

Connected Lighting Systems in Smart Buildings: Findings and Lessons Learned from the U.S. Department of Energy Integrated Lighting Campaign and Multiple Field Evaluations

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ABSTRACT

Commercial buildings are making great strides in transitioning to high-efficacy lighting, with light-emitting diode (LED)—the predominant fixture type in commercial spaces—more than doubling its penetration of linear fixtures in a 2-year time span to over 20% of installed base (DOE 2020a). Although the energy savings from LEDs are a great energy success story, commercial spaces can save more by adopting connected lighting controls in their lighting systems. The energy savings potential of connected controls can be significant for lighting systems, and additional energy savings exist with other building systems. Despite this potential, connected lighting controls/connected lighting systems account for only 2% of the LED market (DOE 2020a), leaving a tremendous amount of energy savings on the table and, worse, foregoing the opportunities sensor data from these lighting systems can afford smart buildings.

Between 2016 and 2020, there were multiple field evaluations completed on these systems that demonstrated 60% lighting energy savings, greater than 30% plug load savings, and greater than 20% heating, ventilation, and air conditioning savings. The Integrated Lighting Campaign was launched in 2020 with an aim to share the benefits of these systems. This paper will present the findings from projects that were recognized in the inaugural year of the Integrated Lighting Campaign for exemplary performance related to the connected use of sensors and controls in lighting, as well as the integration of lighting systems with other building and business systems. Benefits afforded to building owners will be presented, along with best practices and lessons learned from the installation and operation of these systems.

Introduction

Light-emitting diodes (LEDs) have upended the lighting industry in less than 10 years and are expected to grow in market share, approaching saturation in most lighting applications by 2035 (DOE 2019). If LED adoption continues as projected through 2035, an estimated cumulative lighting energy savings of 62 quadrillion British thermal units (quads) of primary energy would be saved (DOE 2019). Department of Energy (DOE) estimates an additional 16 quads of savings is possible from the use of controls and connected systems (DOE 2019).¹

LED retrofit kits and new luminaires typically yield 50% energy savings compared to incumbent fluorescent and high-intensity discharge technologies, and this is before the inclusion

¹ U.S. aggregate annual energy usage for all sectors (e.g., transportation, buildings, etc.) is roughly 100 quads annually. This 62-quad value represents the cumulative savings from lighting energy from 2018–2035.

of lighting controls (Myer 2019). Although LEDs have been an energy-saving success story, additional energy savings and greater benefits for commercial spaces exist via the adoption of connected lighting systems (CLS), also known as advanced lighting controls.² CLS offer many capabilities beyond traditional controls that have great potential to save energy. In 2020, the DesignLights Consortium (DLC) found average energy savings from networked lighting control systems to be 49% (DLC 2020). CLS typically include occupancy sensors, daylight sensors, and when using a networked system, high-end trim. When layered together, the lighting system can be fine-tuned according to the building's characteristics that drive energy use, such as hours of operation, occupancy patterns, some behavioral factors, and the presence of daylight.

CLS can save energy by employing a more granular network of sensors to control the lighting system. For example, when a remote daylight sensor is positioned to control a group of luminaires, the sensitivity of the sensor must be adjusted coarsely to control all luminaires in the group, which may result in undesirable dimming outside of the daylit zone or a loss in energy savings within the daylit zone. In contrast, if there are sensors in every fixture, known as luminaire level lighting control (LLLC), the sensitivity of the sensors can vary on each of the parameters, allowing for much finer control and response, increasing energy savings.

Because CLS can communicate with other building systems—like heating, ventilation, and air conditioning (HVAC) and plug loads—there is potential to save much more energy and realize non-energy benefits by leveraging the data collected by lighting sensors to inform other systems. In addition to the granular network of sensors described above, integrated sensors take advantage of the ideal location of luminaires, offering a birds-eye-view perspective that is conducive to extensive information collection. This allows sensors to collect more types of information, like temperature and humidity that can optimize performance of the HVAC system, and location-based information which offers capabilities not related to energy, like asset tracking and security.

Integrated lighting not only has the potential to save energy but can allow the building to be more flexible on the electric grid. Buildings make up 75% of all U.S. electricity consumption and account for a similarly significant share of peak power demand (DOE 2020b). Most electricity demand from buildings results from key building system loads: HVAC, plug and process loads, and lighting. Integrating the lighting systems with key building systems along with enabling proper communications and controls can optimize these loads to respond to demand needs and adjust when and how much electricity to draw, while still maintaining a comfortable and productive environment for occupants.

