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Slipstream (formerly Seventhwave)
Integrated Controls Package for High Performance Interior Retrofit
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Project Partners Xcel Energy, CREE, Legrand, PNNL

Contents

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INTRODUCTION

For the last few years, networked lighting control (NLCs) have promised significant energy savings beyond what is achieved through a basic light-emitting diode (LED) lighting retrofit. At the same time, NLCs can substantially increase the cost and complexity of the lighting retrofit. And as lighting system wattage declines because of the increasing efficiency of LEDs, advanced controls have less lighting energy to save and the cost-effectiveness of the NLC investment decreases. But NLCs can be leveraged to achieve significant energy savings and value by enhancing control of other building systems.

NLC products deploy distributed sensors throughout a building to collect granular data on building operations—these can allow multiple building systems to respond to real-time feedback on occupancy, daylight, and in some cases even temperature and air quality. These sensor networks allow for optimization of lighting, heating, ventilation, and air conditioning (HVAC) and plug load control to achieve significant reductions in building energy consumption. Integrating NLCs with HVAC, plug load controls, and space utilization assessments all enhance the value of NLC investments.

Historical barriers to integrating control systems at the building-level control have included complexity, cost, and challenges with occupant interactions with the controls. Complexity must be reduced to a straightforward plug-and-play connection between systems, requiring little additional labor for integration. User experience may lead to challenges with energy savings persistence; unhappy users will either turn the controls off or find a way to bypass or defeat the system. If the system does not continue to operate as intended, then the energy savings made possible by the controls will never be achieved.

Two major shifts in technology have allowed for these barriers to be overcome: wireless luminaire-level lighting controls (LLLC) and centralized system control made compatible with open protocols. These technology developments are allowing for major improvements in how we can address the barriers of installing a whole building controls system.

There are already a few LLLC products on the market that can provide these enhanced benefits. Manufacturers and entrepreneurs are working hard to expand the impact of these products. But does system interoperability work? Can it be deployed at scale? Slipstream, together with Xcel Energy, the US Department of Energy (DOE), Cree Lighting, and Legrand/Wattstopper have implemented a pilot in five different buildings in Minnesota to test the integration of NLC with HVAC and plug load controls. All pilot projects successfully integrated NLCs with HVAC, and most also incorporated plug load controls. Each project did encounter challenges in ease of interoperability, commissioning of HVAC controls, and other items.

IMPLEMENTATION GUIDE

The Implementation Guide provides findings from five NLC+ demonstration sites in Minnesota commercial building retrofits. The retrofits included HVAC measures enabled by occupancy sensors, lighting control strategies, and plug load controls. This guide will explain retrofit planning and design, cost, integration steps, installation, as well as lessons learned along the way.

slipstream


Photo courtesy of Cree Lighting

INTEGRATED CONTROLS IMPLEMENTATION GUIDE

This guide provides information on successfully integrating networked lighting controls with HVAC and plug load controls in commercial and institutional buildings.

This guide is intended for facilities managers, lighting designers, electrical and mechanical engineers, contractors, controls technicians, and commissioning agents.

PROJECT PARTNERS

CREE LIGHTING
A COMPANY OF IDEAL INDUSTRIES, INC.

legrand®

Pacific Northwest
NATIONAL LABORATORY

Xcel Energy®

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- The U.S. Department of Energy funded the project.
- Xcel Energy supported recruitment of demonstration sites and provided energy efficiency incentives.
- Cree Lighting manufactured the networked lighting system and supported integration with HVAC and plug load controls.
- Legrand manufactured the plug load controls and supported integration.
- Pacific Northwest National Laboratory measured energy impacts at the demonstration sites.

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Contents

Introduction

Historically, most lighting retrofits have not involved deployment of advanced lighting controls. The typical retrofit approach is to install a few occupancy sensors in the largest spaces with conservative time delays to avoid mistakenly turning off lights while occupants are present. Technology is now allowing for significant improvements that deliver multiple benefits to building owners. Today's **networked lighting control** (NLC) technologies deploy distributed sensors throughout a building to collect granular data on building operations, allowing multiple building systems to respond to real-time feedback on occupancy, daylight, and in some cases even temperature and air quality. These sensor networks allow for optimization of lighting; heating, ventilation and air conditioning (HVAC); and plug load energy use to achieve significant reductions in building energy consumption.

HVAC MEASURES ENABLED BY OCCUPANCY SENSORS

- Thermostat setback
- VAV box turndown/off
- Aggressive pressure/temperature reset
- Ventilation reset
- Demand control ventilation

With funding from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, Slipstream and its partners—Xcel Energy, Cree Lighting, Legrand and Pacific Northwest National Laboratory—have demonstrated a systems integration approach with LED lighting retrofits that deploy luminaire-level NLC. Following a one-for-one retrofit of existing lighting with NLC, the lighting system sends signals to the building automation system (BAS) for HVAC control and communicates wirelessly with outlet-level plug load controls. This guide refers to the integration of NLC with other building control systems as "NLC+."

This guide leverages findings from five NLC+ demonstration sites in Minnesota commercial buildings. The demonstration sites included two offices, a mixed-use facility (clinic and fitness center), a higher-education building, and an outpatient clinic. The foundation of each project was an LED troffer retrofit that packages energy efficient LED technology with luminaire-level lighting controls (LLLC). The NLC system uses wireless communication and automatic setup for straightforward zoning and control programming. The integrated occupancy sensing functionality from the light fixtures is coupled to wireless outlet-level controls to reduce plug load power when occupants are not present. Finally, the system communicates digitally with building automation systems via the BACnet protocol to allow for a broad variety of HVAC efficiency measures.

RESULTS	
Electricity savings	3.8 kWh/ft^2
Natural gas savings	5.6 kBtu/ft^2
Energy cost savings	\$0.45/ft^2
Payback (after utility incentives)	6.9 years
Avoided carbon emissions	6.2 lbs CO_2e/ft^2

Table 1: shows average impacts for the integrated controls projects in the three Minnesota demonstration sites.

State of the Market

Lighting controls offer a variety of opportunities for reducing energy consumption such as occupancy and vacancy sensing, daylight harvesting, task tuning and personal tuning. Studies show the combination of NLC installations and lighting control strategies yield a 40 percent reduction in lighting energy use.[1] These lighting control strategies are increasingly implemented via an **NLC** system, often with the sensors, luminaires, and wall controls installed separately and communicating via a mixture of wired and wireless configurations. **Wireless NLC** is now

[1] Williams et. al. (2012). *Quantifying National Energy Savings Potential of Lighting Controls in Commercial Buildings*. Ernest Orlando Lawrence Berkeley National Laboratory. Available at: https://efficiency.lbl.gov/sites/all/files/quantifying_national_energy_savings_potential_of_lighting_controls_in_commercial_buildings_lbnl-5895e.pdf

Mellinger, D. (2018). *Energy Savings Potential of DLC Commercial Lighting and Networked Lighting Controls*. Prepared by Energy Futures Group for the DesignLights Consortium. Available at: https://www.designlights.org/lighting-controls/reports-tools-resources/nlc-energy-savings-report/

becoming more prevalent, reducing retrofit labor and material costs and making it easier to reconfigure control strategies in response to changes in the workspace.

LLLC have emerged as a subset of NLC, incorporating sensors and controls within each fixture itself. LLLC simplifies system installation and allows for more aggressive control strategies that achieve deeper savings. With more granular sensing you can be more confident in the accuracy of the signal and use more aggressive control parameters.

NLCs can substantially increase the cost and complexity of a lighting retrofit. And as lighting system wattage declines because of the increasing efficiency of LEDs, advanced controls have less lighting energy to save and the cost-effectiveness of the NLC investment decreases. One solution to the cost-effectiveness challenge is to achieve deeper energy savings by integrating NLC systems with HVAC and plug load controls. Throughout this guide, **NLC+** refers to this systems integration approach, while **NLC** refers to just the lighting system. **NLC+** is an emerging practice that involves some implementation hurdles. For example, most contractors have little experience with these kinds of projects and will often inflate bids to reduce risk. Systems from different manufacturers are not always easily interoperable, so configuring the communications pathways takes some effort. This guide was created to help you overcome these and other challenges and implement a successful NLC+ project.

LIGHTING CONTROL STRATEGIES

Occupancy/vacancy sensing: Turning off or reducing lighting output when no one is present.

Daylight harvesting: Turning off or reducing electric light output when enough daylight is present.

Task tuning/high end trim: Setting the maximum light output to something less than 100%, reducing the potential for over-lighting.

Personal tuning: Similar to task tuning but gives individual occupants the control to adjust the light level in their workspace.

Implementation Guide

This guide reviews lessons learned from NLC+ demonstration sites and offers guidance, tools, and resources to help you take your next LED retrofit beyond lighting to achieve deeper savings. Tenant fit-outs and new construction are also great applications for NLC+ and may present fewer implementation hurdles than retrofit projects. Much of the information in this guide is relevant to new construction applications. Call-out boxes highlight aspects of the process that differ slightly in new construction.

SYSTEM ARCHITECTURE

An NLC+ system typically includes or interacts with the following components:

- LED lighting luminaires, increasingly with:
  - Embedded occupancy and daylight sensors at each luminaire.
  - Wireless communications to other elements.
- Wireless dimmer switches for manual lighting control.
- Wireless or low voltage lighting network. May include gateways, network switches, linked hardware devices, network communication cables and software, all communicating NLC+ signals based on sensor output.
- Receptacles controlled from NLC+ signals. In retrofit applications, wireless receptacles can be used with wireless transmitters in the system.
- BAS that can communicate with the lighting system and retrieve sensor signals/values.
- Programmable HVAC controllers that can implement customizable control sequences that utilize NLC+ signals.
- Web interface is also highly desirable for remote access and pushing firmware updates.

Figure 1 illustrates a simplified system architecture for NLC+.

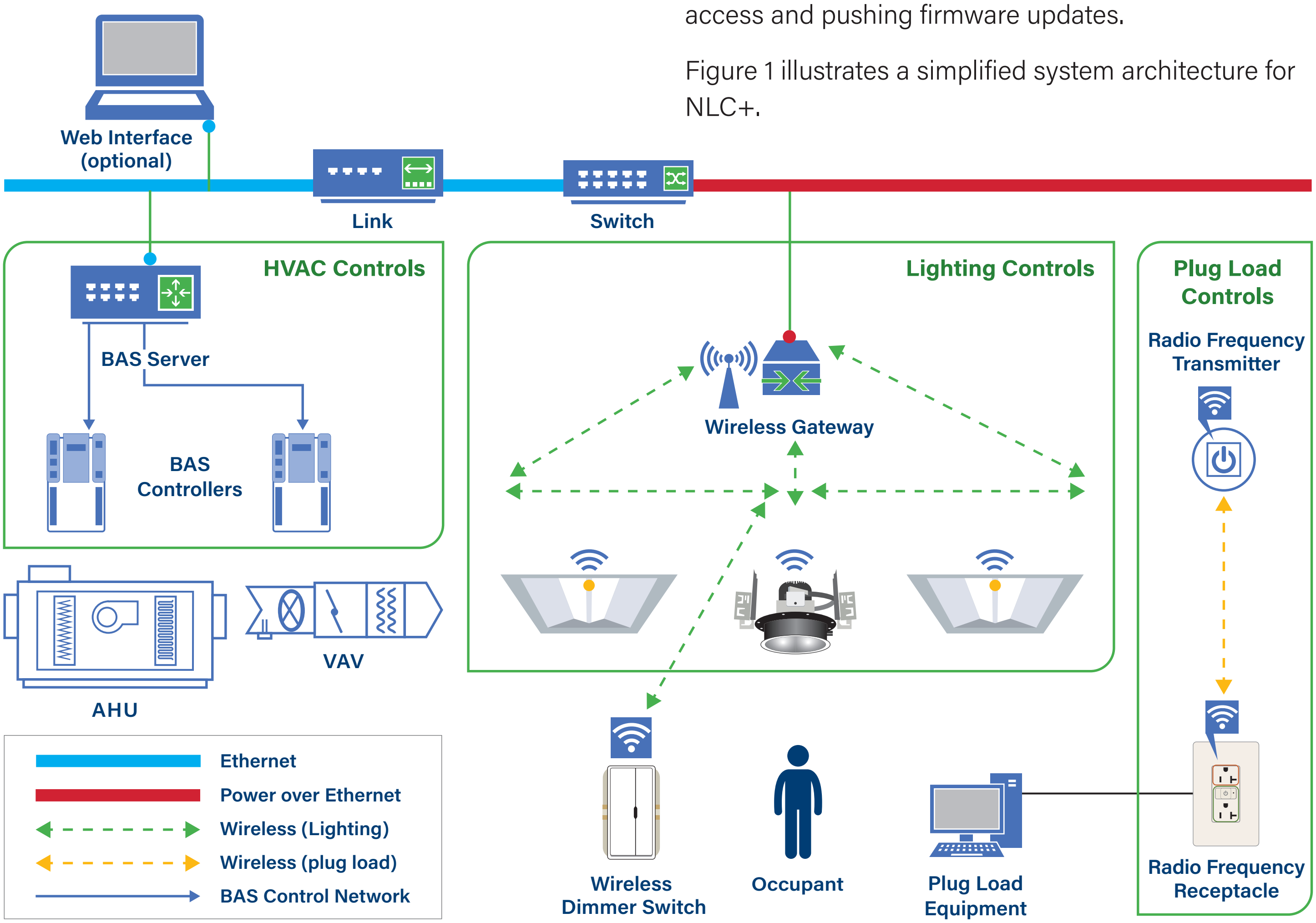


Figure 1: NLC+ system architecture.

The NLC+ system integrates multiple networks and their components: the NLC network itself, the BAS (usually serving HVAC), individual plug load control networks (usually distributed), and optionally a centralized virtual local area network (VLAN) that can more easily link the NLC and BAS together. Each of these networks ultimately receives the signals from the sensors in the NLC system (which can be luminaire-level, embedded in the fixtures). Thus, the NLC system can be used to control not just lighting, but also plug loads and HVAC equipment, to achieve greater energy savings overall.

Planning

- Economic assessment
- Project planning
- Cybersecurity

Design

- Lighting and lighting controls
- Network design
- HVAC control integration
- Plug load control integration

Construction, configuration, and commisioning

- Electrical installation
- Lighting and plug control configuration
- Network setup
- HVAC control programming
- Training

Figure 2: Key steps in a successful NLC+ retrofit.

INTEGRATION STEPS

Figure 2 summarizes the major steps in a successful NLC+ retrofit project.

The following sections provide more detailed guidance for implementing the major components of each step, beginning with a discussion of the team members involved in delivering each step.

PLANNING AND DESIGN

Roles

NLC+ projects require several individuals to divide ownership of a large number of tasks, some of which lie at the intersection between systems (e.g., lighting and HVAC). This division of labor requires some forethought. Figure 3 describes team member roles that are necessary for successful implementation of an NLC+ project. One individual (like the electrical contractor) may cover multiple roles.

The integration manager role is critical and should not be overlooked. Successful integration of different building systems will entail some challenges and someone will need to be accountable for problem-solving and team coordination. The integration manager could be capable of performing the programming tasks necessary to tie systems together, but regardless needs to oversee and coordinate the programming work done by other members of the team. The integration manager role could be fulfilled by the facilities manager, an energy consultant, a lighting professional or any of the other roles identified in Figure 3. The important thing is making sure someone is accountable for this coordination role.

PROJECT OWNER: A facilities manager or staff person representing the building owner.

LIGHTING PROFESSIONAL	INTEGRATION MANAGER	ELECTRICAL CONTRACTOR	HVAC CONTROL CONTRACTOR	COMMISSIONING TECHNICIAN
Leads discussions to optimize the plan for light levels and planned lighting control settings based on owner input. Has an understanding of the lighting technology options.	One individual who has purview over all affected systems (lighting, HVAC, and plug load controls) and can make sure any systems integration challenges are promptly resolved.	Responsible for installing new light fixtures, switches and plug load controls. Ideally has the capability to integrate lighting and plug load controls.	Responsible for connecting the BAS to the lighting control system and adjusting HVAC control sequences based on occupancy signals.	After installation, responsible for programming the lighting control system, adjusting high end trim and other settings, and resolving communications issues between lighting and other systems.

Figure 3: Project team roles.

Economic assessment

One of the first steps that many building owners or operators undertake is conducting an economic assessment to determine the viability of an NLC+ project. These assessments may include comparisons of NLC+ to more traditional, limited lighting control projects or even lighting retrofits without controls. The NLC+ approach will likely have the largest energy savings and non-energy benefits but comes with a cost premium. Less expensive options include no control at all of non-lighting systems based on occupancy sensors or controlling HVAC by installing dedicated sensors. Life-cycle cost analysis can help decision-makers determine which approach has the best net present value, a more useful metric than simple payback analysis.

In retrofit projects, a more accurate financial assessment can be made after an initial lighting count is completed (often as part of an energy audit) and an accurate retrofit bill of materials is assembled. (See the *Project planning* section.) It is important to understand any

FOR NEW CONSTRUCTION

The economic analysis will be similar but slightly simpler for new construction. The cost premium will be lower but energy savings will also be lower because baseline is the locally applicable energy code. Ensure that in calculating the cost premium of NLC+, the cost of all code-required sensors and controls are NOT included; this goes for both lighting and HVAC (e.g., DCV) as some level of control would have been required by code.

differences in manufacturer warranties for lighting versus control components. In addition, the NLC vendor should identify any ongoing costs for controls software.

To give NLC+ full consideration, such assessments—regardless of the method used—should include the costs and benefits shown in Table 2.

There is emerging potential for additional non-energy benefits (and costs) from integrating NLC with other intelligent building systems used for asset tracking, building security, and operational controls. This flexible connectivity to just about any system is commonly referred to as the Internet of Things (IoT).

