpoint being exceeded, the BAS will lower the supply air temperature by a small increment every 5 to 10 minutes until the minimum setpoint is reached or the zone reaches setpoint. Figure 2, below, provides a simplified example.

Figure 2: Example Supply Air Temperature Reset with Trim and Response Logic



The supply air temperature reset afforded by the ALC system offers two benefits over the standard resets available to pneumatically-controlled zones.

- Improvements over Outside Air Temperature-Based Resets: Leveraging the ALC zone data, the reset is based on the actual thermal response of the building, not an abstraction based on the outside air temperature. This reset is more responsive to operating conditions. Therefore, the range of controlled supply air temperatures can be broader.
- Improvements over Return Air Temperature-based Resets: The supply air temperature reset maintains individual zone comfort as opposed to resets based on the return air temperature at the air handler. Basing a supply air temperature reset on the return air temperature removes the hottest and coldest zones from the reset and instead resets based on the average of all zones in the building. Exposing the hottest and coldest zones gives the building operator the ability to identify warm, undersized zones and cool, oversized zones – both of which can be addressed to save additional energy.

Heating Hot Water Reset:

The heating hot water reset, like the supply air temperature reset, is also demand-based, using the zone temperature data available from the occupancy sensors. This can be useful for a wide array of heating systems including VAV reheat terminals, perimeter radiators, and perimeter fan coil units. The energy savings from a heating hot water reset are modest at best for atmospheric boilers (which mostly reduces heat loss from the distribution system). The savings are realized when using a condensing boiler. Condensing boilers are more efficient at lower return water temperatures and lowering the supply temperature can also lower the return temperature. A control interface (compatible with the BAS protocol or with a gateway) is necessary in order for the boiler to receive input from the ALC system.

When the zone temperatures indicate the zones are satisfied, the heating hot water temperature setpoint is decreased by 1 degree every 5 to 10 minutes. This will continue until either the lowest allowed heating hot water temperature is reached or until a certain fraction of the building zones enter heating mode again. For the purposes of this control sequence, heating mode is defined as the zone temperature setpoint at which the reheat valve would open. When zones are in heating mode, the hot water temperature setpoint will rise by a few degrees every 5 to 10 minutes. Directly measuring the variable being controlled (zone temperature) ensures comfort is not sacrificed and maximizes the energy savings from the reset by raising the supply temperature whenever possible.

Optimum Start and Optimum Stop

Conventional building controls without zone feedback use fixed schedules to operate the HVAC equipment. To ensure buildings are comfortable in the morning, these schedules often start well before the building is occupied, as the start time is selected for the worst-case start-up scenario (e.g. a very cold morning). Usually, the schedule will start significantly earlier only on Monday, to recover from the weekend, and start later the rest of the week. For example, in moderate climates, a half-hour morning warm-up is usually sufficient enough to bring the building up to temperature for much of the year.

By leveraging temperature sensors built into ALC control components, optimum start becomes an actionable control measure. The key to implementing an optimum start measure is zone data. Each morning, the zones are polled to see how cold the building actually is. The optimum start logic will calculate the required warm up time based on the average (or minimum) zone temperature and the historic effectiveness of the heating system (based on past performance).

To reduce run time at the end of the day, the BAS can also monitor the occupancy status of the building. When the BAS sees that all zones are unoccupied, the unit can shut down. This is particularly useful in variable-schedule buildings, e.g. college and university classroom buildings.

Recalculating Minimum Outside Air Volume

Demand controlled ventilation is generally not possible with pneumatic zone controls; however, if the air handler has an air flow station, the economizer minimum outside air flow can be dynamically recalculated based on the occupant density of spaces actually occupied. The calculations take the following forms, depending on the relevant ventilation code:

Equation 1: ASHRAE 90.1 Ventilation Calculation

$$Minimum\ Outside\ Air = \sum_{Occupied} R_p \cdot P_z + \sum_{All} R_a \cdot A_z$$

Where:

R_p: $Outdoor\ Airflow\ Rate\ Required\ per\ Person\ [cfm/person]$
P_z: $Zone\ Population\ [people]$
R_a: $Outdoor\ Airflow\ Rate\ Required\ per\ Unit\ Area\ [cfm/ft^2]$

$A_z: Zone\ Area\ [ft^2]$

Equation 2: Title 24 2013 Ventilation Calculation

$$Minimum\ OutsideAir = The\ greater\ of \sum_{Occupied} 15\ cfm \cdot P_z \quad \text{or} \quad \sum_{All} R_a \cdot A_z$$

Where:

$R_p: Outdoor\ Airflow\ Rate\ Required\ per\ Person\ [cfm/person]$

$P_z: Max\ zone\ population\ from\ design\ engineer\ OR$

$50\%\ of\ maximum\ zone\ population\ according\ to\ fire\ code\ [people]$

$R_a: Outdoor\ Airflow\ Rate\ Required\ per\ Unit\ Area\ [cfm/ft^2]$

$A_z: Zone\ Area\ [ft^2]$

To demonstrate the impact, see Table 2 for a sample small office, including a mixture of office and office support areas. Based on this example building, Table 3 and Table 4 calculate the ventilation loads for the fully and partially occupied building for ASHRAE 62.1 and Title 24-2013, respectively.