Currently, CLS are installed on only 2% of LED systems and virtually no currently installed LED systems are controls ready, leaving a tremendous amount of energy savings on the table and foregoing the opportunities sensor data from these lighting systems can afford smart buildings. DOE programs like the Integrated Lighting Campaign (ILC) aim to speed the development and uptake of CLS and the integration of lighting with other building systems to improve efficiency and performance. This paper will introduce the field evaluations, present results from field evaluations of CLS, and then present findings from projects that were

² The terms connected lighting controls, advanced lighting controls, and networked lighting controls are somewhat interchangeable. The terms may also include luminaire level lighting controls. The terms have subtle differences but refer to a system with more granular control and intercommunication than a simple lighting system. CLS is used to refer to this category of systems throughout this paper.

recognized in the inaugural year of the ILC for exemplary performance related to the connected use of sensors and controls and the integration of lighting systems with other building and business systems. Finally, opportunities to building owners will be presented, along with best practices and lessons learned from the installation and operation of these systems.

Field Evaluations

Field Evaluation Sites

As market transformation programs and campaigns are developed, it is helpful to have examples of real projects with robust M&V to demonstrate the benefits and to encourage participation. Verified savings help encourage more building owners to consider CLS projects, and documented field evaluations provide inspiration for similar building types. The following section describes field evaluation sites and savings results from both CLS projects and lighting systems that are integrated with other building systems.

Field Evaluation Sites: Connected Lighting Systems

Since 2016, DOE, U.S. Department of Defense (DoD),³ and U.S. General Services Administration (GSA)⁴ have conducted field evaluations of connected lighting controls with the goal to determine the energy savings and cost-effectiveness of CLS. At Truax Air National Guard Base (ANGB), Selfridge ANGB, and Westover Air Force Base (AFB), DoD investigated the installation, energy savings, cyber challenges, and cost-effectiveness of LED retrofits with CLS. This section provides an overview of the projects, the control strategies used, and the benefits identified. Table 1 presents the project site and type, energy savings from the equipment, energy savings from lighting controls, total lighting energy savings, and simple payback.

Truax Air National Guard Base, 510 and Selfridge Air National Guard Base, 124/127, 303

- Truax 510, a 1,532 ft² office at an ANGB in Wisconsin; Selfridge 124/147, a 2,175 office ft² in Michigan; and Selfridge 303, a 2,175 office ft² at an ANGB in Michigan
- Each office replaced fluorescent lighting with LED retrofit kits and CLS, including task tuning, occupancy, and daylight sensors,
- Each site achieved more than 60% energy savings
- Emergency lighting significantly increased the cost of the system, affecting the payback at a few sites.

Westover Air Reserve Base

- Hangar (90,000 ft²), warehouse (80,000 ft²), and gymnasium (28,500 ft²) in Westover, MA were retrofitted

³ Evaluations were part of the ESTCP: <https://www.serdp-estcp.org/About-SERDP-and-ESTCP/About-ESTCP>

⁴ Evaluations were part of the U.S. GSA Green Proving Grounds (GPG): <https://www.gsa.gov/governmentwide-initiatives/climate-action-and-sustainability/center-for-emerging-building-technologies/about-green-proving-ground-gpg>

- High-intensity discharge (HID) and fluorescent lighting were replaced with LED and wireless CLS, including task tuning, occupancy sensors, and daylight sensors
- Original lighting in certain spaces was under-lighting the space
- Low labor costs enabled a very quick simple payback.

Table 1 - Results from Connected Lighting Control Field Evaluations

Site	Space Type	Energy Savings					Simple Payback (years)
		Lighting Equipment	Lighting Controls	Total Lighting			
				%	kWh /ft²	kWh	
Truax 510	Office	59%	8%	67%	1.2	1,992	25.6
Selfridge 124/127	Office	55%	8%	63%	1.8	3,915	31.3
Selfridge 303	Office	64%	7%	71%	3.6	12,232	14.7
Westover AFB ^{*,†}	Hangar	66%	20%	86%	6.4	575,000	2.8
Westover AFB ^{*,†}	Warehouse	64%	11%	75%	2.4	192,000	5.2
Westover AFB [*]	Gym	63%	25%	88%	3.5	101,000	8.2

* Also participated in the ILC

† = Baseline adjusted for illuminance

The lighting equipment savings in Table 1 is consistent with findings from the Interior Lighting Campaign that a conversion from an incumbent fluorescent or high-intensity discharge technology to LED results in 50% or more energy savings at the equipment level (Myer 2019).

Although lighting controls can save additional energy, the conversion to LED saves the larger portion of energy. Savings from lighting controls are not additive to the savings from the LEDs because controls reduce energy from the new LED baseline. For example, if LEDs save 50% compared to the baseline and lighting controls are added that could save 45%, then resultant energy savings is not 95%, but 73%. As such, while including lighting controls increases the cost and energy savings of the system, it may reduce the overall cost-effectiveness of the system.