Asset tracking can provide operational improvements in healthcare and other sectors. Sensing can be used in retail to track customer patterns and inventory. Over time, manufacturers will add more IoT functionality to NLC systems as well, improving cost-effectiveness by adding more non-energy benefits.

COSTS	BENEFITS
Materials for lighting and controls, including software licenses. These items can be combined with installation and configuration labor bids or materials can be bought directly to avoid markup. **Labor for lighting and controls.** Generally procured from local electrical contractors. Consider who provides configuration/commissioning and setup of lighting and/or plug load controls. If setup is handled by a manufacturer's rep or third party, the contractor must exclude it from their budget. Consider potential time savings from selection of wireless and auto-commissioned systems. **Labor for HVAC controls.** Many buildings with automation systems will have a contracted service provider for HVAC controls. The labor to modify HVAC controls can be covered through an existing building automation service contract, or sometimes by internal facilities technicians.	**Energy cost savings across ALL systems.** This includes all savings on lighting, including installed wattage and controls. It also includes all controlled plug loads as well as all ways that HVAC energy use is reduced based on occupancy control. **Maintenance.** If a fluorescent lighting system is being replaced, then lamp replacement labor will be eliminated. It is possible that the NLC software interface will also allow for simpler remote diagnostics and operations. If no current controls exist, it is possible some additional (minor) labor will occur to maintain the controls. **Non-energy benefits.** The sensors and controls in these systems can provide intelligence to improve operations. For example, occupancy data can inform efforts to optimize space usage by identifying when spaces are in use and when they are not. **Efficiency incentives.** Installation of NLC+ systems can yield significant incentives from energy efficiency programs. Investigate whether your local electric utility or program administrator offers custom incentives based on calculated energy savings or targeted incentives for advanced lighting controls. **Occupant satisfaction.** Improved light quality and control will yield happier occupants; this may be a significant benefit but can be difficult to quantify.

Table 2: Costs and benefits of NLC+ projects.

Project planning

Before design and fixture selection, a few planning steps can reduce challenges later in the process. These steps can in many cases be completed at no cost to the owner as part of a lighting audit. Many lighting distributors and energy efficiency programs will offer lighting audits free of charge.

Ensure compatibility for systems integration. Ensure the existing building systems that will be integrated with the NLC system are compatible. If HVAC is to be integrated, the BAS would ideally be BACnet-compatible. Some NLC systems communicate via other protocols, or as a last resort can be connected to other systems with some additional application programming interface (API) programming. You could also consider connecting the NLC with other building systems that provide asset tracking, space utilization or security functionality if there is value to leveraging the occupancy sensing data generated by the NLC system. Such connections would require a more thorough investigation of each system's communications protocols.

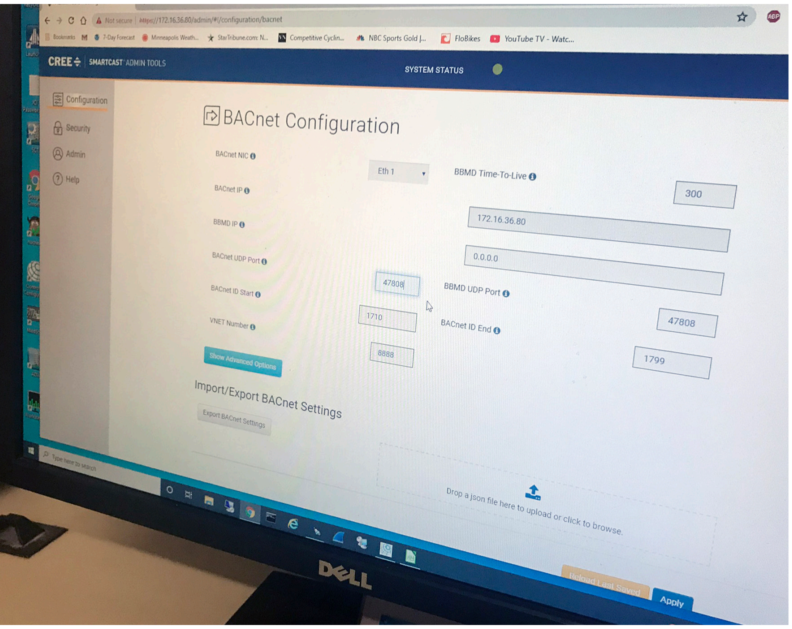
FOR NEW CONSTRUCTION

Instead of assessing systems compatibility, you must coordinate with the designers involved in each building system (e.g. lighting and mechanical) to ensure compatibility between systems.

Accurate count of installed lighting. Obtain drawings in advance and then conduct a walk-through of the site, marking up the drawings where deviations in installed fixtures, lamps, or voltage are found. The most cost-effective projects are one-for-one fixture replacements, so an accurate count of installed fixtures prior to the retrofit helps ensure the new bill of materials is correct.

Evaluate existing controls. Review where lighting controls and switches are currently installed. Discuss what aspects of the current approach are working well and what could be improved. Particularly where the planned installation involves LLLC, there is an opportunity to give occupants a greater degree of control over light levels and controls protocols. For example, should controls be occupancy-based or vacancy based? What is the appropriate time interval that a space should be unoccupied before controls are enacted?

Establish target light levels. When replacing fluorescent lighting with LED fixtures (which come in limited lumen options) on a one-for-one basis, spaces are often over-lit. LED fixtures should be tuned to ensure appropriate light levels for the way the space is being used. Ideally, use a light meter to measure the light levels before the retrofit so that these values can be compared with a photometric analysis as well as to post-retrofit measurements. Also reference the recommended illuminance values for each space type in the Illuminating Engineering Society (IES) *Lighting Handbook*. Later, as part of the control design process, you will need to identify tuning settings that result in the desired light level for each typical space type.



Cybersecurity

Cybersecurity is a consideration with any computer network and must also be considered in NLC+ projects. These projects involve integrating multiple networks: lighting, plug load controls, HVAC controls, and often the enterprise IT network. They also involve multiple network protocols which may be open or proprietary. For some organizations, specific cybersecurity requirements and protocols must be met to ensure proper risk mitigation. One example is the risk management framework developed by the National Institute of Standards and Technology (NIST) which applies to Department of Defense projects.[2] Whatever the approach, ensuring cybersecurity concerns are addressed will require coordination and support from the organization's IT staff.

The project team must work with IT staff—as early in the planning stages as possible—to ensure that cybersecurity requirements can be met by the NLC+ system. IT staff may not be familiar with the network infrastructure, functions, and capabilities of facility-related control networks (categorized as operational technology or "OT" networks.) The team should first identify cybersecurity requirements for the system and discuss project integration pathways that can meet those requirements. Many NLC manufacturers are now prepared to address cybersecurity concerns, so they can aid in these efforts.

During project implementation, communication with IT staff continues. The team needs to procure sufficiently secure hardware and software to meet organizational requirements. Technical integration challenges will arise that require cybersecurity to be considered in the decision-making process. Default network ports and passwords need to be re-configured and kept in safe places. Operators need cybersecurity training to implement routine patches, manage user credentials, and must have a system recovery plan in place.

In future it is likely that NLC systems will be certified to a cybersecurity standard that an end-user can look for and consider in product purchasing decisions.

Design: the four major steps

Once a project is planned and funded, system hardware and software must be selected and designed. This section reviews the design process for each major component: lighting and lighting controls design; network design; HVAC control integration; and plug load control integration.

STEP 1: Lighting and lighting controls

The **design process** in a retrofit scenario can be relatively simple. The most cost-effective path is one-for-one replacement of existing fixtures. Making changes to the installed lighting grid that affects drywall and/or suspended ceilings adds significant cost. (One exception would be changing from 2x4 to 2x2 fixtures, which is easier than other kinds of reconfiguration.) Many spaces will have some decorative fixtures that need to remain or be changed to different fixture types. NLC+ systems generally have add-on controllers to deal with these exceptions.

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[2] US Department of Commerce, National Institute of Standards and Technology. (2018). *Risk Management Framework for Information Systems and Organizations.* NIST Special Publication 800-37. Available at: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-37r2.pdf

With a simple fixture replacement, the lighting design can be streamlined and completed by a skilled individual employed by the electrical contractor or the distributor. Regardless of who completes the task, design involves selecting the right replacement luminaires for the major space types based on form and size, mounting type, illuminance, fixture aesthetic, and other considerations.

LIGHTING DESIGN TASKS

- Fixture selection
- Zoning and switch configuration
- Lighting control design
- Photometric analysis

Next, determine how many **lighting control zones** there should be in the retrofit area and where the zones should be located. Identify each space that will have the same protocol for lighting controls. For example, each private office could comprise a separate zone with the same control protocol. Similarly, all conference rooms could be different zones, each with the same control protocol. The smaller the zones the greater the flexibility to occupant needs and therefore resulting energy savings. At the same time, a larger number of zones could lead to higher configuration costs depending on the NLC provider.

LIGHTING CONTROL ZONE

A defined area where light fixtures have the same control protocol.

FOR NEW CONSTRUCTION

Follow typical lighting design processes and ensure that all fixtures are compatible with system controls. Also follow the controls setup planning approach described in the next few paragraphs.

Review the current **configuration of light switches** to determine where switches need to be replaced, removed, or added. Consider whether a switch is needed in each individual zone (some zones may not have switches). Document the design intent in a lighting plan with some zoning notation and fixture selections and locations.

One of the largest energy-saving features of NLC+ systems is light level tuning. This is especially true in retrofits where one-for-one fixture replacement and the limited lumen options in LED fixtures can lead to over-lit spaces. Tuning also has benefits in new construction due to conservative design practice or unknowns about space use during design. Installation will progress smoothest if estimates of proper tuning levels are done during design. Ideally, use **photometric analysis** (a basic computer simulation predicting light levels in the space) to determine the appropriate level of task tuning. Software like AGi-32 can be used to analyze major space types in the retrofit (e.g., open office, private office, conference room, copy room). For each typical space type (not every single space), create the 3D geometry, select associated .IES files from the manufacturer's website for each fixture to be used in the retrofit, and locate the fixtures in the model.

Compare the modeled light level from new fixtures with target light levels for the project based on measured existing levels, IES recommendations, and occupant feedback on current levels. The task tuning percentage (known as high end trim) can be estimated as:

$$\textit{Tuning \%} = \frac{\textit{Target light level}}{\textit{Modeled light level}}$$

If this analysis is not done ahead of time, light levels must be carefully measured during setup which is time-intensive and may not be a priority for personnel involved in configuring the lighting system.

As all these control decisions are being made, develop a **Control Matrix** (see example in Appendix A) to document the control protocol for typical zones. A protocol is not needed for every specific space, as many 'like' spaces can share a common protocol. The protocol answers questions like:

- Will lights automatically turn on when someone enters a space (occupancy mode) or require manual switching on and turn off automatically when the space is vacant for a specified interval (vacancy mode)?
- What is the time interval after which the lights will automatically be turned off or dimmed? What is the desired level of tuning in each space?

FOR DEEPER SAVINGS

Twenty minutes is the typical time delay for occupancy-based controls. With luminaire-level sensors this interval can be decreased to ten or even five minutes in many spaces.

Use the Control Matrix to document the task tuning levels that were developed during the photometric analysis described earlier. The Control Matrix will serve as the primary reference document during setup and commissioning.

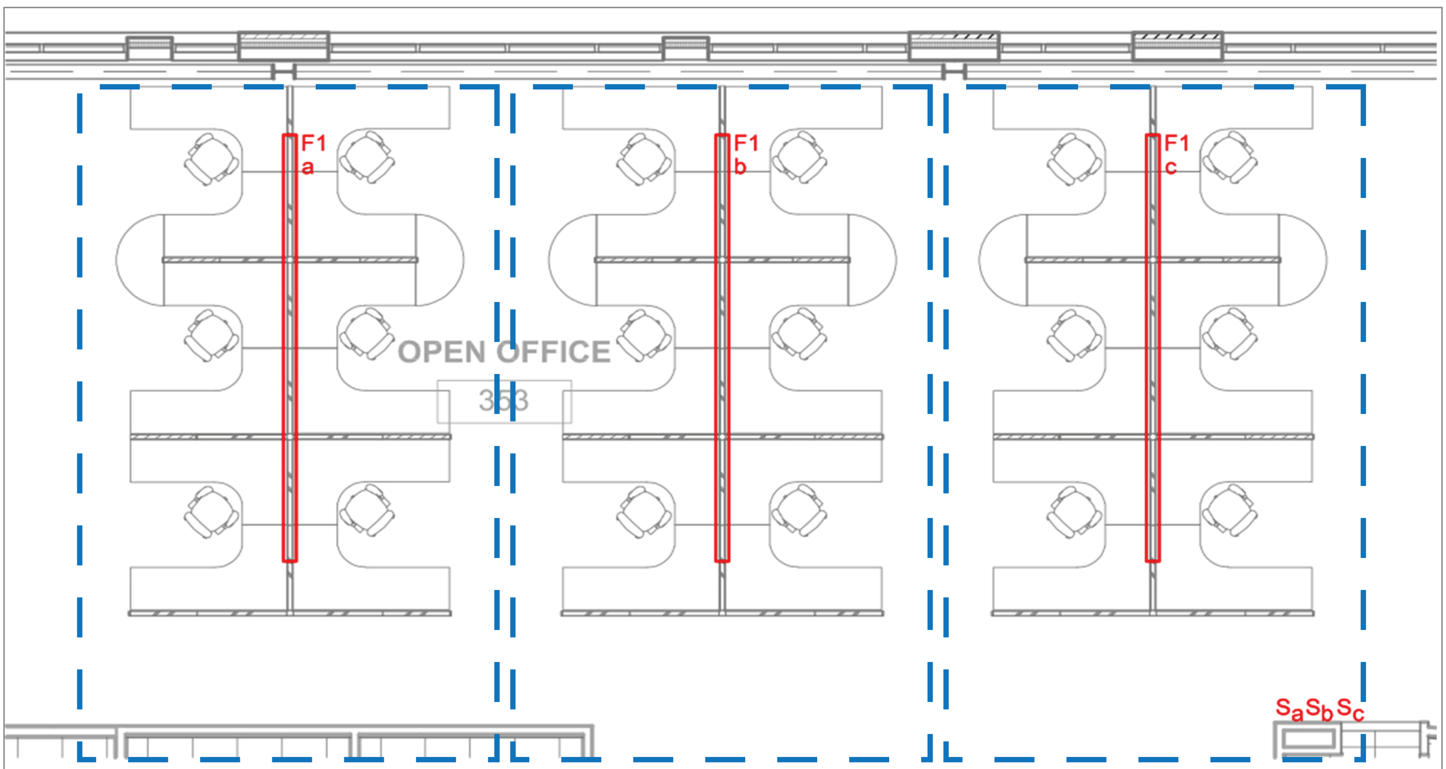


Figure 4: Lighting controls design diagram

STEP 2: Network design

Once the scope and scale of the lighting control retrofit has been established, some additional effort is needed to plan networking components and configuration. Whether the majority of the lighting control system is wireless or wired, some wired networking will be necessary for the integration inherent in NLC+. The electrical contractor takes the lead on this with help from the NLC manufacturer's sales representative.

The networks can be very simple, but some forethought is still needed. Considerations include:

- Can all the luminaires in the retrofit be handled on one network or are multiple networks required? Typically, there are limitations on the number of devices that can be served by a given network and signals from wireless gateways degrade over large areas. The lighting manufacturer's sales representative should specify the required number of networks and the resulting number of wireless gateways, power over ethernet (PoE) switches, and any manufacturer-specific supervisory controllers (see Figure 1).
- The planned configuration should be documented in a network diagram (a simplified conceptual networking diagram is illustrated in Figure 8). Include notation regarding the location of the hardware linking the lighting network to existing building networks. In which room are those wired connection ports available? Check that there are open, available ports. The electrical contractor will use this plan to generate a bill of materials and to guide installation of the wireless gateways, PoE equipment, and CAT wiring.
- Will the system require connection to a local IT network, virtual or otherwise? NLC+ can be achieved without such connection, but integration may be easier when these networks are used. See the *Cybersecurity* section for discussion of this issue and determining whether support from IT staff is needed.

STEP 3: HVAC control integration

The intent of HVAC system integration in an NLC+ project is to utilize the lighting system's granular occupancy sensing capabilities to enable demand control of much of the building's HVAC equipment. New sensing capabilities such as air temperature, relative humidity, and carbon dioxide levels may be added to LLLC products in the future which could further improve HVAC system efficiency and potentially have a positive impact on occupant comfort.