Table 2: Sample Office Building Details

Zone	Space Type	Zone Area (ft^2)	ASHRAE 62.1 Max Population (# people)	California Fire Code Max Population (# people)
1	Private Office	250	1.25	2.5
2	Private Office	250	1.25	2.5
3	Private Office	250	1.25	2.5
4	Private Office	250	1.25	2.5
5	Break Room	800	20	53.3
6	Conference Room	400	20	26.7
7	Conference Room	400	20	26.7
8	Open Office	2,200	11	22
9	Lobby	1,600	16	16
Total		6,400	92	155

Table 3: ASHRAE 62.1 Sample Office Ventilation Calculations

Zone	R_a (cfm per ft²)	R_p (cfm per person)	Full-Load Ventilation Volume [1] (CFM)	Occupancy Status	Adjusted Ventilation Volume (CFM)
1	0.06	5	21.25	Occupied	21.25
2	0.06	5	21.25	Occupied	21.25
3	0.06	5	21.25	Empty	15
4	0.06	5	21.25	Empty	15
5	0.12	5	196	Occupied	196
6	0.06	5	124	Empty	24
7	0.06	5	124	Empty	24
8	0.06	5	187	Occupied	187
9	0.06	5	176	Empty	96
Total			892		600

Table 4: Title 24 2013 Sample Office Ventilation Calculations

Zone	R_a (cfm per ft²)	R_p (cfm per person)	Full-Load Ventilation Volume (CFM)	Occupancy Status	Adjusted Ventilation Volume (CFM)
1	0.15	15	37.5	Occupied	37.5
2	0.15	15	37.5	Occupied	37.5
3	0.15	15	37.5	Empty	37.5
4	0.15	15	37.5	Empty	37.5
5	0.15	15	399.75	Occupied	399.8
6	0.15	15	200.25	Empty	60
7	0.15	15	200.25	Empty	60
8	0.15	15	330	Occupied	330
9	0.15	15	240	Empty	240
Total			1,520		1,240

When using ASHRAE 62.1 as the ventilation standard, the minimum outside air flow decreases by 33%. When using Title 24 as the ventilation standard, the minimum outside air flow decreases by 18%. The ASHRAE ventilation standard provides more savings with a pneumatic system because the area-related ventilation requirement is significantly lower than Title 24 for office buildings.

[1] The full-load ventilation volume is calculated prior to evaluating the system efficiency effects, as documented in ASHRAE 62.1. For a fully code compliant calculation, see the ASHRAE-provided spreadsheet at: https://www.ashrae.org/File%20Library/docLib/Public/2005859331_347.xls

Fan Speed Limiting for Demand Response

Limiting supply fan speeds is one approach to reduce electric demand in response to a curtailment event. Temperature sensors can provide feedback for a fan speed limiting logic which will prevent a zone from experiencing a rapid temperature increase or exceeding a maximum threshold.

The control strategy takes a snap shot of all zone temperatures before the curtailment event begins. After regular intervals, such as every 30 minutes, the supply fan speed is reduced a small increment such as 5-10%. At each interval, the temperature rise is calculated in each zone. If the temperature rise is too great, the increment is reduced. If the temperature exceeds a maximum threshold the supply fan speed limiting logic is disabled.

Duct Static Pressure Reset

The last potential ALC-based pneumatic HVAC integration measure requires an ALC system that is compatible with third-party sensors. When using a vendor with this capability, it's possible to install a few duct static pressure sensors connected to the pneumatic damper actuator control signal on the most hydraulically-distant zones from the air handler or those zones with the highest loads. This allows the DDC controls to monitor the damper position of the worst case terminal units.

While not as common, there are vendors with 0-10VDC control signal devices with auxiliary inputs. Using the ALC system to carry the signal reduces the installation cost, as the infrastructure to carry the signal is now present (without having to install a potentially long home-run to carry the signal back to the BAS). The remote pneumatic pressure signal indicates the remote VAV box damper positions so the duct static pressure setpoint can be reset based on actual demand.

When the BAS is aware of the damper position on the remote VAV boxes, the duct static pressure setpoint can be reset. One of the most effective ways of resetting the duct static pressure setpoint is another trim-and-respond algorithm, similar to the strategy described above, for the supply air temperature reset.