Table 1 also shows simple payback, which varies in part due to differing equipment densities (fixtures/ft²); offices have high equipment density with light fixtures spaced 8–10 feet apart, whereas hangars and warehouses have low equipment density with higher ceilings where light fixtures may be spaced much farther apart. Higher equipment densities usually require more nodes, sensors, and control devices for the same area, which may reduce the overall cost-effectiveness of the system.

Field Evaluation Sites: Lighting Systems Integrated with HVAC and/or Plug Loads

After evaluating CLS that only operated lighting, DOE and others started evaluating integrating the lighting controls with other building systems to increase the total energy savings as well as improve the cost-effectiveness of these solutions. This section provides an overview of the projects, control strategies, and benefits of integrated lighting. Results of field evaluations from integrating the lighting systems with other building systems are shown in Table 2.

CentraCare

- Outpatient medical office building in Becker, Minnesota (12,400 ft²).
- Replaced fluorescent lighting with LED retrofit kits and CLS, including task tuning, occupancy sensors, and daylighting controls
- The lighting occupancy sensors were integrated with the space building automation system (BAS) and plug loads to set back the temperature setpoints and/or turn off plug loads when the spaces were unoccupied.

Hennepin County

- Lobby in a high-rise building in Minneapolis, Minnesota with an outpatient medical office and fitness center (7,300 ft² total)
- Fluorescent lighting replaced with LED retrofit kits and CLS including task tuning, occupancy sensors, and daylighting controls
- The lighting occupancy sensors were integrated with the space BAS and plug loads to set back the temperature setpoints and/or turn off plug loads when unoccupied.

John C. Kluczynski (JCK) Federal Building

- Three floors (60,000 ft² total) of a historic 43-story federal building
- Fluorescent lighting replaced with LED retrofit kits and CLS including task tuning, occupancy sensors, and daylighting controls
- The lighting occupancy sensors were integrated with the space BAS to set back the temperature setpoints when unoccupied
- The project attempted to integrate the CLS with the BAS, but the integration was unsuccessful because the space had multiple HVAC systems serving the space and one system would counteract the other system as it set back. Additionally, the air-handling unit served six floors and verification was too difficult. Finally, the on-site staff changed the BAS infrastructure and that further limited the success of the integration.

Cedar Avenue Truck Station, Minnesota Department of Transportation (MnDOT)

- One-story office building (11,300 ft²) that handles road plowing, maintenance, and other road duties located near Minneapolis Airport, MN
- Replaced fluorescent lighting with LED retrofit kits and CLS including task tuning, occupancy sensors, and daylighting controls
- The lighting occupancy sensors were integrated with the space BAS and plug loads to set back the temperature setpoints and/or turn off plug loads when unoccupied
- Significant mechanical (83%) and plug load (73%) energy savings were achieved. Baseline building operation was 24-hours because of unpredictable occupancy (e.g., snow being cleared Tuesday, dry conditions Thursday). Significant plug load savings stem from reduced occupancy from COVID.

St. Paul Traffic Operations

- One-story office building (13,100 ft²) that handles traffic operations for St. Paul, MN
- Replaced fluorescent lighting with LED retrofit kits and CLS, including task tuning, occupancy sensors, and daylighting controls

- The lighting occupancy sensors were integrated with the space BAS and plug loads to set back the temperature setpoint and/or turn off plug loads when unoccupied
A manual temperature change during a cold week caused the BAS and lighting systems to temporarily stop communicating with each other.

Tinker Air Force Base

- Office (5,000 ft²) and high-bay space (21,000 ft²) at AFB in Oklahoma
- Replaced fluorescent and HID lighting with LED retrofit kits and CLS including task tuning, occupancy sensors, and daylighting controls
- The lighting occupancy sensors were integrated with the space BAS and plug loads to set back the temperature setpoint and/or turn off plug loads when unoccupied
Low labor cost of integration with mechanical system and good mechanical energy savings reduced the cost recovery period of the connected lighting system.

Jones Hall, University of Minnesota (UMN)

- Mixed-use higher education building with offices, classrooms, and public spaces
- Replaced fluorescent lighting with LED retrofit kits and connected lighting system
- Lighting controls included task tuning, occupancy sensors, and daylighting controls
- The lighting occupancy sensors were integrated with the space BAS and plug loads to set back the temperature setpoints and/ or turn off plug loads when unoccupied
- The lighting retrofit saved 0.9 kWh/ft², and HVAC integration saved an additional 2.8 kWh/ft² and 0.06 therm/ft². In total, UMN saved \$0.45/ft.