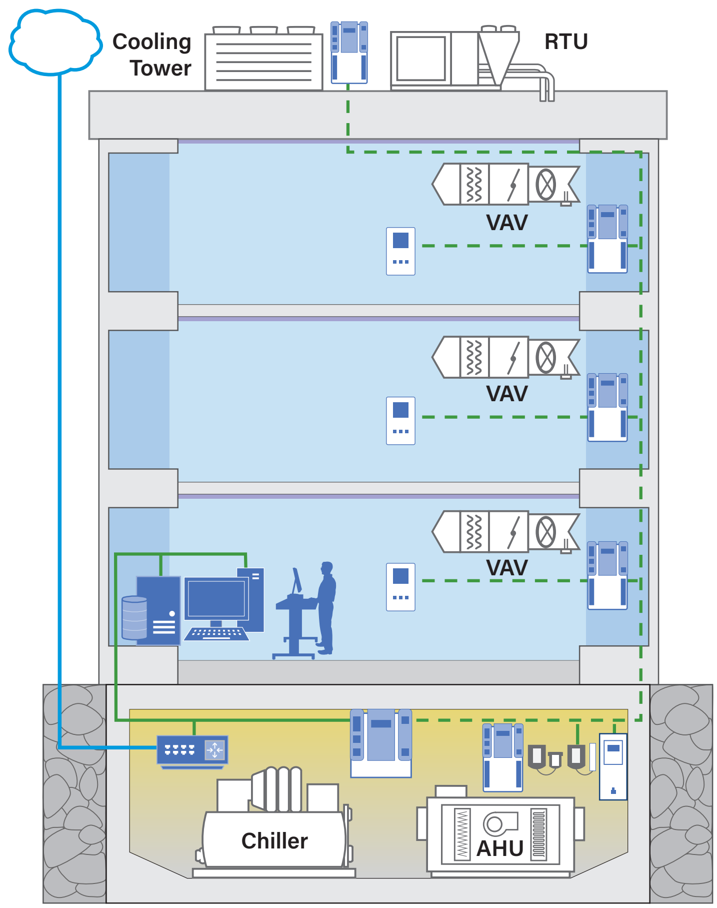


Figure 5: BAS schematic

The first step in integrating HVAC control is to make sure lighting and building automation networks can communicate using the same protocol. Most modern HVAC BAS now use the industry standard BACnet protocol for communication. Most lighting networks

are not inherently BACnet based but increasingly offer hardware/software packages that enable BACnet communication with BAS. Ensure that the lighting system you are choosing has a BACnet interface or other API that is compatible with the existing BAS and that your vendor has fully tested this integration for different levels of BACnet compatibility. Test results or certifications should be available in detailed technical documents, including configuration requirements for the setup phase. Where the lighting system does not natively communicate via BACnet or other BMS protocol, the budget should include time for a system integrator to program connectivity to a lighting system API.

The second step is to match the new lighting control zones with the HVAC control zones. The HVAC control zones are largely driven by existing HVAC system design and thermostat or terminal unit locations. The new lighting control zones, which can be relatively easily configured based on luminaire and light switch locations and space usages, should be designed to match up with the existing HVAC control zones as closely as possible. Zone matching need not be on a one-for-one basis; multiple lighting control zones will often be part of a larger HVAC control zone.

The third step is custom HVAC control sequence design. The control sequences can be written by a design consultant if desired, but it may be more cost-effective to have them written by the mechanical or controls contractor who will be responsible for reprogramming them in the building. See *Roles* section for more discussion on the functions performed by this individual. At some point during the process of determining the desired controls sequences, this contractor should also provide a price for implementing the necessary changes.

The goal of designing custom HVAC control sequences is to fully utilize the available luminaire-level sensor signals to control HVAC equipment more efficiently and achieve greater heating and cooling energy savings. A useful reference for AHU + VAV systems is ASHRAE Guideline 36, *High-Performance Sequences of Operation for HVAC Systems*. The project team members who are responsible for HVAC design and integration should first review the existing HVAC system design, control system schematics, and sequences, and discuss how to integrate occupancy signals into existing controls. Ideally, systems (and certainly any new construction or tenant build out projects) should incorporate most of *Guideline 36*. At an absolute minimum, basic measures such as zone airflow and thermostat adjustment should respond to occupancy signals. Some control options are presented below; specific detailed sequences are available in Appendix C.

FOR ALL SYSTEMS

Zone-level temperature setpoint setback. When all occupancy signals indicate zone is unoccupied for five minutes continuously during the Occupied Mode, the active heating/cooling setpoints are set back by 3–4°F (amount of setback can be adjusted to user preference).

FOR VARIABLE AIR VOLUME (VAV) SYSTEMS

Zone-level minimum airflow reduction. When all occupancy signals indicate zone is unoccupied for five minutes continuously during the Occupied Mode, the occupied minimum airflow (Vmin*) shall be set to 0.

AHU/RTU supply air fan control. When all occupancy signals for all zones controlled by an AHU/RTU indicate unoccupied for five minutes continuously during the Occupied Mode, the corresponding AHU/RTU supply fan should either be set to minimum speed or shut down.

Demand control ventilation. In AHU/RTU Occupied Mode, if the existing outside air damper is controlled at a fixed minimum position, the minimum outside air damper position can be reduced based on the number of zones that are unoccupied.

Ventilation reset. If ASHRAE 62.1 compliant ventilation logic is employed, the multiple-spaces equation can be recalculated continuously and account for zones that are unoccupied.

Trim and respond reset controls. To maximize the effect from occupancy control, both static pressure and supply air temperature reset control should be implemented using trim and respond logic.

FOR CONSTANT AIR VOLUME (CAV) SYSTEMS

AHU/RTU supply air fan control. When all occupancy signals for all zones controlled by an AHU/RTU indicate zone is unoccupied for five minutes during the Occupied Mode, the corresponding AHU/RTU supply fan should either be set to minimum speed or shut down.

Demand control ventilation. In AHU/RTU Occupied Mode, if the existing outside air damper is controlled at a fixed minimum position, the minimum outside air damper position can be reduced based on the number of zones that are unoccupied.

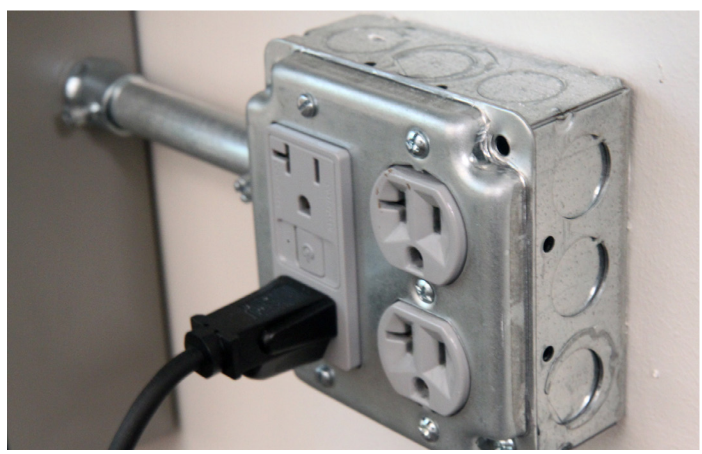
FOR OTHER HVAC SYSTEMS

Similar airside concepts as described at left can be applied in almost any HVAC system type. Specific control sequences should be developed by HVAC design or controls engineers.

In hydronic systems, such as hot water **reheat** or baseboard heat, trim and respond logic may also be used to reset the supply water temperature according to demand.

Retrofit projects should use this opportunity to incorporate other industry-standard advanced control sequences like those in ASHRAE Guideline 36, even beyond those that use occupancy signals. Examples include "dual-max" control logic for VAV boxes, AHU supply air static pressure reset and temperature reset logics, hydronic supply temperature resets, and more. Because control sequences are being redesigned for the NLC+ project, incorporating these additional elements will ensure that HVAC control savings are maximized.

STEP 4: Plug load control integration



Plug load control design is comparatively simpler than lighting and HVAC design, but still important. The following steps are recommended:

- A site visit should occur to determine which plug load receptacles (outlets) should be controlled. The day-to-day office manager should be present for the walkthrough and identify any receptacles that should not be controlled (typically this includes desktop PCs, refrigerators, and critical battery chargers). For additional guidance on identifying plug loads that are worth controlling, see the research conducted by National Renewable Energy Laboratory (NREL) on behalf of DOE.[3]

PLUG LOADS TO CONTROL

Monitors | Printers | Water coolers | Exercise equipment

PLUG LOADS NOT TO CONTROL

Personal computers | Refrigerators | Battery chargers

- This visit should inform a layout drawing that identifies the location of each controlled receptacle with a symbol, and any notes regarding specifications like half- or full-controlled, color, hospital-grade, etc. Half-controlled receptacles are generally recommended when there is only one receptacle at a given workstation so the user has a choice.
- Consider purchasing different colored receptacles (if available) for controlled and not controlled so occupants can easily distinguish between them.
- The cost-effectiveness of a controlled receptacle is heavily dependent on the wattage of devices installed that are likely to be left on overnight. Monitors, printers, water coolers, exercise equipment, and any equipment with large parasitic energy load are all great candidates for plug load control. Receptacles with low-wattage equipment (e.g. a workstation with one monitor and a few peripherals) are generally not cost-effective to retrofit.
- Wireless receptacle controls are now available for ease of retrofit and future flexibility. Where powered cubicle furniture is used however, it may be simpler

to just control one circuit leg of the furniture feed (most such furniture has two or more circuits) at the ceiling, so that many cubicles can be impacted by each controller. The zoning of the lighting must be considered in making this choice.

- Map each controlled receptacle to a specific zone on the Control Matrix. An alternative option in some systems is to place the receptacles on a schedule for control and use the output of the NLC system to determine that schedule.

Figure 6 is a schematic showing how lighting, HVAC and plug load controls could be configured in a given space.

FOR NEW CONSTRUCTION

The recommendations in this section are still applicable although wired connections are easier to accommodate while construction is underway.

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[3] U.S. Department of Energy, Better Buildings Alliance. *Office Building Plug Load Disaggregation*. Accessed March 26, 2020. Available at: https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/PPL_Disaggregation_NREL.pdf

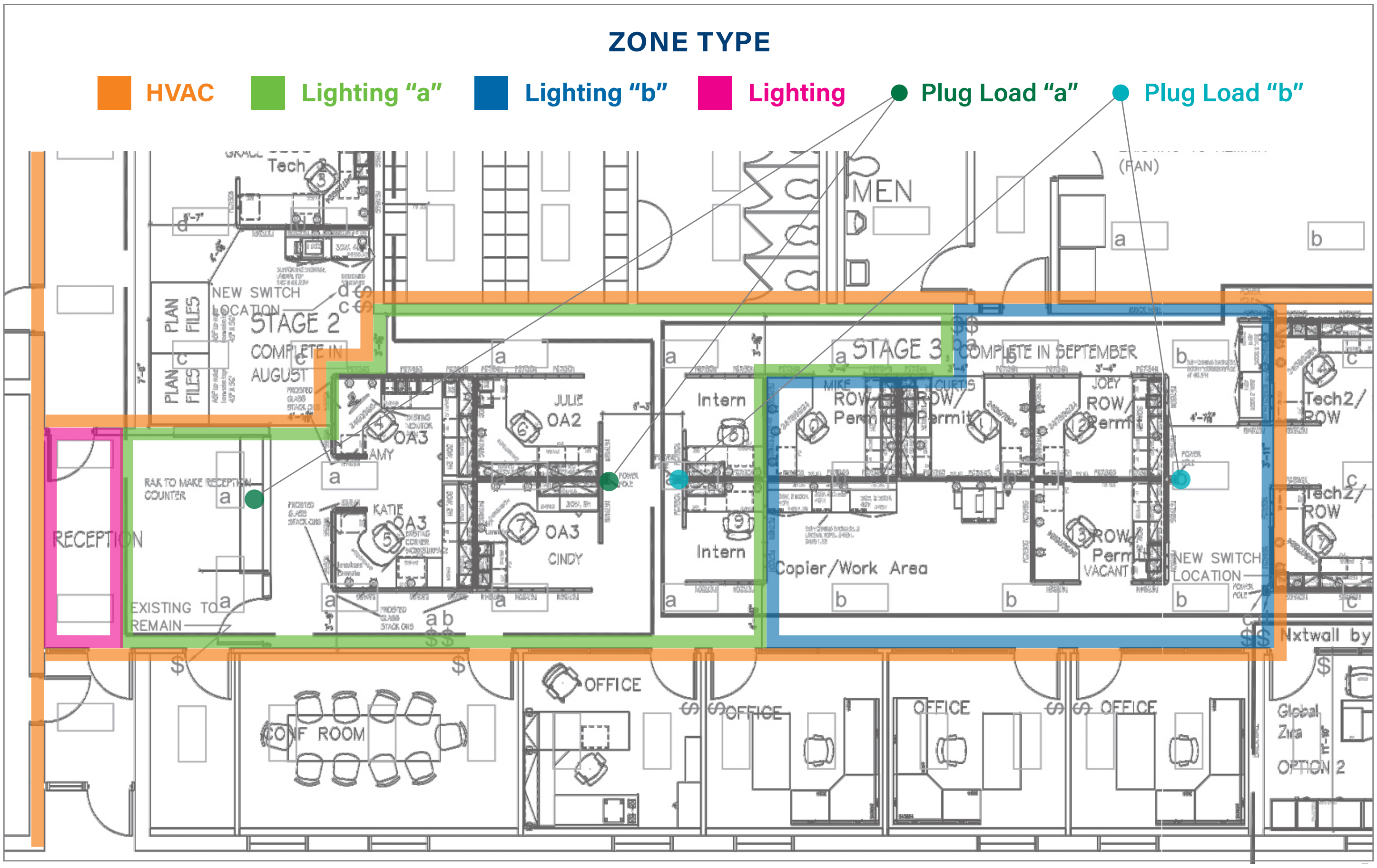


Figure 6: Mapping control zones

Code considerations

There are a few building code considerations to be addressed during design. The most critical consideration is in life safety: codes require egress lighting that operates during a power outage to allow for safe exit from the building. There are a few options for how egress lighting can be handled: a backup generator powering a subset of light fixtures; batteries installed on a subset of light fixtures; or dedicated “bug eye” emergency lighting units that only illuminate in a loss of building power. Make sure the retrofit design includes a plan to replace any portion of an egress lighting system that is removed by the retrofit. Also be mindful of energy code provisions that will likely require some basic occupancy and daylighting controls if more than ten percent of existing fixtures are replaced.

CONSTRUCTION, CONFIGURATION, AND COMMISSIONING

Installation of lighting and plug load controls

Early in the project planning stage, owners must select an electrical contractor for installation of lighting and plug load controls. Owners may use a bidding process, sole source their favorite contractor, or conduct the work with in-house electricians. Most NLC+ systems are configured and commissioned by manufacturer’s representatives, so ensure that contractor bids do **not** include this scope to avoid an unnecessary cost. Once design is complete, the selected contractor will work with the lighting distributor to order the required materials for the project.

Installation of all luminaires, wall controls, and external sensors progresses in the same fashion as any traditional lighting controls retrofit, including installation of CAT cable if the system is not wireless.

COMMISSIONING TIP

Avoid configuring daylighting controls on bright, sunny days so that dimming levels are not calibrated too aggressively. Alternately, close shades on sunny days prior to calibration.

The plug load control system is generally installed by the electrical contractor at the same time the lighting is installed. This installation will generally include plug load receptacles and transmitter devices that communicate between the lighting controls and receptacles. If the plug load receptacles and/or the transmitter are from different manufacturers, some troubleshooting may be needed to ensure communications between the devices.

Finally, the NLC+ networks—whether wireless or wired—will likely require installation of network gateways that allow the lighting control system to communicate with supervisory controls, user interfaces, and other building systems (e.g., HVAC). These should also be installed and wired (via CAT cable, per ***Network Design*** *section*) by the electrical contractor.

COMMISSIONING TIP

Some NLC systems require installation of a neutral wire; others operate with battery power. Make sure contractors are aware of how wireless devices are powered in the selected system.

Once installation is complete, either the electrical contractor, integration manager, or commissioning technician should complete basic setup tasks to ensure simple on/off functionality using wall switches. This step is important as in-depth system configuration (usually done by the manufacturer) may take weeks to complete given the time needed for scheduling and completion of the work. Most NLC systems provide an app that facilitates completion of basic setup steps. As a check at this stage, make sure that the system is recognizing the correct number of total installed devices in its network count.

Lighting control configuration and setup

In depth programming of the NLC system requires detailed knowledge of the system configuration process. One option is to utilize the manufacturer's representative for this task. If that is not an option for the selected NLC system, an experienced technician should be hired to complete the work. Configuration should ideally be scheduled as soon after the installation as possible. Programming and configuration involve applying the Control Matrix specifications to each lighting zone in the retrofitted area: control mode (manual control, occupancy control or vacancy control); duration of vacancy time-outs; and task tuning percentages. If facilities staff will play a role in ongoing adjustments, they should shadow the controls programmer during this process to gain a basic familiarity with the programming device and steps needed to configure the system.

Materials for occupant education about the NLC+ system should be distributed during or shortly after completion of control configuration. Appendix D includes informational materials that were distributed for the Cree Lighting SmartCast control system used in the Minnesota demonstration sites. This handout explains the basics of occupancy sensing and daylight harvesting, expected levels of energy savings, and instructions for operating manual switches.

A key step in system configuration is assigning each lighting control zone a meaningful name. The default values (e.g., Zone 1, Zone 2) should be renamed to describe the spaces they cover (e.g., Conference Room 121, Private Office 101, Open Office Near Window). Meaningful names will aid in zone association during HVAC integration and with commissioning of the lighting controls.

After initial programming, the controls in each zone should be tested to ensure occupancy and daylight sensing functions are working correctly. Minor adjustments to control parameters may be necessary to ensure operation aligns with the design intent. For instance, at the borders between zones (e.g., a doorway between private and open office), it may be necessary to reduce sensor sensitivity settings or disable the sensors entirely to ensure that lights within the office are not responding to activity outside the office.