DDC-Zone Control HVAC Integration Measures

Most DDC zone control installations are limited to major renovations and new construction. Direct digital control of HVAC zones offers in-depth views of the entire HVAC system and far exceeds conventional pneumatic zone control. The benefits of DDC includes improved, granular data collection, deeper energy saving strategies, and feedback to building operation staff. There are still a few control strategies that can be improved by leveraging advanced lighting controls. Most of the control sequences identified for pneumatic zone control can be applied to DDC-zone controls without the need for an ALC system. Rather than competing with ALC systems, however, buildings with DDC-zone controls can be improved by and benefit from the lighting-related control improvements and use of occupancy data in HVAC control sequences. Recalculating minimum outside air and the optimized stop sequence requires occupancy data provided by the ALC system. The approach in the preceding sections for these measures remains unchanged from pneumatic zones.

The following section details a potential energy saving control strategy for deploying an ALC system with HVAC DDC controls to the zone.

Occupancy Control Ventilation

The ventilation standards in ASHRAE 62.1 and California's Title 24 allow the HVAC system to reduce air flow to unoccupied zones. Using the ALC occupancy output, the BAS can control VAV box damper positions to reduce airflow in unoccupied spaces. Current occupancy sensor technologies, however, cannot adjust ventilation rates based on changing numbers of occupants.[2] There are slightly different approaches between ASJRAE 62.1 and Title 24-2013.

The ASHRAE 62.1-2010 standard[3] specifically maintains the area-based ventilation component ($R_a \cdot A_z$) when the space is unoccupied. Therefore, when the zone is unoccupied, while meeting the space temperature setpoint, the VAV box damper must be at a minimum position that provides the minimum, area-based ventilation flow rate. The 2007 and 2004 standards[4] are less specific. ASHRAE 62.1-2007 and 2004 state that only variations in the zone population or zone area can be the basis for reducing the ventilation rate. Since zone area does not typically change during normal operations; the standard implies the area-based ventilation component should be maintained.

Title 24-2013 includes a new section describing occupancy-sensor ventilation control devices.[5] During scheduled occupancy hours, the VAV box may close while a space is unoccupied; however, the VAV damper must open periodically over a rolling two-hour window to supply at least 25% of the area-based ventilation component.

From a practical, programming setpoint, meeting Title 24-2013 means the VAV box control sequence must determine how much air has been provided to the space and have a running average of the CFM of ventilation air supplied in the course of maintaining the space temperature setpoint. If the CFM total falls below the 25% ventilation component, the VAV damper must open from the closed position until CFM total increases above setpoint.

To prevent the supply fan from dramatically speeding up two-hours after multiple zones become unoccupied (i.e. a couple hours after a long lunch or a half-day business day not in the BAS schedule), the VAV damper sequence should include a predictive algorithm to select some zones to ventilate prior to reaching the two-hour maximum. Failure to include this demand-management sequence could result in a power demand spike that could set the monthly electrical demand charge or the yearly ratchet.

Implementation and Other Opportunities

The ALC integration measures offer significant potential for savings and can help make the case for manufacturers and customers to deploy advance technology solutions in buildings today by increasing the value proposition associated with advanced lighting controls. At this time, there are no detailed, final assessments available from ALC manufacturers or utilities enumerating the total scope of energy savings attributed to ALC integration with conventional BAS controls as described in this paper. Some studies are underway (B. Lyon, Utility Program Manager, Enlighted, pers. comm., February 26, 2014) quantifying the results of ALC integration. Studying and documenting the energy savings associated with actual projects will increase the accuracy of the estimated value proposition and increase the likelihood that building owners, lighting designers, and engineers move forward with these integrated measures.

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[2] Zhang et al. 2013 discusses the savings potential of occupant-counting sensors applied to DCV
[3] ASHRAE 62.1-2010 §6.2.7.1.2
[4] ASHRAE 62.1-2007 and 2004 §6.2.7
[5] Title 24, 2013 §120.1(c)5

Implementation Coordination from Design through Occupancy

Once the energy saving potential is documented, the main barrier to implementation will likely be the coordination required between the different professional and skilled trades during design and construction. During design, the lighting control specifier and mechanical engineer will need to coordinate to ensure that the specified lighting control systems will work with the engineering sequences. At a minimum, this will include at least the following:

- Sensor selection (including coverage, accuracy, and any other on-board sensors)
- ALC system communication protocol
- Sensor & VAV zoning
- Point mapping between ALC & HVAC control systems
- Protocol compatibility between ALC & HVAC control systems
- Naming convention/consistency between VAV zones and lighting zones
- Completing contractor responsibility matrices
- Writing the control sequences for lighting & mechanical systems

During the submittal review phase, the mechanical engineer and the lighting control specifier should review the ALC system submittals to confirm compatibility with the proposed equipment. Any value engineering agreements between the contractor and the building owner must be communicated to the professional trades to ensure the continued successful implementation of the control sequences as designed.