Field Evaluation Results

The results of seven projects that integrated the lighting with the HVAC systems are presented in Table 2. As an energy-saving tactic, HVAC temperature set points can be set back when building spaces are not occupied. However, HVAC zones are typically large and do not have sufficient information to adjust the temperature set points at a granular scale. CLS have occupancy sensors that can be used to provide granular occupancy information to the BAS. By integrating the lighting system with the BAS, different elements of the HVAC system can be set back when the spaces are unoccupied, saving operational energy. The integration involves little equipment but can yield significant energy savings, and as a result, this synergy saves mechanical energy and improves the cost-effectiveness of the CLS.

Additionally, six of the seven projects in Table 2 integrated the lighting system with the plug loads using automatic receptacle controls (ARC). ARC turn off selected receptacles using the occupancy sensors from the lighting system when the space is unoccupied or by using a time clock to create schedules. ARC are typically connected to non-critical loads at workstations, like task lighting and peripheral equipment charging, while critical loads like computers and networking equipment remain energized.

Table 2 - Early Findings from Lighting Systems Integrated with HVAC and/or Plug Loads

Site	Savings					Simple Payback (years) ††
	Lighting Equipment	Lighting Control	Total Lighting	Plug Loads	HVAC	
CentraCare	58%	1%	59%	53%	---	34.2
Hennepin	63%	5%	68%	53%†	30%	26.8
JCK	54%	9%	63%	N/A	---	70+**
MnDOT*#	63%	14%	77%	76%	83%	2.4
St. Paul	60%	3%	63%	56%	---	47.6
Tinker AFB	64%	3%	67%	38%	26%	10.3
UMN*	29%	28%	57%	49%†	20%	17.6

* Indicates that the project was also recognized in the Integrated Lighting Campaign

** Site characteristics affected simple payback unrelated to the lighting technology

N/A means integration for the technology was not attempted

--- means no value measure/detected even though technology integration was attempted

† Based on modeled data, not direct results

†† Based on national electricity and gas prices

Results measured during COVID shutdown from a pre-COVID baseline; actual savings expected to be lower

Integrated Lighting Campaign

DOE commercial building-focused campaigns target building owners and managers who are open to early adoption of new products and willing to go above and beyond typical solutions. Campaigns are designed to demonstrate real-world savings and other benefits of newer technology and to provide resources that make it easier for buyers to consider new or underutilized products and solutions. Campaigns also inform technology developers of real-world performance, user feedback, and opportunities for improvement.

DOE had run earlier lighting campaigns focused on high-efficiency interior lighting solutions but were retired in 2019 when it became clear that the market adoption of LEDs in key interior applications was well underway (Myer 2019). In 2020, DOE introduced the ILC, a program designed to advance connected lighting controls that are integrated into building systems while still recognizing advances in sensors and controls for lighting.

Key measures of success for DOE campaigns are increased technology adoption and the resulting energy savings. Adoption can be tracked by units installed, sites with new technology/practices, incentives paid, and/or participating entities. Campaigns will use energy savings that are directly quantifiable and/or estimates of energy savings provided by campaign partners, such as building owners and utilities, when measured savings are not available.

ILC Recognized Projects

In 2021, the ILC recognized 13 projects as part of the inaugural recognition cycle. The projects recognized were varied with both interior and exterior sites at various locations and with different levels of integration selected. Each project resulted in both energy and non-energy benefits. This section provides an overview of the projects, control strategies, and benefits. Table 3 summarizes the control strategies of these projects.

Bryan Health

- Nonprofit healthcare organization serving patients in Nebraska
- Lighting upgrade replaced all fluorescent luminaires with LEDs and CLS
- The retrofitted lighting system featured occupancy sensors and task tuning levels that were automatically incorporated with preset scenes, enabling highly accurate (medical) diagnoses for specific purposes, like examinations and X-ray viewing.
- Retrofit reduced lighting energy use by 75%

California State University, Dominguez Hills

- James L. Welch Hall is a four-story, multiuse college campus building that was retrofitted with occupancy, photo-sensing, temperature sensors, and wireless networking
- The increased number of sensors helps prevent lights turning off while occupied (i.e., false-offs). LLLC also facilitates allowing users to select light levels to their comfort
- HVAC sequences were programmed using occupancy data from the lighting sensors and allows the damper to be shut off in over 90% of the spaces when vacant. Over one year, lighting and fan energy use was reduced by 34%, resulting in savings of 0.9 kWh/ft². The building reduced heating and cooling by 27% and saved nearly 0.16 therm/ft².

City of Wilmington, Delaware

- Upgraded 1,732 streetlights to reduce energy use and streamline maintenance
- Existing fixtures were retrofitted with LED fixtures with advanced control capabilities, such as photocontrol, status communication, high end trim, and dimming control.
- Luminaires were commissioned at 80% of full power with the intention of increasing the power 1% per year for 20 years to account for lumen depreciation
- The LED conversion not only saved significant amounts of energy, but it also vastly reduced streetlight maintenance costs from fewer lamp burnouts.