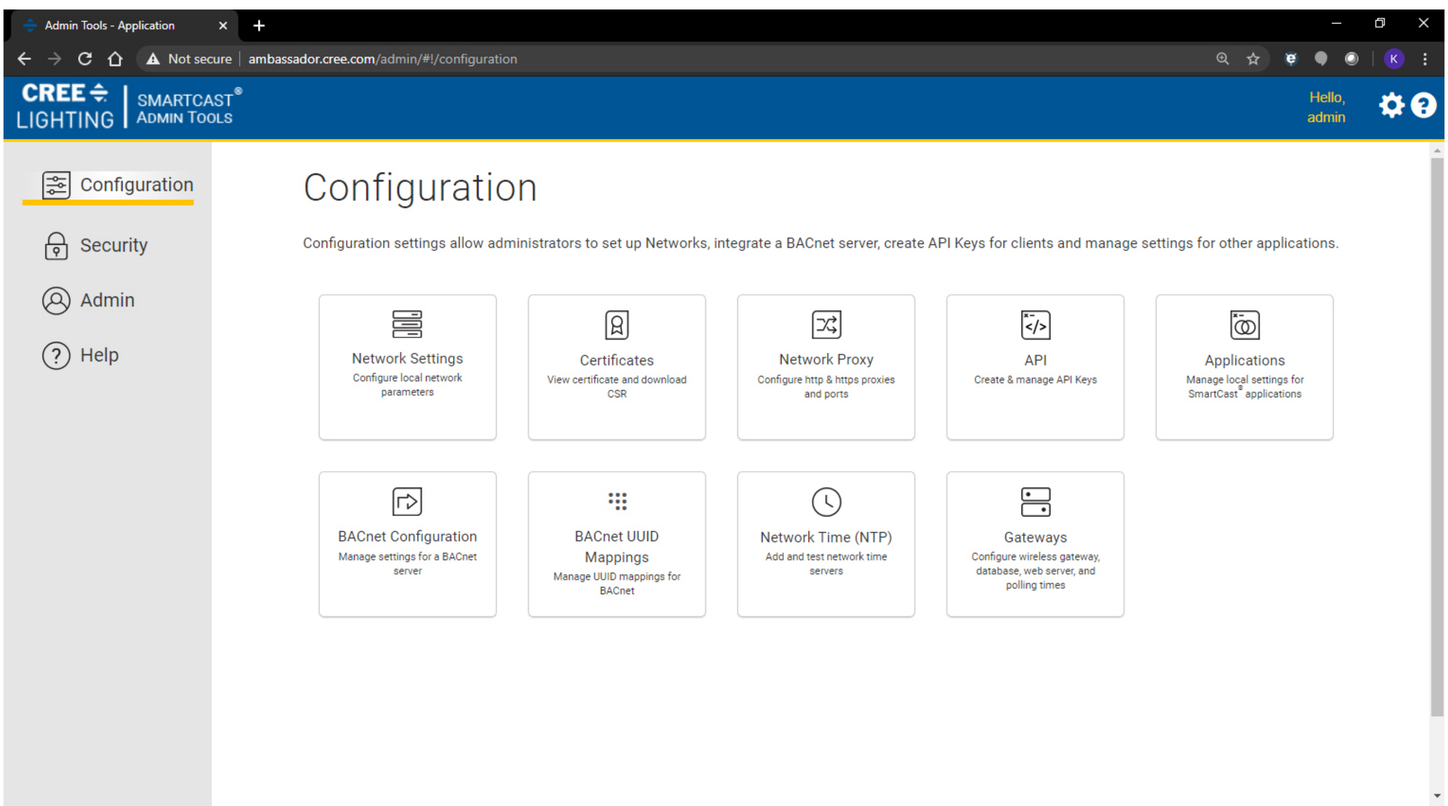
One benefit of NLC+ systems is the ability to easily make changes to system programming any time after initial commissioning. Because individual preferences vary, one strategy to maximize energy savings would be to start with reasonably stringent control settings in most zones, and simply back off the settings (light level, time outs, etc.) in selected zones based on occupant feedback during the first day or two of operation.

Personnel that will be maintaining the lighting system over time should be trained on a few basic lighting control programming functions. At the very least this training should include how to:

- Add a luminaire to the system
- Move a luminaire from one zone to another
- Adjust light level tuning settings
- Switch between occupancy and vacancy modes
- Adjust occupancy/vacancy timeout settings
- Adjust or disable daylight harvesting settings
- Use associated applications (handheld device and/or web-based)

Training can be very efficient if done while the system is being configured. Simply have maintenance personnel join the configuration process and participate in configuring a few elements of the system to give them some practice with the items listed above.

If the electrician is the most likely person to implement a control change later, training them is worthwhile.



If a manufacturer's rep or third party is handling configuration/commissioning to save cost, the training should be communicated carefully to avoid the electrician budgeting significant effort for configuration and commissioning in their bid.

Plug load control configuration and setup

Once the plug load control devices are installed, they will need some basic setup. Prior to setup, occupants of the building should be notified of the controls going live and be given instructions for how to use the receptacles. Figure 7 is an example of such instructions from one receptacle brand.

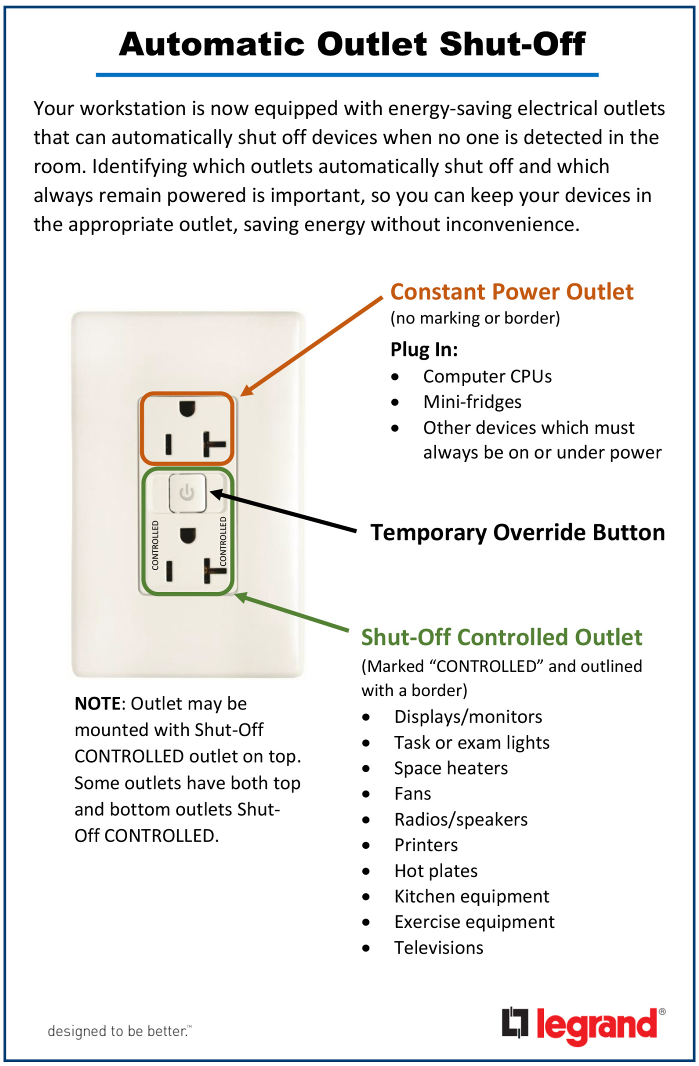


Figure 7: Plug load control instructions

The primary setup task is linking any wireless devices with the relevant lighting control zone. This may be a simple button push on the two wireless devices being linked or a basic function on a handheld app provided by the NLC manufacturer. The integration manager (see Figure 3) may be needed if there are any communication issues between systems from two different manufacturers. This communication will most often be through an open communication protocol, though it may also use an API.

Once controlled receptacles are operable, go to each workstation or room where there is plug load control and rearrange the cords. Re-plug most devices in those spaces into one of the *controlled* outlets of the receptacle. If at this stage there are multiple items to plug into a single controlled outlet, simply add a power strip at that location. ***There are some devices that should not be plugged into controlled receptacles:*** desktop PCs, refrigerators, and larger battery chargers for things like two-way radios that need to charge overnight should be plugged into uncontrolled receptacles. When in doubt, communicate with the site contact about whether specific types of equipment should be controlled. Plug load controls will easily frustrate users if control is applied to more items than they would like.

Once plugs are in place, consider labeling the controlled outlets if they are not already color-coded. Some manufacturers provide stickers indicating which outlets are controlled; address labels with the word 'CONTROLLED' printed on them also work. Finally, test a sample of the controlled outlets to be sure that they work based on occupancy in the space. Task lamps provide good visual indictors that plug load controls are working correctly.

Network setup

At this point the lighting controls and network gateways are in place and set up. NLC+ systems generally require some additional network setup for integration with the BAS, supervisory control, system monitoring, and other advanced functions. This network represents the link between the lighting control system and other building systems, such as the BAS.

At this stage the integration manager role (see Figure 3) is critical to ensure that the technicians representing lighting controls, HVAC controls, and IT are collaboratively solving issues instead of waiting for others to address them. Collaboration between multiple parties will likely be required to achieve full functionality. If the local IT network (separate from the BAS network) is connected to the system or there are any cybersecurity protocols required, then local IT staff will also need to be involved at this stage.

CONFIGURATION TIP

Once all network hardware is connected and only software and configuration of network components remains incomplete, it can be invaluable to hold a conference call with the technician responsible for each system on the line, using a screen share to allow the team to view all user interfaces. This type of collaboration can be a huge time saver over the typical practice of having each technician take turns trying to solve problems entirely from their system's viewpoint.

The network hardware for this integration is relatively simple (see Figure 8). Basic PoE hardware is usually used to connect the lighting network to a central server or other link device. CAT cable then connects that central device to other building or internet systems, such as the BAS. In the case of the BAS, this CAT cable facilitates communication over BACnet. Network installation may be as simple as connecting one CAT cable between the two systems being integrated.

CONFIGURATION TIP

Validate licensing for all impacted systems within a given project—BAS, lighting, plug load, HVAC—early in the design process.

Configuration of the firmware and software embedded in the hardware is often more complex. Since the lighting, IT, and HVAC networks are set up for entirely different purposes, some adjustments and configuration changes of firmware and software will be needed to make the system work. Both the lighting commissioning technician and the HVAC technician are involved in active collaboration to resolve any issues. The lighting and BAS manufacturers should provide BACnet communication specifications to aid technicians in these configurations. Common problems to look out for could include:

- Bad CAT cable termination; cables not tested.
- Firmware version updates needed on BAS or lighting units to allow latest BACnet functionality.
- Port names are not consistent with BACnet assumptions.
- IT network is not allowing access out to the internet for firmware and other needs.
- Internet protocol (IP) settings on the local network cause communications problems.
- External network components, such as PoE switches, are not compatible with lighting system.
- BACnet license adjustments may be needed for additional devices. The lighting system should be set up to create as few additional BACnet devices as possible to reduce license cost.

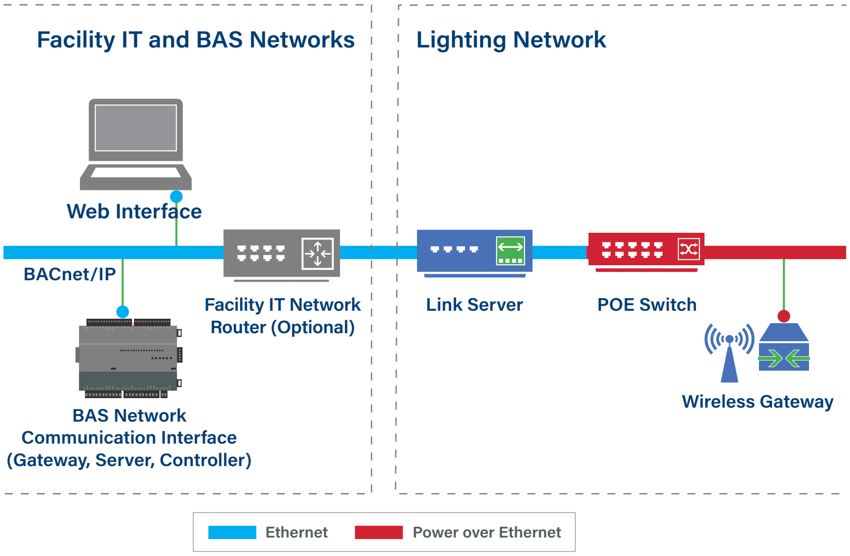


Figure 8: Network integration

HVAC control programming

During configuration of the NLC+ system, facility IT staff, the lighting control commissioning technician, and the HVAC control contractor or technician will need to work together closely to discuss and resolve network integration issues as discussed above. The integration manager's role is making sure these parties are brought together promptly to discuss and resolve these kinds of challenges. Potential issues could be related to hardware, software, network infrastructure, or configuration on any part of the NLC+ system including the facility IT network. Though the notion of connecting to lighting may be new to the HVAC control technician, these technicians are very comfortable connecting to different types of networks and will be useful participants in these kinds of discussions.

The HVAC control contractor or technician should have software that can automatically discover luminaire-level occupancy BACnet objects on the connected lighting network and bring these objects and values into HVAC control programs. If the NLC+ system is integrated into the facility IT network, IT staff should make sure necessary network hardware /software ports are open to allow communication among multiple networks while maintaining overall system security. Other tips are given in the *Network setup* section earlier. Once the HVAC system is receiving the appropriate BACnet objects representing zone occupancy, the HVAC technician should be able to revise existing sequences to reflect the design decisions discussed in *Step 3: HVAC control integration*.

After the custom HVAC control programming is implemented, commissioning should start with function tests for all occupancy signals that are being integrated into the HVAC control system. The integration manager can take the lead on this task or it could be performed by the HVAC control technician. This step is to make sure lighting control zones and HVAC control zones are designed/mapped appropriately and occupancy values represent actual zone occupancy and design intent. The next step is functional tests of zone-level and AHU/RTU logics for each zone terminal unit and AHU/RTU involved. Finally, system-level functionalities should be checked to make sure zone-level control and AHU/RTU-level control are properly coordinated. If available, real-time debugging tools can be used on building control programming during the commissioning process.

CONFIGURATION TIP

Confirmation of HVAC operation is critical. View trends of one-minute interval data of occupancy and HVAC setpoints like zone temperature, static pressure, and VAV minimum to confirm proper operation.

Records (such as control logic screenshots and trend data) should be preserved as evidence the new HVAC control is commissioned and the custom sequences work as expected. Figure 9 and Figure 10 show sections of the sample custom HVAC program codes and trend charts for HVAC integration commissioning verification.

If possible, set up a BAS alarm to alert if the lighting occupancy data ever stops being 'seen' by the BAS. If integration fails, do not assume the lighting system will offer any alert.

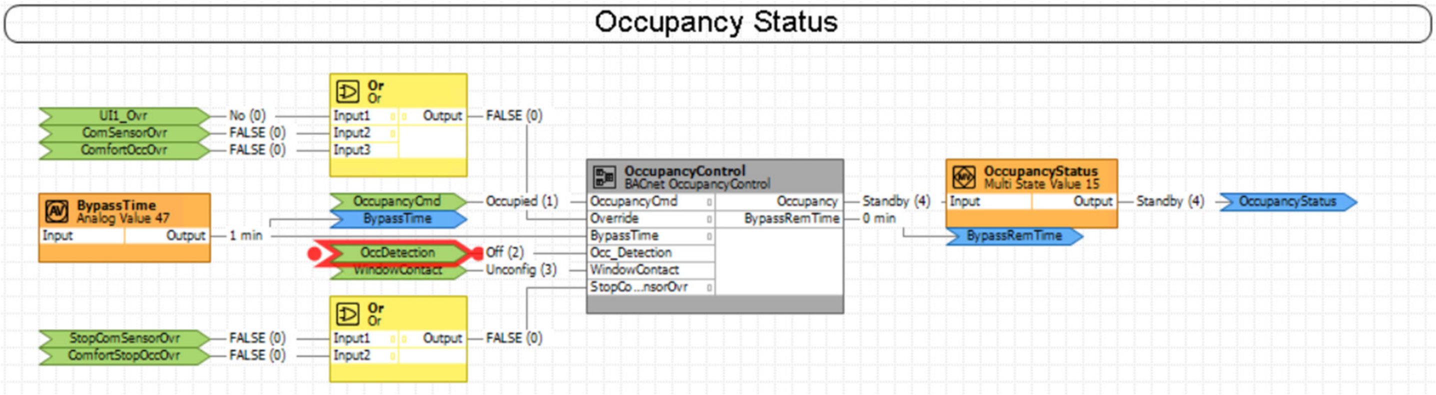


Figure 9: A sample custom HVAC programming code

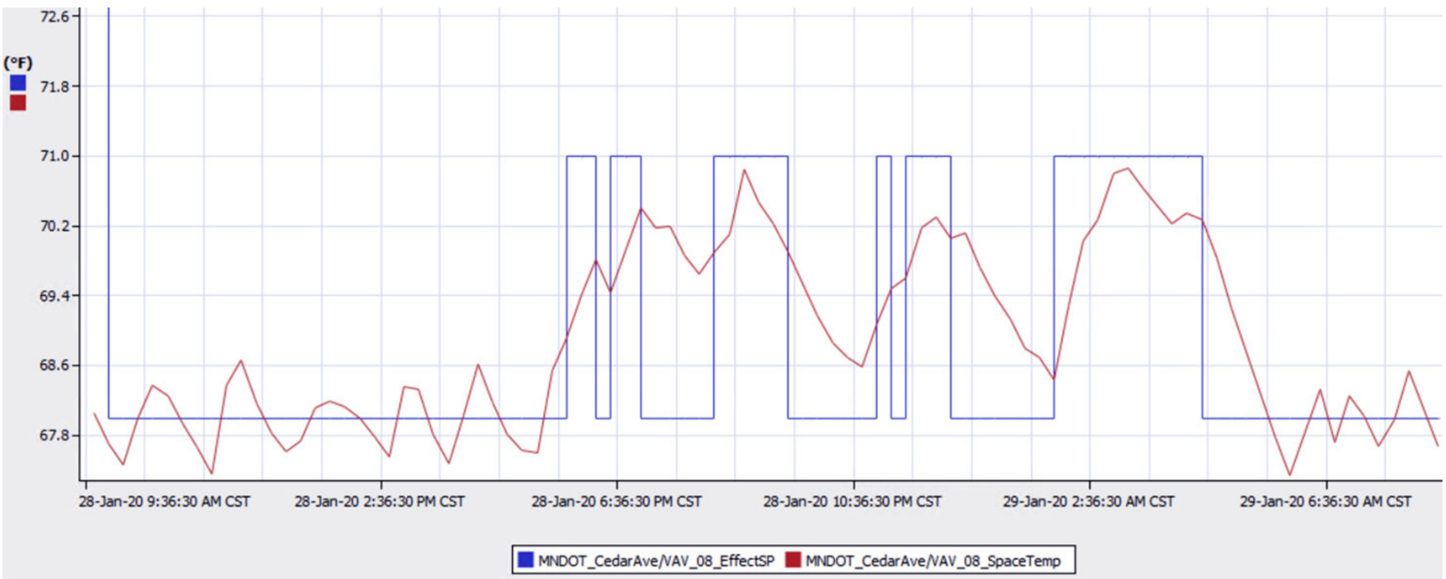


Figure 10: A sample trend chart for commissioning verification

CONCLUSION

If executed properly, NLC+ offers a proven approach to optimizing lighting, HVAC and plug load performance in a retrofit. Technology is changing rapidly, and we expect that costs and implementation challenges will both be reduced as key players gain experience with products and system integration. We hope this guide helps bridge the gap toward an optimized energy future.