Throughout the construction process, the general contractor should ensure that the subcontractors responsible for the control components and programming continue to work together and that all of the necessary requirements for integration are included in the scope. During the programming phase, the general contractor will need to ensure that the lighting and mechanical control contractors use consistent space-naming conventions to ensure that the ALC occupancy data readily aligns with the mechanical zones, and vice versa. Failure to do so will result in delays in programming completion and increase the likelihood that functional performance tests will fail during commissioning. As the construction process nears completion, acceptance test technicians and/or building commissioning personnel should perform functional performance testing (FPT) using a representative sampling. The FPTs should include not only the mechanical sequences, but should also test the accuracy and functionality of the ALC system and components.

At the completion of construction, the training materials for the building operators and stakeholders should include both lighting and mechanical control systems, with an emphasis on troubleshooting any apparent discrepancies between the two. All design, construction, and test documents should be collected in a systems manual for the building operator to refer to in the future.

Other Integration Opportunities

While this paper focused primarily on the integration opportunities associated with ALC systems and BAS systems, there are other potential integration goals that may further increase the value proposition of ALC systems. Zhang (2012) provides a thorough analysis for using ALC systems and lighting controls in general to bring plug loads under control. Although less developed for practical, wide-spread adoption, there is the potential to use ALC systems to offset security equipment costs (DiLouie 2009) and/or reduce the insurance burden of the occupied building (Resource Nation 2014). These integration opportunities can help reduce the first-cost associated with a building improvement by reducing redundancies and the annual facility operating costs.

Conclusion

Advanced lighting controls offer additional insight into building operations and enable greater energy savings for both lighting and HVAC end-uses. Integrating the ALC data into HVAC control sequences will bring greater value to building owners and help accelerate deployment of this technology. At this time, the lack of finalized, independent energy-saving studies creates some uncertainty for designers, installers, and building owners.

To foster confidence and better integration practices, the industry and electric utilities should consider working together on more pilot projects in this area. The pilot projects will provide insight on three levels:

- Pilot projects from partnerships with independent, third parties (like electric utilities) will give building owners, designers, and engineers greater trust in the energy saving results.
- Pilot projects that provide example sequences will spread understanding between professional trades. Sequences can be very difficult to design and having a sequence to start from can help with first time integration projects.
- Pilot projects that provide commissioning and troubleshooting assistance in the form of functional performance tests will ensure that other projects are commissioned properly. The functional performance tests will also increase persistence in the industry by providing the building operators with sufficient resources to troubleshoot problems that occur later.
- Pilot projects should provide insight into project problems and resolutions. All designers continue to learn from previous challenges. Documenting and sharing the problems and resolutions makes the industry more resilient and moves it forward.
- For pneumatic projects, each pilot should include a discussion of the relative merits between integrating ALC systems with existing pneumatic controls and document the capital cost reduction (if any) relative to a new DDC-zone control system.
- Follow-up after the completion of the study, one to two years later, will provide insight into maintenance issues associated with the greater complexity of the integration of the two control systems. Interviews with building operators and maintenance contractors will provide information to improve the deployment of future ALC integration projects.

Advanced lighting controls will become more common as technology continues to mature. Learning how to leverage the most from the systems now will ensure that future deployments reach the maximum operating potential possible.

References

DiLouie, C. 2009. *Integrating Lighting and Building Control*. Rosslyn, VA: Lighting Controls Association http://lightingcontrolsassociation.org/integrating-lighting-and-building-control/

EIA (Energy Information Administration). 2008. *2003 Commercial Building Energy Consumption Survey Data*. Washington, DC: http://www.eia.gov/consumption/commercial/data/archive/cbecs/cbecs2003/detailed_tables_2003/2003set19/2003html/e03.html

Pacific Gas and Electric Company. 2012. *Scaled Field Placement of Wireless Pneumatic Thermostats (WPT)*. San Francisco, CA http://www.etcc-ca.com/sites/default/files/reports/PGE%20Wireless%20Pneumatic%20Thermostat%20ET%20Final%20Report.pdf

Resource Nation. 2014. *Business Improvements that Lower Insurance Premiums*. http://www.resourcenation.com/article/business-improvements-lower-insurance-premiums/

Zhang, J. et. al. 2013. *Energy Savings for Occupancy-Based Control (OBC) of Variable-Air-Volume Systems*. Richland, WA: Pacific Northwest National Laboratory http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22072.pdf

Zhang, Y. et. al. 2012. *Integrated Lighting and Plug Load Controls*. Washington, DC: ACEEE http://www.aceee.org/files/proceedings/2012/data/papers/0193-000089.pdf