Denver Water

- The 35-acre campus is home to nine buildings, seven of which are newly constructed
- Designed to improve energy efficiency, the Administration building was completed in 2019 and is certified Leadership in Energy and Environmental Design (LEED) Platinum
- Included a CLS that is BACnet-integrated and shares the real-time status of the networked occupancy sensors located in nearly all spaces of the building
- The building was only used for a short time before operations and occupancy were adjusted due to the COVID-19 pandemic in March 2020. Denver Water estimates that the strategies leveraged from integration save 2–4% over non-integrated controls.

IMEG Headquarters

- The national engineering and design consulting firm implemented several emerging lighting techniques as part of a study to better understand the physiological and psychological impacts on occupant comfort, well-being, and energy savings.
- IMEG explored color tunable lighting; low glare luminaires; biophilic fractal (i.e., nature-like) experience; wireless sensors; enhanced acoustic performance; and hospitality-supported workplace

- Overall, post-retrofit, lighting power density is 37% below International Energy Conservation Code 2018, resulting in significant reduced energy consumption.

Johnson Controls

- Retrofitted its headquarters in Milwaukee, Wisconsin with several different lighting controls systems that were combined with building systems
- The use of the lighting sensors allows the building operators to better understand and proactively control the buildings and maximize space utilization
- Control devices turn lights off when vacant, reduce time navigating, change color temperature based on time of day, and allow occupants to control their lighting.

Massachusetts Port Authority

- Upgraded 23 existing high-mast light poles that illuminate an active container yard
- CLS is integrated with existing Wi-Fi enabled systems for enhanced control of light levels and improved energy and operating efficiency, allowing operators to control the lighting via wireless controls as they receive real-time utilization information
- Controls were given to the port police to allow them to automatically turn on all the light poles to high mode in an emergency.

Office of Personnel Management, Theodore Roosevelt Federal Building

- Office complex in downtown Washington, D.C. that serves as the US OPM headquarters
- Two-phase HVAC integration project included LED upgrades and installation of over 1,000 new occupancy and daylight sensors
- Over 900 variable air volume (VAV) boxes were mapped to occupancy sensors and integrated with BACnet to automatically set back HVAC when spaces are unoccupied
- Savings from HVAC integration and associated strategies exceed 900,000 kWh/year.

State of Vermont

- Integrated a new lighting system with HVAC controls at two large state buildings in Burlington: the Costello Courthouse and the Zampieri Office Building.
- Lighting occupancy sensors trigger HVAC system to reduce the ventilation levels provided to unoccupied spaces as well as modify temperature set points
- Run times of the 135 fan-powered variable air volume boxes were reduced, and the 50 horsepower supply fans were turned down based on occupancy.

Walgreens

- Upgraded to LED luminaires with preset light levels, zoned to adjust for daylight
- Two pilot projects were conducted: First, visual indication of emergency lighting operation, automation of emergency lighting remote testing and reporting, and failure reporting of luminaires/parts. Second, shopping cart and basket tagging pilot where carts were equipped with Bluetooth enabled asset tags to track traffic patterns
- Pilots resulted in insights about ideal points of entry/exit, traffic patterns, higher positioning accuracy used for wayfinding and product search, inventory management, and analytics of key performance indicators for dwell, speed, and departments visited.

Table 3 - Summary of 2021 ILC Recognized Projects

Site	CLS	Integrations		
		HVAC	Plug Load	Other
Bryan Health*	✓			✓
Cal State University, Dominguez Hills*	✓	✓		
City of Wilmington, Delaware*	✓			
Denver Water*		✓		
IMEG Headquarters*	✓			
Johnson Controls		✓		✓
Massachusetts Port Authority*	✓			
Minnesota Department of Transportation*		✓	✓	
Office of Personnel Management*		✓		
State of Vermont		✓		
University of Minnesota*			✓	
Walgreens				✓
Westover Air Reserve Base	✓			

* Case studies can be found on the ILC website: <https://integratedlightingcampaign.energy.gov/>

Outcomes

Field evaluations and case studies are a valuable source of information. These sites are willing to take a technology proven in the laboratory and install and evaluate it in a real-world setting. Lab evaluations are a critical but controlled step. Field evaluations allow the technology to perform in the wild, yielding or revealing many valuable benefits, lessons learned, and best practices. This section outlines benefits, lessons learned, and best practices for the integration strategies discussed: CLS, CLS integrated with plug loads, and CLS integrated with HVAC.

Connected Lighting Controls

Opportunities

Lighting controls offer users the right amount of light at the right time. Allowing the luminaires to be dimmed or turned off when not in use saves energy and extends equipment life. Additionally, proper lighting controls are a critical piece of occupant comfort and satisfaction in the space, where they feel safe and in control of their surroundings. CLS can serve a critical role in smart buildings, enabling grid services like demand response.