SUMMARY CHECKLIST

PLANNING

- **Economic assessment:** Use lifecycle cost analysis to evaluate the financial feasibility of an NLC+ project.
- **Project planning:**
  - [ ] Investigate networked lighting system compatibility with existing building HVAC controls infrastructure.
  - [ ] Survey existing lighting fixtures and controls.
  - [ ] Establish target light levels for the post-retrofit space (use IES recommendations and/or measurement).
- **Cybersecurity:** Coordinate with IT staff to understand cybersecurity requirements.

DESIGN

- **Lighting and lighting controls:**
  - [ ] Select replacement luminaires for each major space type. Consider form, size, mounting type, illuminance and aesthetics.
  - [ ] Determine number and scope of lighting control zones. Document the post-retrofit lighting control decisions in a Control Matrix.
  - [ ] Document switch locations along with fixture selections and locations in a layout drawing.
  - [ ] Conduct photometric analysis to determine the appropriate level of high-end trim; document in the Control Matrix.
  - [ ] Consult building code for egress lighting and energy requirements.
- **Network design:**
  - [ ] Determine number of lighting networks and associated wireless gateways, PoE switches, and product-specific communication interface needed for desired integration.
  - [ ] Document conceptual approach using a network diagram.
- **HVAC control integration:**
  - [ ] Confirm communications protocols used by NLC and BAS systems and determine whether API programming is needed.
  - [ ] Map the HVAC control zones to lighting zones. Document a list of HVAC zone names and corresponding lighting zone names from the lighting network.
  - [ ] Design new HVAC control sequences and program them utilizing luminaire-level sensing signals.
- **Plug load control integration:**
  - [ ] Conduct site survey of which plug load receptacles will be controlled, prioritizing higher-wattage equipment that could be turned off overnight/weekends.
  - [ ] Document controlled receptacles on a layout drawing. Indicate half/full control. Map each controlled receptacle to a specific zone on the Control Matrix.

CONSTRUCTION, CONFIGURATION, AND COMMISSIONING

- **Electrical installation:**
  - [ ] Install lighting and NLC system, plug load controls and any CAT cable.
  - [ ] Install lighting network gateways for communication with supervisory controls, user interfaces, and other building systems.
  - [ ] Complete setup tasks to ensure basic functionality like manual on/off.
  - [ ] Ensure the NLC system is recognizing the correct number of total installed devices in its network count.

SUMMARY CHECKLIST continued

Lighting and plug load control configuration:

- [ ] Complete NLC programming; apply the Control Matrix specifications to each lighting zone.
- [ ] Give each lighting control zone a descriptive name so it can be easily identified when integrating with other systems.
- [ ] Test the lighting controls in each zone to ensure that occupancy- and daylight-sensing functions are working correctly.
- [ ] Link wireless plug load control devices with the relevant lighting control zone.
- [ ] Plug devices into the controlled receptacles according to the plug load control plan.
- [ ] Ensure that controlled outlets are labelled or color-coded for easy identification.
- [ ] Test a sample of controlled outlets to ensure occupancy controls are working correctly.
- [ ] Inform building occupants about the new lighting and plug load controls and provide instructions on use.

Network setup:

- [ ] Work with facility IT stuff to connect and configure any routers, gateways, and firewalls involved in integrating the lighting network and the BAS network.
- [ ] Perform lighting network setup tasks such as configuration of embedded firmware and software of the lighting network communication interface to facilitate NLC system integration with the BAS, third-party monitoring and control, and other advanced functions.
- [ ] Perform BAS network integration preparation tasks such as adding hardware or new BACnet license needed, and connection and configuration of the BAS subnetwork that allows the detection of lighting BACnet objects through the lighting network communication interface.
- [ ] To identify and resolve system communications issues, conduct a conference call (with screen share) that includes IT staff, the lighting network engineer/technician, and HVAC controls contractor.

HVAC control programming:

- [ ] Ensure that BACnet objects on the connected lighting network are communicating to the HVAC control program.
- [ ] Customize HVAC control sequences to reflect the new HVAC control design utilizing luminaire-level sensing signals.
- [ ] Conduct functional tests at both system and zone level to ensure that the HVAC system is responding to the sensing signals per design intent.
- [ ] Check system-level functionalities to make sure zone-level control and system-level control are properly coordinated.
- [ ] Take some program screenshots and trend graphs as evidence that new HVAC integration/control work as intended.
- [ ] If possible, set up a BAS alarm to alert if the lighting occupancy data every stops being 'seen' by the BAS.

Training:

- [ ] Ensure that facilities staff are familiar with how to adjust basic NLC system programming functions, as well as understanding expected functionality of HVAC controls.
- [ ] Keep all project records, documents, and contact information for future ongoing maintenance and operations.

APPENDICES

APPENDIX A: CONTROL MATRIX

Space Name	Local Control	Control Mode	Occupied Level	Unoccupied Level	Occupancy Timeout	Calculated Average Illuminance	Target Illuminance	Task Tuning Percentage
Private Office	Y	Vacancy	100%	0%	10 mins	41	30	75%
Open Office	Y	Vacancy	100%	0%	10 mins	34	30	90%
Conference Rm	Y	Vacancy	100%	0%	10 mins	47	30	65%
Break Room	Y	Occupancy	50%	0%	10 mins	47	30	65%
Reception - desk	Y	Vacancy	100%	0%	10 mins	32	30	95%
Reception	Y	Vacancy	100%	0%	10 mins	58	30	55%
Waiting	N	Occupancy	100%	0%	10 mins	35	30	90%
Changing	Y	Vacancy	100%	0%	10 mins	28	30	100%
Vitals	Y	Occupancy	100%	0%	5 mins	42	50	100%
Nurse Station - desk	Y	Vacancy	100%	0%	10 mins	33	30	95%
Nurse Station	Y	Vacancy	100%	0%	10 mins	50	30	60%
Exam Rm	Y	Occupancy	100%	0%	10 mins	49	50	100%
Procedure	Y	Occupancy	90%	5%	10 mins	57	50	100%
PT Exam	Y	Occupancy	100%	0%	10 mins	65	50	80%
PT Gym	Y	Occupancy	100%	0%	10 mins	36	30	85%
Lab - small	Y	Vacancy	100%	0%	10 mins	41	50	100%
Lab - large	Y	Occupancy	50%	0%	10 mins	52	50	100%
Soiled Storage	Y	Vacancy	100%	0%	5 mins	45	20	50%
Clean Storage	Y	Vacancy	100%	0%	5 mins	41	30	75%
Vestible	N	Occupancy	100%	0%	10 mins	32	20	65%
Circulation	N	Occupancy	100%	0%	10 mins	24	30	100%
Toilet Rm - private	Y	Occupancy	100%	0%	10 mins	32	30	95%
Toilet Rm - partitions	Y	Occupancy	100%	0%	10 mins	34	30	90%
IT	Y	Occupancy	100%	0%	10 mins	39	30	80%

APPENDIX B: SPECIFICATION TEMPLATES

If NLC+ is a fit for your building, it helps to start with a set of specifications to use in bidding or procuring services for the project. While we do not yet have a full integrated controls specification developed, example specifications for the major project components can be found in the links provided.

Lighting and HVAC control tenant fit-out specification, Lawrence Berkeley National Lab. This is the most complete of the specifications in this Appendix. It includes lighting and HVAC controls as well as an optional plug load control component. However, the specification does not address integrating the controls across systems so the multi-system integration best practices from this implementation guide are not fully included.

Available at:

https://drive.google.com/file/d/1B_Gi4_9T0-NQgjvLhdYUWTPWgQKqI-bz/view

HVAC control specifications, ASHRAE. The implementation guide recommends using ASHRAE Guideline 36 as a starting point for new HVAC control sequences. See Appendix C and *Step 3: HVAC control integration* in this document for general discussion of control sequences, or access the link to purchase the guideline.

Available at:

https://www.ashrae.org/news/esociety/new-guideline-on-standardized-advanced-sequences-of-operation-for-common-hvac-systems

NLC Qualified Product List (QPL), DesignLights Consortium. DesignLights does not provide a full specification but does maintain a QPL of NLC products that meet their technical requirements. The DLC QPL is used as the basis for many energy efficiency incentive offerings for NLC. Similarly, project specifications can require that the selected products be named on this list. There is also a parameter on the QPL stating whether the system can be integrated with building automation, and how.

Available at:

https://www.designlights.org/lighting-controls/qualify-a-system/technical-requirements/

APPENDIX C: HVAC SEQUENCE EXAMPLES

The following HVAC sequence example applies to a site with single-duct variable-air-volume (VAV) systems and VAV terminal units with hot water reheat.

Outline of proposed controls

- VAV Terminal Units with Hot Water Reheat
  - Occupancy control
  - Zone minimum primary airflow, and heating/cooling airflow
  - AHU static pressure reset
  - Hot Water Supply Temperature Reset

- VAV Terminal Units
  - Similar sub-items as to above

- Multiple Zone VAV Air Handling Unit
  - AHU cooling SAT reset
  - AHU static pressure reset

VAV Terminal Units with Hot Water Reheat

1.1 Setpoints and control modes

Occupancy control ("standby mode"). For zones that have at least one occupancy sensor, it is required that:

a. When the occupancy sensor indicates that the space has been unpopulated for 5 minutes continuously during the Occupied Mode, the active heating setpoint shall be decreased (setback) by 1°F and the cooling setpoint shall be increased (setback) by 1°F.
b. The maximum temperature setpoint setback is limited to 4°F as a default, with 3°F used for heating setback in spaces with substantial external exposure
c. When the sensor indicates that the space has been populated for 30 seconds continuously, the active heating and cooling setpoints shall be restored to their previous values.
d. This occupancy control should not be employed during morning warm-up or for 15 minutes after.

1.2 Zone primary airflow. The airflow from the air handling unit to the ventilation zone, including outdoor air and recirculated air.

Zone minimum primary airflow (Vmin)

a. Select Vmin to be the existing design zone minimum outdoor airflow rate, for use when space is occupied

b. The occupied minimum airflow Vmin* shall be equal to Vmin except if the zone has an occupancy sensor and is unpopulated, where Vmin* = 0.

c. Use existing design values for cooling airflow setpoint (Vcool-max) and heating airflow setpoint (Vheat-min).

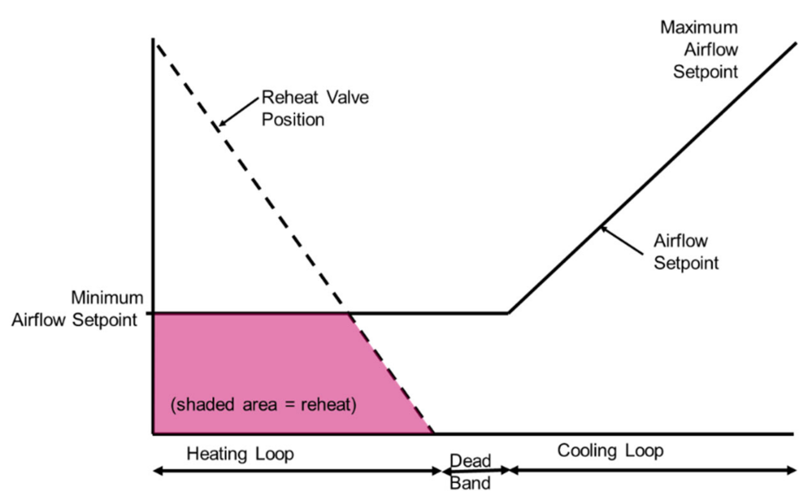
d. Active maximum and minimum heating and cooling airflow setpoints shall vary depending on the Mode of the zone (Figure 1):

Figure 1: Set points as a function of zone group mode

Setpoint	**Occupied**	**Standby or Unoccupied**
Cooling maximum	Vcool-max	0
Cooling minimum	Vmin*	0
Minimum	Vmin*	0
Heating minimum	Max (Vheat-min, Vmin*)	0

This all assumes that a "single max" control logic as depicted in Figure 2:

Figure 2: Single max control logic for VAV terminal unit with hot water reheat



e. In larger spaces (fitness center, open office, etc.) scale the VAV minimum setpoint between 0 and Vmin based on the %-of-space occupied.

1.3 System resets; zone-level input.

i. **AHU Static Pressure Reset.** Reset static pressure according to (for all digital VAV boxes):

a. If the measured zone airflow is less than 50% of setpoint while setpoint is greater than zero and the VAV damper position is greater than 95% for 1 minute, send 3 AHU Static Pressure Reset Requests,

b. Else if the measured zone airflow is less than 70% of setpoint while setpoint is greater than zero and the VAV damper position is greater than 95% for 1 minute, send 2 Requests,

c. Else if the VAV damper position is greater than 95%, send 1 Request until the damper position is less than 85%,

d. Else if the VAV damper position is less than 95%, send 0 Requests

ii. **Hot Water Supply Temperature Reset**

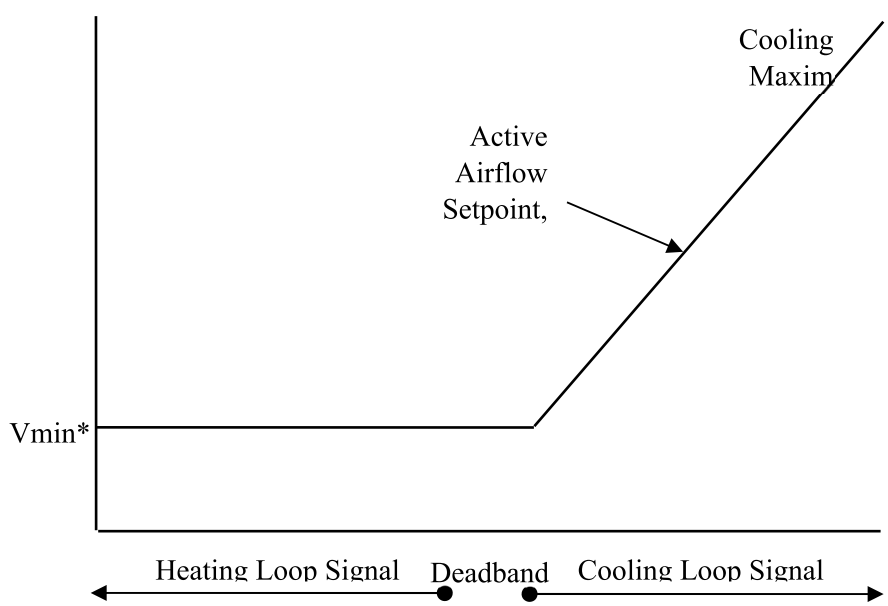
a. If the VAV heating water (HW) valve position is greater than 95%, send 1 Request until the HW valve position is less than 85%,

b. Else if the HW valve position is less than 95%, send 0 Requests

VAV Terminal Unit, Cooling Only

The control logic for cooling-only terminal units is essentially identical to units with reheat discussed above, just without the addition of heating modes. Operation is depicted schematically in Figure 3:

Figure 3: Control logic for cooling-only VAV terminal unit



Multiple Zone VAV Air Handling Unit

2.1 System resets; system-level operation.

i. **AHU Static Pressure Reset.** Reset static pressure with Trim & Respond logic using the parameters shown in Table 1:

Table 1: Default Trim & Respond variables

Variable	**Value**
Device	Supply Fan
SP_0	120 Pa. (0.5 inches)
SP_{min}	25 Pa. (0.1 inches)
SP_{max}	Maximum Design Static Pressure
T_d	10 minutes
T	2 minutes
I	2
R	Zone Static Pressure Reset Requests (see section 1.5.ii)
SP_{trim}	-12 Pa (-0.05 inches)
SP_{res}	15 Pa (+0.06 inches)
$SP_{res-max}$	32 Pa (+0.13 inches)

ii. **AHU Cooling SAT Reset. (**Discharge Air Temperature). Change existing reset to act between 55 Deg F to 65oF, using current control logic.
If there is no current SAT Reset, this topic should be discussed again.