Beyond energy savings, occupant comfort, and grid services, CLS also provide other value through networking capabilities. Both the JCK field evaluation site and the Walgreens site evaluated the use of the CLS for Internet-of-Things (IoT) features. Both were using secondary sensors in the lighting system to help better determine how people moved in their spaces as well as how much time they spent in certain areas. Massport used light fixtures to extend their wireless network to improve communications. The City of Wilmington saved significant

amounts of labor cost by using a system that automatically reported outages in their streetlights. These are just a few examples of how CLS can add value beyond energy efficiency.

Lessons Learned

There is low adoption of CLS, which leaves energy savings untapped and misses out on opportunities to use sensor data in other building systems. Barriers to CLS adoption include high cost, lack of standardization, and complexity. DOE campaigns, like the ILC, aim to increase adoption and help building owners overcome these barriers.

Software for complex controls systems can be challenging and may not always be intuitive. Owners will learn over the course of six months to a year what really works for them and may find that there are areas where they wish to change illuminance levels, auto off delay times, or more holistic scheduling changes.

CLS projects are inherently multidisciplinary; many different departments and stakeholders will be involved, including facilities, management, contractors, and end users, and all have different priorities and measures of success.

Emergency lighting is required in all buildings for egress purposes. Lighting fixtures with CLS that have emergency batteries inside the luminaire can drastically increase the cost compared to non-CLS luminaires. However, an advantage of CLS is that the emergency lighting can be tested via the control interface, saving time spent manually testing.

Best Practices

Many of the ILC participants said that training is key to project success, for both facilities staff and building occupants. Organizations should train occupants on proper operation of lighting controls and train a dedicated member of the facilities team during commissioning, so there is someone on staff who can make necessary adjustments and troubleshoot when necessary.

ILC participants also suggest partnering early with the information technology (IT) team of the building early to overcome compatibility challenges. To achieve a seamless integration with the OPM project, their IT team built two new servers and installed two network interface communication cards in each server to allow communication between the LAN networks. Similarly, Massport, who integrated their lighting and Wi-Fi systems, worked with their IT team to make sure there were enough access points and the right level of bandwidth available.

Finally, proper zoning is key to a well-functioning CLS and/or LLC system. With the increased granularity of sensors, special attention to control zones must be given to ensure that the correct luminaires are responding to control signals.

Lighting Integrated with Plug Loads

Opportunities

Seven projects described in this paper integrated plug loads with their lighting. Over the next 30 years, plug load energy is expected to grow, whereas lighting energy is expected to decrease. As such, it is a priority to control plug loads to address the projected growth.

ARC save energy and are often required in some form for building energy codes. Integrating lighting and plug loads reduces equipment as well as potentially installation time. Treating each building system as a standalone system increases costs and misses potential

benefits of the dual use of connected lighting control systems. Using the lighting systems occupancy sensors and/or scheduling capabilities to turn off appliances when the space is vacant adds to the energy savings of lighting controls and extends equipment life of the appliances.

Table 4 summarizes opportunities and lessons learned of the control strategies discussed.

Lessons Learned

A key challenge with plug loads is the electrical load is user dependent, meaning a user can plug in a 5-watt device (e.g., cell phone charger) or a 1,500-watt device (e.g., space heater) with no difference in effort. This dynamic range of options relates to many of the lessons that were learned from these field evaluations about integrating plug load controls and lighting systems. Energy saved by the ARC range from 30–70%; however, actual savings were very small because most of the loads controlled by the ARC are low power devices. Because the actual energy saved is small and ARC are two to five times more expensive than constant-on receptacles, cost-effectiveness is low with ARC devices.

Occupant education is critical to achieve energy savings and user satisfaction from ARC. As devices become smarter and more connected, they may spend time on ramp-up processes (e.g., acquiring an IP address), which can be disrupted by repeated power cycling of the ARC in response to vacancy. While the field evaluations left behind a sheet explaining the receptacles with suggested loads to users, they may not read or remember to consult this sheet when using the ARC. In some of the spaces with ARC, users opted to not use the controlled receptacle at all.

Similarly, ARC often look like typical plugs and occupants may not know they are using a controlled receptacle. During the field evaluations, some occupants were unaware of the word “controlled” engraved on the plastic of the receptacle, denoting the controlled outlet. By only engraving in small text and not using a more conspicuous indicator (e.g., blue circle, green square, etc.), identifying the ARC is very difficult, especially considering plugs are low and often under desks or other devices. Not being able to easily determine which receptacle was controlled is believed to be one reason for the low effectiveness of ARC.