APPENDIX D: OCCUPANT EDUCATION

WELCOME

to the World of Intelligent Light from Cree

CREE

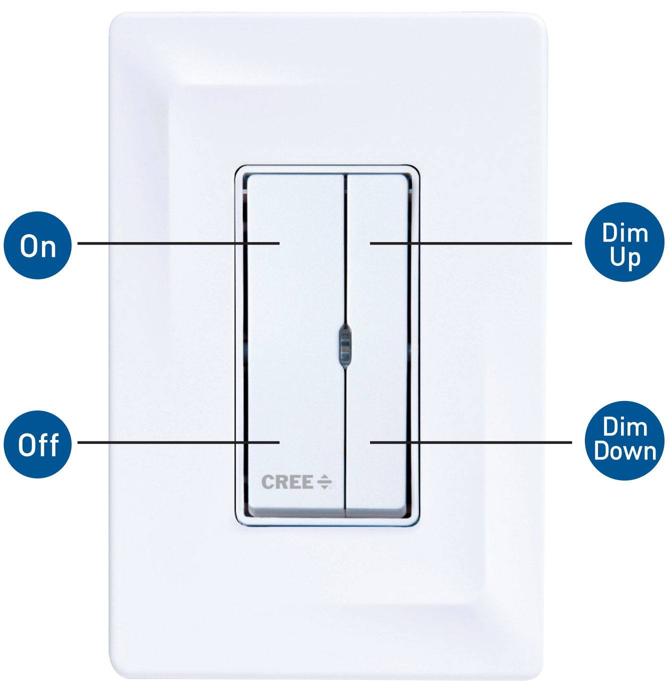
While you were gone, your office underwent a lighting makeover. Each room is now equipped with Cree LED lighting enabled with the SmartCast Intelligence Platform™. It's intelligent lighting aimed at improving your workday experience while saving money for your company. It's lighting so intuitive and simple, it just works — for you and for everyone who experiences it.

Occupancy Sensing uses sensors in each light to detect movement and turn lights on or off as needed.

Daylight Harvesting senses the natural sunlight in a room and dims lights accordingly.

In total, Cree SmartCast® is saving your company on average 70% on their lighting bill!

Flip this page over to learn more about Occupancy Sensing and Daylight Harvesting along with links to their videos.

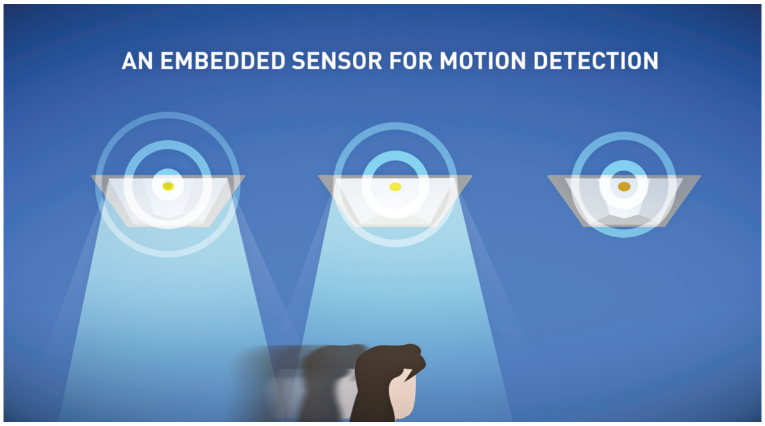


DIMMING

You may notice these dimmers around your office. They are there to easily assist you in adapting the light to user or situational preferences. The left side works like a normal switch to turn lights on and off, while the right side works like a sliding scale to adjust the amount of light each fixture produces.

OCCUPANCY SENSING

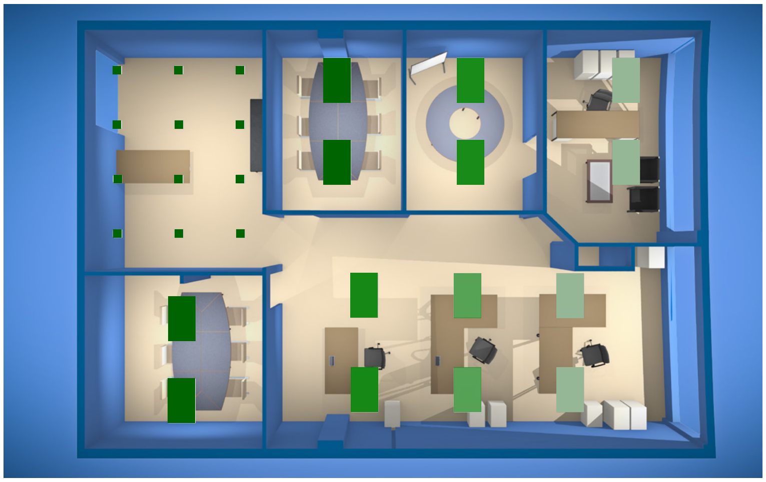
Whether you noticed your office's updated lighting or not, it noticed you. For many businesses, lighting can be 40% of their energy costs. Cree has solved that problem with Cree SmartCast® Technology with Motion Sensing. Each light comes with an embedded sensor for motion detection to sense changes in your environment. Lights automatically turn off when you leave and return to full power when you enter the room. Sometimes after an extended period of time with no movement in the room, the lights could turn off on you. This is the Occupancy Sensing feature at work to save energy, but a simple movement by you will turn the lights back on! This process is so seamless you won't even notice it happening, but your CFO will!



WATCH THE VIDEO:
https://tinyurl.com/CreeMotion

DAYLIGHT HARVESTING

The sun generates about 400 trillion watts of energy per second. Why not harness that and put it to work for your company? With Cree SmartCast® Technology with Daylight Harvesting, it can! As the amount of sunlight entering a building changes over time, the Daylight Harvesting sensor automatically dials the lights up or down to ensure consistent, comfortable light levels. Each individual light has its own sensor to detect and respond to daylight based on its unique position in the building. So, you may notice that some lights closer to the windows are dimmed down while others in interior spaces are brighter. It's all just another way the lights are working to harness more energy savings for your company. The easiest intelligent light solution under the sun, literally.



WATCH THE VIDEO:
https://tinyurl.com/CreeDaylight

All of this only scratches the surface of what Intelligent Lighting from Cree can do. For more insight, visit our website, **lighting.cree.com/SmartCast**.

We hope you have a great experience with your new Cree LED lighting system.

Rev. Date: 11/07/2017

WELCOME

to the World of Intelligent Light from Cree

CREE

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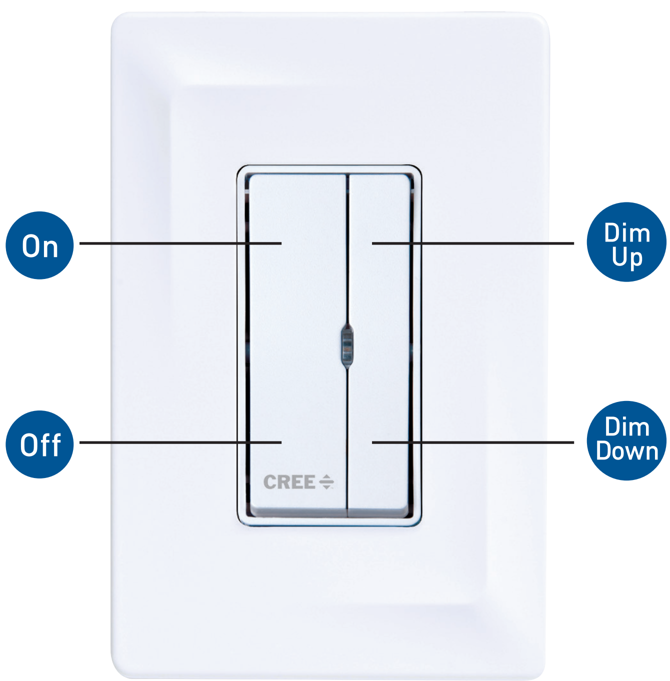

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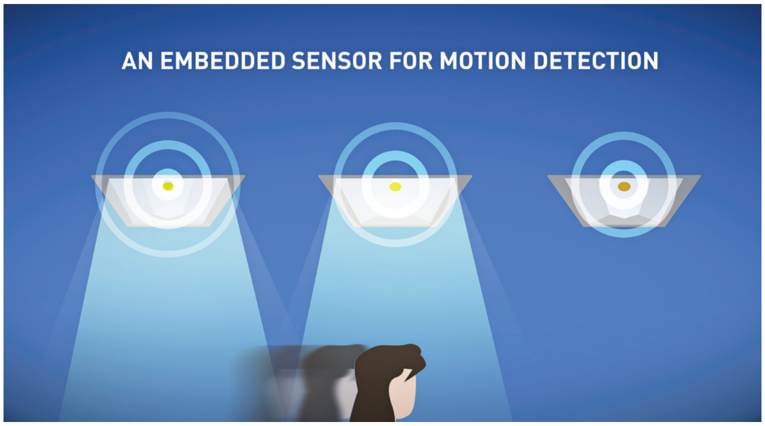

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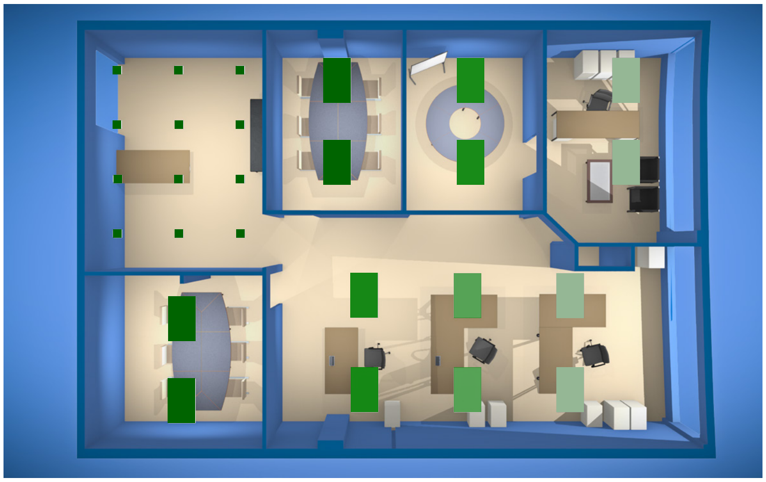

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All of this only scratches the surface of what Intelligent Lighting from Cree can do. For more insight, visit our website, **lighting.cree.com/SmartCast**.

We hope you have a great experience with your new Cree LED lighting system.

CREE ™

PROJECT RESULTS

Measurement and verification for the pilot was completed by Pacific Northwest National Laboratory (PNNL). They are still creating their final report as of this writing but have shared most of their quantitative results for inclusion in our close-out report, summarized below.

Energy Impacts

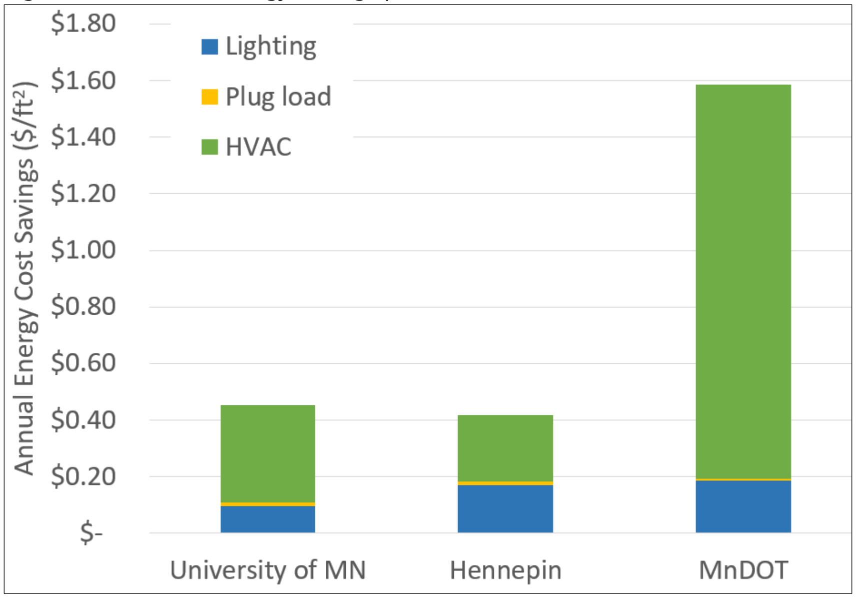
Energy impacts for each of the five projects are described in Table 1. Note that one site (City of St. Paul) did not have completed analysis as of this writing.

Table 1. Energy impacts of the integrated controls retrofits for each site.

		UMN	Hennepin	City of St Paul	MnDOT	CentraCare
Lighting savings	kWh/ft^2	0.9	1.5	M&V still ongoing	1.7	M&V was inconclusive, though HVAC and plug savings appear to be small
Plug load savings	kWh/ft^2	0.1	0.1		0.1	
HVAC savings	kWh/ft^2	2.8	1.4		12.6	
	$therms/ft^2$	0.06	0.13		0.02	
Total cost savings	$\$/ft^2$	0.45	0.42		1.59	

For the three sites with conclusive M&V, results are shown graphically in Figure 1.

Figure 1. Measured energy savings for three sites.



Note that lighting savings are smaller than those achieved by typical networked lighting control retrofits because we were working with earlier adopters who already had some occupancy control in place. Note that the MnDOT building was operated 24 hours a day, which led to larger HVAC savings. That building was also studied at partially lowered occupancy due the COVID pandemic. (The others were studied pre-pandemic.)

Overall, the resulting median savings from these projects are shown in Table 2.

Table 2. Median energy impacts for the three projects.

Electricity savings	3.8 kWh/ft^2
Natural gas savings	5.6 kBtu/ft^2
Energy cost savings	\$0.45/ft^2
Avoided carbon emissions	6.2 lbs. CO_2e/ft^2

Costs

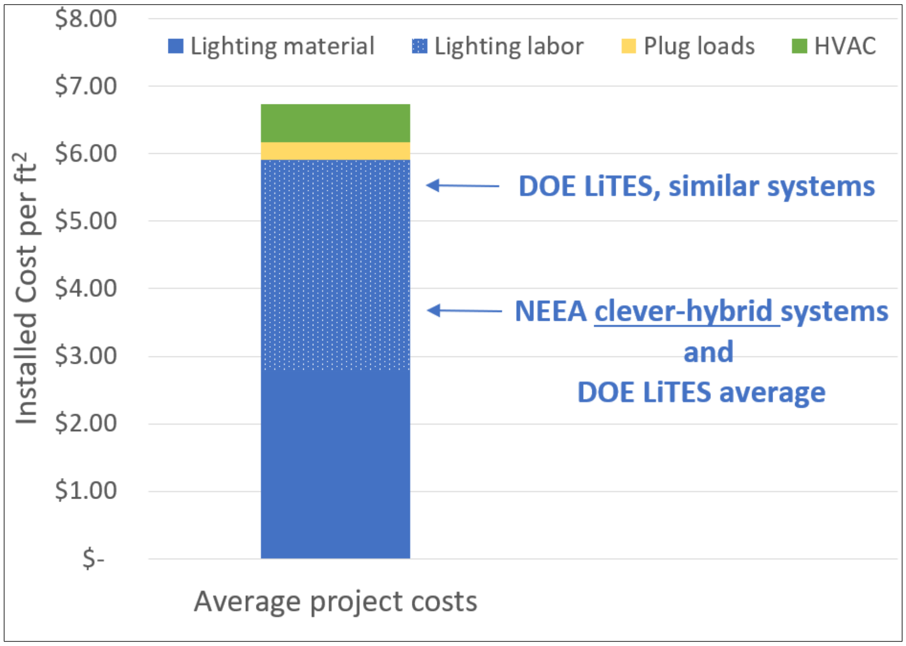
The costs incurred across the five sites are described in Table 3. We found that Hennepin County incurred abnormally high cost due to its small size, and sole-sourcing all the work, requiring electrical work to be done at night. Across the other four more typical sites, the average cost was \$6.73.

Table 3. Cost data from each site.

	Area (ft^2)	**Installed cost, per ft^2**					
		Lighting material	Lighting labor	Plug load materials	Plug load labor	HVAC	**Total**
UoM	25,000	\$2.27	\$2.37	\$0.21	\$0.07	\$0.37	**\$5.30**
St Paul	13,100	\$2.95	\$4.02	\$0.25	\$0.08	\$0.88	**\$8.18**
Hennepin	7,300	\$4.41	\$4.52	\$0.42	\$0.14	\$1.60	**\$11.08**
MNDot	11,300	\$2.93	\$4.07	\$0.15	\$0.05	\$0.38	**\$7.58**
CentraCare	12,400	\$3.01	\$1.99	\$0.16	\$0.06	\$0.64	**\$5.86**

These costs are also shown in Figure 2. Here, we also compare the costs we observed with two lighting control benchmarks, for similar lighting control systems installed in markets that were more mature. The first is cost found in the DOE LiTES pilot, which included significant training and market transformation effort (that served to familiarize these systems with contractors, thereby reducing cost) in addition to field demonstrations. The second is the cost observed in the territory of the Northwest Energy Efficiency Alliance, where they've had an intensive market transformation effort behind this type of lighting control for multiple years.

Figure 2. Average cost data observed in the pilot, compared with two other industry data points for lighting controls.



Economic impacts

A summary of the economic outcomes of these projects is given in Table 4. Costs are averaged for the four typical sites (excluding Hennepin; see above). Payback is based on those costs applied to average measured savings across the first three sites with conclusive measured data. These results suggest that if we had removed the less cost-effective plug load controls from the projects, we would expect to see an 8-year payback.

Table 4. Observed economics based on savings from three sites and costs from the four typical sites.

Approach	**Cost per ft^2**	**Payback**
Lighting + HVAC + plugs	$6.73	8.4 yrs.
Lighting + HVAC	$6.47	8.0 yrs.

As discussed in the Costs section, it may be useful to consider the economics of this type of retrofit in a market where the retrofits are more mature and well understood by contractors, generally after some market transformation. That scenario is described in Table 5. Given this data, we predict that if this retrofit approach were undertaken in these buildings without plug load controls, with incentives from Xcel Energy included, and with more mature-market costs for the lighting controls, the system payback would typically be approximately 5 years.

Table 5. Observed economics based on savings from three sites and costs for HVAC from the four typical sites, with costs for lighting from secondary data in more mature markets.

Approach	**Cost per ft^2**	**Payback**
Lighting control only	$4.50	30 yrs.*
Lighting + HVAC + plugs	$5.33	6.6 yrs.
Lighting + HVAC	$5.07	6.2 yrs.
Lighting + HVAC w/incentives	$4.19	5.2 yrs.

We’ve also analyzed a couple additional scenarios:

- Some of these networked lighting controls also offer additional non-energy functionality such as space utilization. If we factor in the benefit from space utilization using a conservative assumption for space that could be saved in the next build-out or retrofit, the payback for an integrated retrofit may decrease to as low as 2 years.
- If we consider a scenario where networked lighting controls are already being planned and the only decision is whether to add HVAC control integration or not, we estimate that decision to have a payback of approximately 1 year.

CASE STUDIES

a. University of Minnesota Jones Hall

The University's historic Jones Hall had fallen behind in sustainability initiatives and needed new lighting and controls. A retrofit of the complete building included lighting, lighting controls, HVAC building automation system, and hardware.

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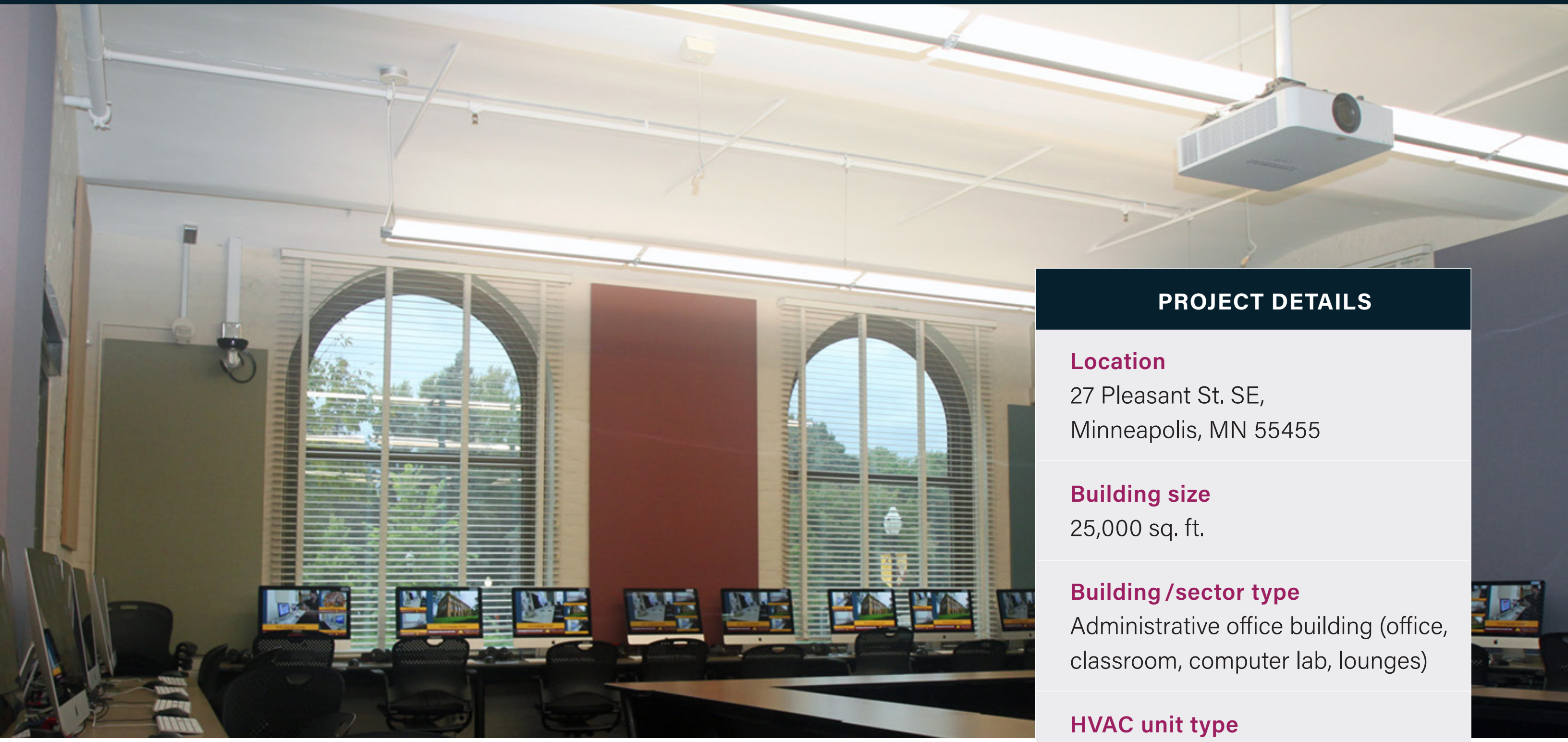
INTEGRATED CONTROLS PILOT PROGRAM | **CASE STUDY**



University of Minnesota Jones Hall

PROJECT BACKGROUND

The University of Minnesota wanted to decrease energy costs in Jones Hall, one of their mixed-use buildings on campus with a combination of offices, classrooms, and public space. The building is a historic component of the campus, hosting many functions over the years, and is currently home to the University's Admissions, Language Center, and College of Liberal Arts classrooms. The building had fallen behind in some of the University's aggressive sustainability initiatives and needed new lighting and controls.

The Integrated Controls pilot program, co-funded by Xcel Energy and the US Department of Energy (DOE), could deliver the deeper, more holistic energy retrofit

PROJECT DETAILS

Location
27 Pleasant St. SE,
Minneapolis, MN 55455

Building size
25,000 sq. ft.

Building / sector type
Administrative office building (office, classroom, computer lab, lounges)

HVAC unit type
One single duct, variable air volume (VAV) AHU serving several zones. Most are hot water reheat boxes. Served by district steam and chilled water.

BAS system type
Johnson Controls METASYS system, with controls technicians at the University making the improvements

Occupancy description
95 occupants, 6 a.m.–9 p.m., Monday–Friday, variable Saturday usage

Incentives
DOE incentive: $35,000
Xcel incentive: $16,100

PROJECT PARTNERS

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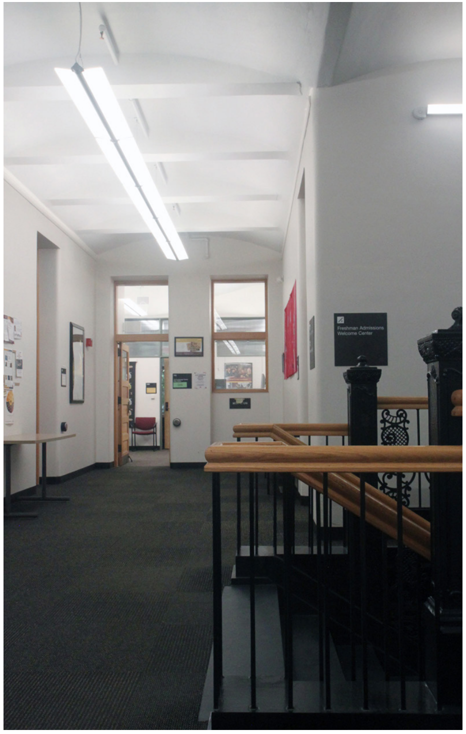
Pacific Northwest NATIONAL LABORATORY

Xcel Energy®



The new suspended linear lighting not only provides energy savings, but significant improvement in lighting quality with direct/indirect, task tunable fixtures.

they were looking for. It included a complete lighting retrofit with a luminaire-level lighting controls system, wireless outlet controls, and a tie from the lighting controls to the HVAC building automation system. This took advantage of the highly variable occupancy in the higher education building.

PROJECT SUMMARY

The University chose to retrofit the entirety of Jones Hall, which is approximately 25,000 square feet. The pilot provided a packaged solution for complete retrofit of the building, including site survey, design, and selection of the systems, and some financial assistance with materials and labor. The University managed the lighting and controls hardware retrofit, the majority of which took about 8 weeks (with a number of follow-up items taking a while longer).

The backbone of the new hardware was a luminaire-level lighting control system provided by Cree—their SmartCast platform. This system incorporates dimming control, photosensing, and occupancy sensing all onboard each individual fixture. The existing fixtures were replaced with SmartCast on a one-for-one basis. Sensors communicate wirelessly with each other to create a flexible, granular mesh network of sensing throughout the building from just replacing the fixtures themselves. This network is accurate enough to be used for individual outlet control, HVAC zone control, and of course lighting control. In addition to the new lighting fixtures and onboard controls, the other hardware component installed were the wirelessly-controlled outlets.

The project was not complete once this hardware was installed. Commissioning of the controls was an important step:

- The lighting and plug load controls were commissioned by the vendor, Cree, as a service included with the purchase of the fixtures.
- New HVAC sequences were implemented by the building's designated controls contractor that took advantage of the occupancy data from the lighting network. These sequences were programmed by University energy management staff.
- Building operators and occupants were trained on use of the lighting controls and outlet controls.

ENERGY SAVING CONTROL STRATEGIES
SmartCast lighting and all its associated energy-saving controls and features
Plug load controls in office spaces
Plug load controls on common area equipment like printers and chargers
Thermostat setback based on occupancy
VAV box shut off based on occupancy
SAT reset
Demand control ventilation

LESSONS LEARNED

The concept of integrating controls across systems is relatively new, and lessons were learned along the way:

- The lighting control implementation and commissioning of the lighting was made fairly simple for the owner and their contractor due to Cree's assistance, but it did take significant time and multiple separate trips.
- The integration with HVAC was not yet plug and play. Cree learned several lessons about configuring their system to communicate readily with the HVAC system. And once integration is complete, alarms should be set to ensure that it remains functional; lighting systems will not alarm if that connection goes down.
- Some wall controls required a neutral wire to be fed to power the device. This took some time.
- IT staff should be involved early to ensure the controls system has a path to connect to the internet. Initial implementation was attempted without this connection, which led to challenges.
- Mapping control points between lighting and HVAC involves coordination between multiple parties; the lighting and HVAC zones should be planned in advance.
- In order to tune light levels, just enough high-end trim was implemented for the task in each space. This was initially planned using photometric calculations but the commissioning agent did need to make some adjustments in the first weeks following installation based on occupant feedback.
- Occupants do need to be informed of both the purpose of the lighting controls and how they operate. Outlet controls especially need to be communicated clearly. In the future color-coded outlets would be an improvement.
- Plan on training someone on the building owner's staff as commissioning is taking place so they have someone local who knows how to make any necessary adjustments.

PAYBACK INFORMATION

The impacts table describes the savings, cost, and resulting payback for this project. Electricity savings for lighting are shown as measured at the site.

The atrium area, served by wall mounted fixtures with supplemental control modules.

IMPACTS	
Lighting savings	0.9 kWh/sq. ft.
Plug load savings	N/A
HVAC savings	2.8 kWh/sq. ft. 0.06 therms/sq. ft.
Total cost savings	$0.45/sq. ft.
Cost (after incentives)	$4.81/sq. ft.
Payback	10.6 years
Payback, mature product*	10.2 years

*Based on system costs in more mature markets, and excluding plug load controls.

FOR MORE INFORMATION

info@slipstreaminc.org

ACKNOWLEDGMENT: "This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Building Technologies Office, Commercial Buildings Integration Program, Award Number DE-EE0001890."

b. Hennepin County 701 Building

Hennepin County, Minnesota has a goal of reducing greenhouse gas emissions from their massive portfolio of buildings by 25% by 2025. The county did a retrofit of an outpatient clinic and adjoining fitness center that included lighting controls, HVAC services and plug loads.

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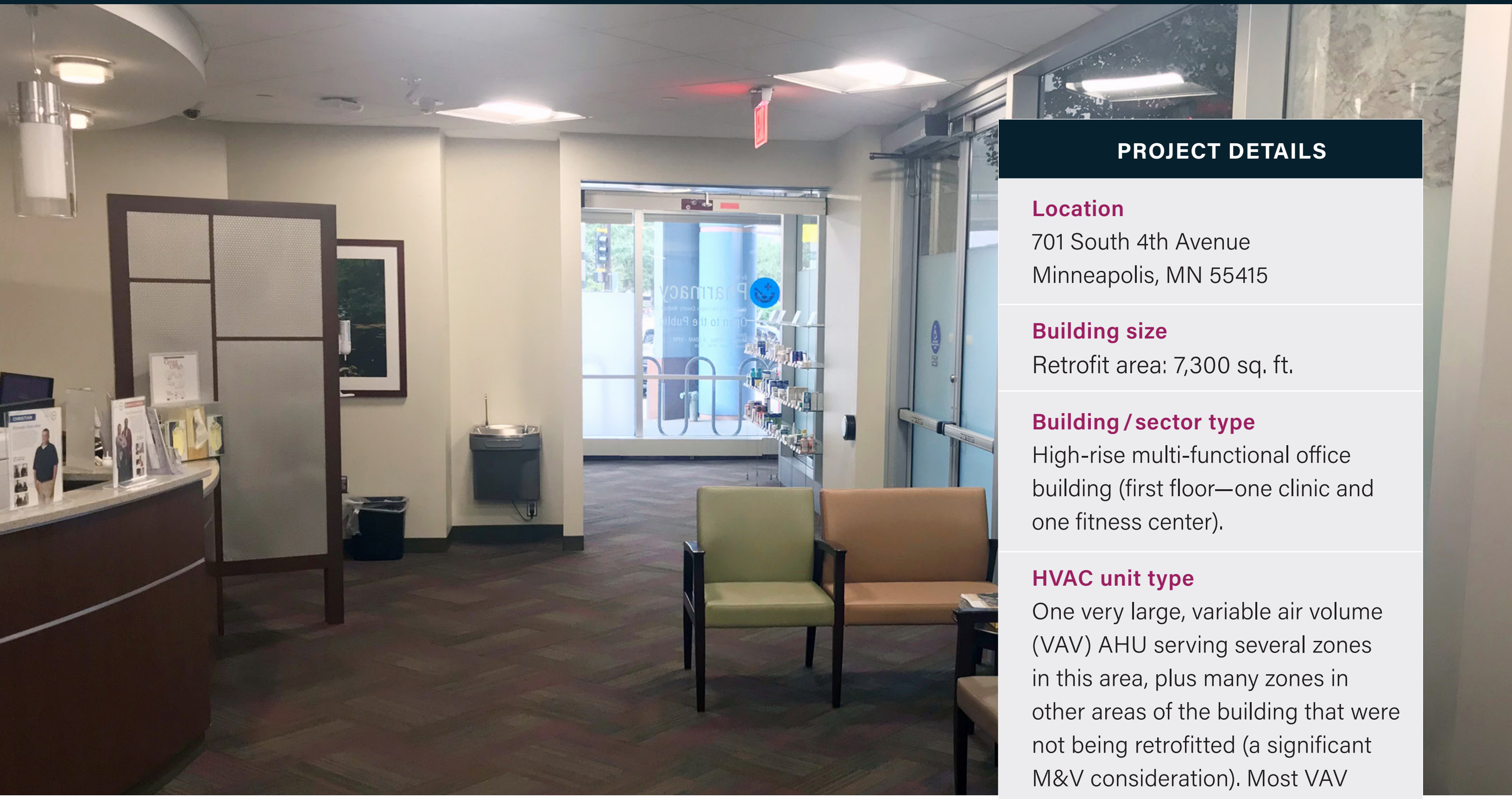
INTEGRATED CONTROLS PILOT PROGRAM | **CASE STUDY**



Hennepin County 701 Building

PROJECT BACKGROUND

Hennepin County, the most populated county in Minnesota, operates a massive portfolio of buildings covering most building types. They also have a goal of reducing greenhouse gas emissions from their operations by 25% by 2025. As a result, they have undertaken significant energy retrofits over the past decade, with much effort focused on lighting retrofit. They recently investigated broader uses of smart building controls and were subsequently introduced to Slipstream's integrated controls pilot. The County saw value in testing the integration of these

PROJECT DETAILS

Location
701 South 4th Avenue
Minneapolis, MN 55415

Building size
Retrofit area: 7,300 sq. ft.

Building / sector type
High-rise multi-functional office building (first floor—one clinic and one fitness center).

HVAC unit type
One very large, variable air volume (VAV) AHU serving several zones in this area, plus many zones in other areas of the building that were not being retrofitted (a significant M&V consideration). Most VAV boxes are hot water (HW) reheat boxes. Building has a HW and chilled water system for heating and cooling the AHU.

BAS system type
Automatrix system with JACE

Occupancy description
Fitness area is 24/7 with highly variable occupancy. Outpatient Clinic has regular occupancy 6 a.m.–6 p.m. Monday–Friday.