Similarity between ARC and ground-fault arc interrupter (GFCI) receptacles that have a reset button also causes confusion. One site had an ARC with an override button that looked very similar to a GFCI button; both receptacles looked similar in shape, both had buttons on the receptacle, and both had green LED status lights (in different places). The GFCI was confused by one of the staff members for the ARC, leading to improper use.

Improper installation can also lead to lost savings. One product where the top receptacle was the constant-on and the bottom receptacle was controlled, included an information sheet showing the grounding pin in the up position. However, receptacles were installed with the grounding pin in the down position, i.e., rotated 180 degrees compared to the information sheet. In this case, users were following the information sheet and using the bottom receptacle for their appliance to be controlled but because of a subtle, yet substantial difference between the information sheet and installation, savings were lost.

Finally, wiring ARC can lead to problems. Receptacles are often wired in a downstream scenario, where the branch circuit is wired to a single receptacle and each subsequent receptacle in the space is powered from the previous. Because of the way the neutral wires were installed in the room to the other receptacles, when the automatic receptacle turned off, it was turning off the other receptacles downstream. This was reconciled, but it required an on-site visit.

Best Practices

Generally, occupants are most familiar with constant-on receptacles, so education is critical for users as they become more familiar with the concept and the technology. Clear, consistent markings on both the receptacles and the device plugs are needed to ensure proper use and energy savings. Because plug loads are heavily dependent on occupant behavior and choices, best practices require an on-site champion. On-site champions can inform new staff members of ARC as well as remind existing staff members when new equipment is acquired and which equipment is suitable for use with ARC.

Avoid using ARC on equipment with a long (30 seconds or more) warm-up/boot-up time and on equipment where constant power cycling can lead to user dissatisfaction. Any technology or equipment that cannot readily be used once energized should not be powered by ARC.

Lighting Integrated with HVAC

Opportunities

Successful HVAC integration can achieve significant energy savings, greatly improving the cost-effectiveness of the lighting control system. Using the lighting systems granular network of sensors can offer better occupant control and comfort. As with integrated plug loads, optimizing use of the HVAC system using occupancy sensors can also extend equipment life, such as fans, compressors, and filters.

Lessons Learned

Most building automation systems use the well-established BACnet protocol, with which most devices are tested to work. However, not all the sites had lighting equipment ready to work with BACnet, and others had unique BACnet features that had to be addressed.

One challenge is that some types of BACnet licenses are based on the number of objects on the network. Lighting systems involve more components, and as a result, can increase needs of the network. Sites may have to shift to a larger BACnet license in preparation for the integration. For example, UMN has several buildings with extensive energy management systems and had modified the BACnet addresses to be building and port specific. This change is abnormal for standalone buildings or small sites but may be more common with large campuses. The lighting system struggled with the integration because of this unique port naming. Ultimately, the lighting system firmware had to be modified to accommodate the naming system.

BASs gather and store data from the mechanical system, known as “trend data.” However, BASs do not analyze the data; third-party software, coupled with staff knowledgeable of the systems is necessary for analysis. Only once the data are analyzed can the integration be verified. In these field evaluations, the lighting is sending a one-way signal and the BAS is using that signal. Mechanical systems have many components (e.g., dampers, temperature, fans, etc.) that can be modified in response to the lighting signal. These components are already changing in response to building occupancy and environmental conditions (e.g., temperature, humidity, etc.). Verification of integration requires a keen understanding of mechanical systems, the building mechanical zoning, the normal daily and seasonal changes, and how a signal from the lighting system should change the system. Although not overly complex, this does require knowledge of the systems as well as the different software that can handle these functions.

Because mechanical systems have many components changing in response to the external environment, the verification of integration with the lighting system is more complex and timelier than other systems. Integration of the lighting and plugs can be tested and verified in a few hours. In contrast, mechanical and lighting integration needs a minimum of one week (more is better) to run together, and then the data must be processed. If the processing of the data suggests that the integration was not successful, the process needs to be repeated. The process is also not automated. The data need to be reviewed periodically to determine if the integration may have stopped for a reason. Third-party software may be able to automatically alert the building staff if the integration stops, but that is not a common current practice.

Control persistence is a concept for CLS; when the power fails, the control system retains memory functions instead of needing reprogramming to work when power returns. Similarly, mechanical integration persistence is also needed. The St. Paul site lighting and mechanical systems were integrated, but during an abnormally cold week, the heating thermostat was manually changed on-site, which caused the integration to stop working. After a thorough review of the data, the team was able to determine the integration had stopped.

Not all building or mechanical systems are ideal for lighting/mechanical integration. The St. Paul site had predictable occupancy, but because of the mechanical system design and zoning, all four zones had to be unoccupied before the setbacks from the mechanical system started. Time-based controls of the BAS would have been just as successful because of the predictable building occupancy coupled with the system design. Had either been different, the integration would have provided more benefits than time-based switching.

In contrast, the MnDOT mechanical system operated 24/7 because building occupancy was unknown. As a transportation service center, the building could be busy all day and night on a Tuesday because of a snowstorm, and the following Thursday could be normal day operations. The mechanical savings at MnDOT were significant because the integration changed the mechanical system from operating 24 hours per day to setbacks based on occupancy.

Best Practices

For greater savings from the HVAC system, more granular sensors are needed to optimize the system. This could be accomplished with an additional set of dedicated HVAC system occupancy sensors, but those sensors need to be physically located and powered. Ideally, occupancy sensors and data from the lighting system can be used and the systems can be integrated to provide HVAC system energy savings.

HVAC temperature set points can be set back when building spaces are not occupied, and CLS occupancy sensors can be used to provide occupancy information to the BAS. By integrating the lighting system with the BAS, different elements of the HVAC system can be set back when the spaces are unoccupied, saving operational energy. However, education, knowledge, and testing the equipment for BACnet as well as being able to modify or configure the system for unique BACnet needs is essential. When integrating with mechanical systems, data need to be reviewed periodically to determine if the integration may have stopped for any reason, such as manual thermostat changes.

Lighting integration with mechanical systems performs better in certain buildings. Buildings with unpredictable occupancy yield greater savings than buildings with fixed occupancy schedules (e.g., a school). Mechanical systems with small zones and variable equipment fare much better than large systems. Older buildings may have an air handling unit

(AHU) that serves multiple floors. The granular sensing of integration will have almost no effect on an AHU serving multiple floors. Similarly, if a building has multiple zones that need to be unoccupied before a damper setback, the integration will have little effect as well.

It is critical to engage both building information technology (IT) staff and mechanical contractors early in the process. Most mechanical systems use BACnet and integrating the lighting system can require the BACnet license. The BACnet system should be separate from the building IT system, but the building IT staff can address issues early.

Table 4 - Summary of opportunities and lessons learned of the control strategies discussed

Control Strategy	Opportunities	Lessons Learned
Connected Lighting Controls	- Provides good energy savings - Offers better control of lighting - Extends equipment life - Improves occupant comfort - Enables IoT benefits	- Low adoption of CLS - Can be complex and expensive - Requires stakeholder coordination - Lighting fixtures with CLS that have emergency batteries can be expensive
Lighting Integrated with Plug Loads	- Has increasing opportunity for energy savings - Potentially reduces equipment and installation time - Extends equipment life	- Low power devices are most often controlled with ARC - ARC are 2 to 5 times more expensive than typical receptacles - There is low user understanding, unclear markings and instructions - There is potential for improper wiring
Lighting Integrated with HVAC	- Provides significant energy savings - Improves cost-effectiveness of lighting upgrades - Improves occupant comfort	- Requires BAS interoperability - Verification requires advanced understanding of mechanical systems - Mechanical integration persistence is needed - Savings are heavily dependent on building occupancy patterns

Summary

Commercial buildings are making great strides in transitioning to high-efficacy lighting with LEDs. Although the energy savings from LEDs are a great energy success story, commercial spaces can do more through the adoption of CLS. The energy savings potential of connected controls can be significant for lighting systems, but additional energy savings exist with other building systems. Despite this potential, CLS account for only 2% of the LED market, leaving a tremendous amount of energy savings on the table, and worse, foregoing the opportunities sensor data from these lighting systems can afford smart buildings.

When encouraging new technology, it is valuable to have examples of real projects with robust M&V to demonstrate the benefits and to encourage participation. Verified savings help

encourage more building owners to consider CLS projects, and documented field evaluations provide inspiration for similar building types.

Technology campaigns seek to accelerate the adoption of emerging technologies, such as connected lighting controls and integrated lighting systems. To date, the ILC has successfully identified and overcome market adoption barriers; created awareness of new technology; provided technical assistance to support early adopters; recognized successful applications of the technology; and leveraged a diverse set of partners to provide outreach and support. However, as technology progresses, how can the ILC continue to transform the market and realize its potential for significant energy and non-energy benefits?

Field evaluations and campaigns aim to continue to build the body of knowledge of connected and integrated lighting and share with the industry to reduce barriers to adoption, such as system complexity, lack of standardization, and poorly understood benefits. The already-growing body of knowledge includes case studies on recognized projects, technical reports and fact sheets, utility incentive databases, trainings, and more. New and existing users can tap these resources to better understand how they can upgrade their facilities, find the best lighting solutions, and connect with similar stakeholders to borrow inspiration and experience. The campaign and body of knowledge effectively creates a community of building owners, managers, utilities, and service providers that work together to save energy and money in their facilities.

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