Incentives
DOE incentive: $21,315
Xcel Energy incentive: $8,700

PROJECT PARTNERS

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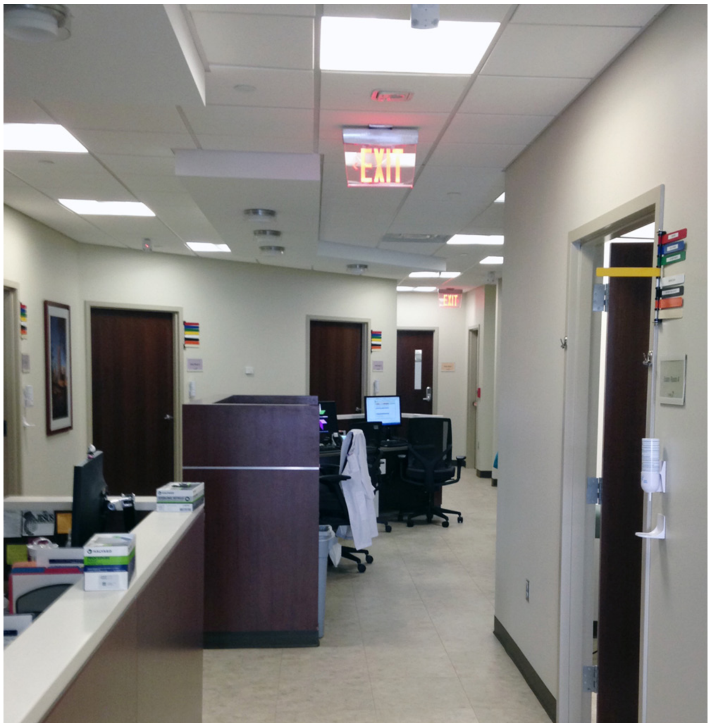
Xcel Energy



Lighting quality was improved in nurses areas.

Specific industry requirements needed to be met for pharmacy lighting.

different building systems and decided to apply the approach to one floor of a large building in downtown Minneapolis.

PROJECT SUMMARY

The project studied the impacts and trade-offs from integrating LED lighting with luminaire-level lighting controls with plug load controls, and zone HVAC controls. Slipstream conducted field measurement of the demonstration to evaluate the energy savings potential from reducing lighting, plug load, and HVAC system operation when spaces are unoccupied. Slipstream also assessed the ease of installation and documented occupant feedback of the new technologies compared to the baseline systems.

PROJECT DETAILS

The project retrofitted two separate spaces with an integrated controls system, both served by a common VAV system, covering a total of 7,300 square feet. One space was an outpatient clinic. In this space the different exam rooms, nurses' stations, pharmacy, and reception area all had highly variable occupancy, making it an excellent candidate for control of lighting, HVAC services, and a few select outlets. The other space on the floor is a fitness center that serves a building amenity. The center was open 24/7 to serve varying needs of building occupants, so lighting, HVAC, and plug loads all operated all day even though there are significant periods when no one was using the center. The system allows all three systems to shut down during those times. The project required coordination between the County,

ENERGY SAVING CONTROL STRATEGIES
SmartCast lighting and all its associated energy-saving controls and features
Plug load controls in office spaces
Plug load controls on common area equipment like printers and chargers
Plug load controls on the fitness center exercise equipment
Thermostat setback based on occupancy
VAV box shut off based on occupancy
SAT reset
Static pressure reset based on VAV box position (which is based on occupancy)

the building's property management firm (which also managed the fitness center), clinic staff, lighting control vendor, and contractor. It was truly an integrated effort, and this did lead to some challenges.

The backbone of the new hardware for the retrofit was a luminaire-level lighting control system provided by Cree—their SmartCast platform. This system incorporates dimming control, photosensing, and occupancy sensing all onboard each individual fixture. The existing fixtures were replaced with SmartCast on a one-for-one basis. Sensors communicate wirelessly with each other, creating a flexible, granular mesh network of sensing throughout the building from just replacing the fixtures themselves. This network is accurate enough to be used for individual outlet control, HVAC zone control, and of course lighting control. In addition to the new lighting fixtures and onboard controls, the other hardware component installed were the wirelessly-controlled outlets.

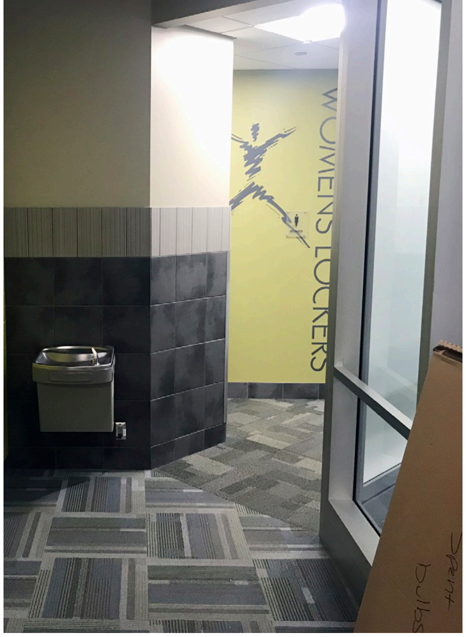
Being a controls-focused project, the project was not complete once this hardware was installed. Commissioning of the controls was an important step:

- The lighting and plug load controls were commissioned by the vendor, Cree, as a service included with the purchase of the fixtures.
- New HVAC sequences were implemented by the building's designated controls contractor that took advantage of the occupancy data from the lighting network.
- Building operators and occupants were trained on use of the lighting controls and outlet controls.

LESSONS LEARNED

The concept of integrating controls across systems is relatively new, and lessons were learned along the way:

- The lighting control implementation and commissioning were relatively simple for the County and their electrician, with help from Cree's in-field representatives.
- The integration across systems was not quite plug and play. Cree learned several lessons about configuring their system to communicate readily with the HVAC system. Most notably, the importance of having up-to-date and compatible firmware on all devices.
- Lighting in the pharmacy on this site did present challenges in finding an LED solution that could achieve enough illumination with only one-for-one retrofit.
- Mapping control points between lighting and HVAC involves coordination between multiple parties; the lighting and HVAC zones should be planned in advance.
- The fitness center had some unique decorative fixtures that were harder to integrate into the Cree platform. The solution in the end was to use a tubular LED retrofit coupled to an independent Cree control module, demonstrating that there are options when a SmartCast-branded fixture did not meet project requirements.
- In order to tune light levels, just enough high-end trim was implemented for the task in each space. This was done with photometric calculations in many spaces,



(Top) **The fitness center is infrequently used, making controls effective.** *(Middle)* **Locker rooms were included in both lighting and HVAC control.** *(Above)* **The building's VAV system utilizes the sensing to turn down individual zones when nobody is present.**

Controls are particularly impactful in the pharmacy, where light levels (and therefore base energy usage) are higher.

but these calculations were lacking in some cases, requiring field measurements of illuminance as commissioning progressed.

- Occupants need to be informed of both the purpose of the lighting controls and how they operate in order for them to persist.
- In retrospect someone on the building owner's staff should have been trained as commissioning was taking place so that once it's done, there is someone local who knows how to make necessary adjustments.
- At this site the retrofit only covered one floor of a large office tower. The partial nature of the retrofit did not affect lighting, plug load, or zone HVAC control savings, but the ability to impact overall HVAC energy performance at the *system* level was hindered. Many potential AHU-level control improvements were omitted or constrained because the HVAC systems served many floors that did not include the new zone controls.

PAYBACK INFORMATION

The impacts table describes the savings, cost, and resulting payback for this project. This site demonstrated that the economics of integrated controls are challenging for small retrofits. The cost of integration and HVAC improvements remain fixed while the savings are significantly smaller. Payback would improve if a much bigger portion of the building were retrofit.

IMPACTS	
Lighting savings	1.5 kWh/sq. ft.
Plug load savings	0.1 kWh/sq. ft.
HVAC savings	1.4 kWh/sq. ft. 0.13 therms/sq. ft.
Total cost savings	$0.42/sq. ft.
Cost (after incentives)	$10.6/sq. ft.
Payback	25.4 years
Payback, mature product*	11.1 years

*Based on system costs in more mature markets, and excluding plug load controls.

FOR MORE INFORMATION

info@slipstreaminc.org

ACKNOWLEDGMENT: "This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Building Technologies Office, Commercial Buildings Integration Program, Award Number DE-EE0001890."

c. State of Minnesota, Department of Transportation (MnDOT)

The MnDOT Cedar Truck Avenue maintains state roads and highways in the Twin Cities metro area.

Lunchroom before the retrofit.

State of Minnesota, Department of Transportation

PROJECT BACKGROUND

The Minnesota Department of Transportation (MnDOT) Cedar Avenue truck station is a key facility from which the department maintains the many state roads and highways in the Twin Cities metro area. Prior to the retrofit the building had an older fluorescent lighting system that was overlit and largely operated 24 hours a day without much automated lighting controls.

The Integrated Controls pilot program, co-funded by Xcel Energy and the US Department of Energy (DOE), could deliver deeper, more holistic energy retrofits. The MnDOT retrofit included a complete lighting retrofit with a luminaire-level lighting controls system, wireless outlet controls, and a tie from the lighting

PROJECT DETAILS

Location
1900 East 66th Street
Richfield, MN 55423

Building size
Building size: 74,776 sq. ft.
Retrofit areas: 11,300 sq. ft.

Building / sector type
One-story administrative office and maintenance facility (conference room, office areas with enclosed and open offices, lunch room, hallway, locker rooms, storage areas, and warehouse area.)

HVAC unit type
One single-duct, variable air volume (VAV) AHU serving 10 zones controlled by series fan-powered VAV terminal units with hot water reheat coils. The fan-powered VAV boxes have fan speed control regulators.

BAS system type
Distech Controls (Tridium Niagara framework)

Occupancy description
30 occupants, operating 24/7

Incentives
DOE incentive: $27,800
Xcel incentive: $11,224

PROJECT PARTNERS

CREE LIGHTING — A COMPANY OF IDEAL INDUSTRIES, INC.
legrand
Pacific Northwest NATIONAL LABORATORY
Xcel Energy


Office in training room 131 before the retrofit.


Office 139 before the retrofit.

controls to the HVAC building automation system. This took advantage of the highly variable occupancy in the building to drive deeper energy savings.

MnDOT retrofitted approximately 11,300 sq. ft. with full design and commissioning services from Cree, and measurement and verification from PNNL. MnDOT received funding from the DOE and incentives from Xcel Energy for a portion of the retrofit.

The backbone of the new hardware for the retrofit was a luminaire-level lighting control system provided by Cree—their SmartCast platform. This system incorporates dimming control, photosensing, and occupancy sensing onboard each individual fixture. The existing fixtures were replaced with SmartCast on a one-for-one basis. Sensors communicate wirelessly with each other, creating a flexible, granular mesh network of sensing throughout the building. This lighting network is integrated with individual outlet control and HVAC zone control.

The project team, led by Slipstream, used this project as a demonstration of the impacts and trade-offs from integrating luminaire-level lighting control with plug load controls and HVAC controls. We assessed energy impacts, ease of installation and data retrieval, and obtained occupant feedback on the new technologies.

ENERGY SAVING CONTROL STRATEGIES
SmartCast lighting and all its associated energy-saving controls and features
Plug load controls in office spaces
Plug load controls on common area equipment like printers and chargers
Thermostat setback based on occupancy
VAV box shut off based on occupancy
AHU supply air temperature reset
Hot water supply temperature reset

LESSONS LEARNED

The concept of integrating controls across systems is relatively new, and lessons were learned along the way:

- Overall, the lighting control implementation and commissioning were straightforward for MnDOT, aided by Cree's representatives supporting field implementation. The control integration was done by the facility staff and there was no additional hardware/software upgrade cost.
- The outlet controls were costly to install and would likely only be cost-effective where very large plug loads are identified.

Training room before the retrofit.

Training room after the retrofit.

- Once lighting integration with HVAC is complete, alarms should be set to ensure that it remains functional; lighting systems will not alarm if that connection goes down.
- Mapping control points between lighting and HVAC involves coordination between multiple parties; zoning pairs should be planned in advance.
- Lighting high-end trim was implemented to tune light levels to just enough for the task in each space; photometric calculations were used to plan this tuning and decrease time spent in the field.
- Plan on training someone on the building owner's staff as commissioning is taking place so they have someone local who knows how to make any necessary adjustments.

IMPACT INFORMATION

The impacts table describes the savings, cost, and resulting payback for this project. **Note:** This building was studied at partially lowered occupancy due the COVID-19 pandemic.

IMPACTS	
Lighting savings	1.7 kWh/sq. ft.
Plug load savings	0.1 kWh/sq. ft.
HVAC savings	12.6 kWh/sq. ft. 0.02 therms/sq. ft.
Total cost savings	$1.59/sq. ft.
Cost (after incentives)	$5.85/sq. ft.
Payback	3.7 years
Payback, mature product*	2.1 years

*Based on system costs in more mature markets, and excluding plug load controls.

FOR MORE INFORMATION

info@slipstreaminc.org

ACKNOWLEDGMENT: "This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Building Technologies Office, Commercial Buildings Integration Program, Award Number DE-EE0001890."

d. City of St. Paul Streets Maintenance Building

This 1970s building houses Department of Public Works staff that was using mostly inefficient fluorescent lighting, and lacked occupancy controls.

PROJECT DETAILS

Location
899 Dale St. North
Saint Paul, MN 55103

Building size
60,546 sq. ft.
Retrofit area: 13,100 sq. ft.

Building / sector type
Administrative office building (private and open offices, meeting room, lunchroom, locker room, repair shop, storage room).

HVAC unit type
Two dual-duct, single fan, multi-zone, constant air volume (CAV) AHUs (each serving four zones.) One single-duct, single-zone, constant air volume AHU. One rooftop unit serving one zone. Independently controlled hot-water radiant heating in perimeter rooms.

BAS system type
Johnson Controls METASYS system, with a local controls contractor maintaining the system.

Occupancy description
30 occupants, 7:30 a.m. to 4:30 p.m., Monday–Friday.

Incentives
Xcel Energy incentive: $11,000
DOE incentive: $36,525

City of St. Paul Streets Maintenance Building

PROJECT BACKGROUND

The city of St. Paul Streets Maintenance building houses the Department of Public Works staff who administer and maintain the public street traffic signals, signs, and lighting. The building was built in 1970s and is a mixed-use building with a combination of private and open offices, meeting rooms, a lunchroom, locker rooms, repair shop area, and storage rooms. Its interior lighting was still mostly inefficient fluorescent fixtures before the pilot. Because of the financial incentives provided by the Integrated Controls pilot program, co-funded by Xcel Energy and the US Department of Energy (DOE), the City agreed to retrofit part of the building

PROJECT PARTNERS

CREE LIGHTING — A COMPANY OF IDEAL INDUSTRIES, INC. | legrand | Pacific Northwest NATIONAL LABORATORY | Xcel Energy


***(Above)* LED troffers above the open office area cubicles; *(Right)* Existing BAS controllers.**

areas with the new networked, integrated lighting controls package. It included a complete lighting retrofit with a luminaire-level lighting controls system, wireless outlet controls, and a tie from the lighting controls to the existing HVAC building automation system.

PROJECT SUMMARY

The city of St. Paul decided to retrofit about 13,100 square feet of its Streets Maintenance building in this pilot project. The pilot included site survey, design and a selection of the networked LED lighting systems, plug load controls and integration, HVAC controls integration, and some financial assistance with materials and labor. The City managed the lighting and plug load controls hardware installation. The lighting manufacturer commissioned the networked lighting control system. A local HVAC controls contractor was responsible for the HVAC integration with the lighting system.

The key component in this pilot was Cree's SmartCast platform with LED fixtures and a luminaire-level lighting sensing and control. This system incorporates dimming control, photosensing, and occupancy sensing all onboard each individual fixture. These sensors communicate wirelessly with each other to create a flexible, granular mesh network of sensing throughout the building from just replacing the fixtures themselves. These sensor signals were used for individual outlet control, HVAC zone and AHU control, and of course individual lighting fixture control. In addition to the new lighting fixtures and onboard controls, the other hardware component installed were the wirelessly-controlled outlets.

ENERGY SAVING CONTROL STRATEGIES
SmartCast and all its associated energy-saving features
Plug load controls in private offices, conference room, lunchroom, and common area cubicles
Plug load controls on common area equipment like printers and chargers
Zone temperature setpoint setback based on occupancy
Dual-duct, CAV AHU supply air temperature setpoint reset or unit shut off based on occupancy
AHU outside air damper minimum position control based on occupancy
Perimeter zone radiation heating control based on occupancy
Boiler hot water temperature reset

Lunch room fluorescent fixtures before retrofit.

Lunch room LED fixtures after retrofit, a significant energy savings and improvement in lighting quality.

The commissioning of the system involved the following important steps:

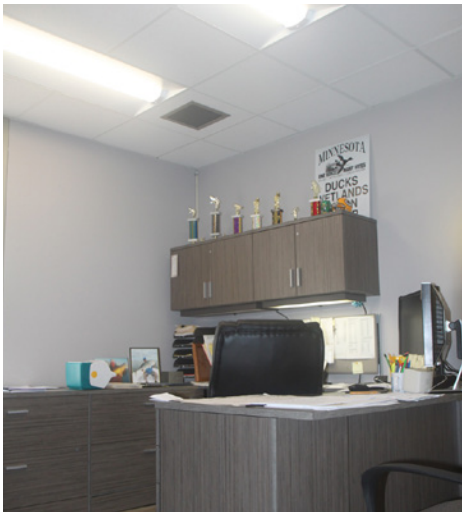
- The lighting and plug load controls were commissioned by the vendor, Cree, as a service included with the purchase of the fixtures.
- The integration of the luminaire-level lighting sensing (occupancy status) signals with the HVAC control system was done under the collaboration of the City's IT staff, the Cree commissioning agent, and the local HVAC control contractor. The integration of lighting occupancy signals into the HVAC control system was through BACnet.
- New HVAC sequences implemented took advantage of the occupancy data from the lighting network. These sequences were programmed by the local HVAC control contractor.
- Building operators and occupants were trained on use of the lighting controls and outlet controls.

LESSONS LEARNED

- Project cost is a key barrier to this type of project. The City would not be able to commit to the project without the DOE and Xcel Energy incentives.
- The lighting, plug loads, and HVAC control designs and integration strategies need to be well thought-out during the design stage. The control areas for these different systems need to coordinate among designers/implementers of these systems. The lighting and HVAC zones should be planned in advance.
- The lighting and plug load system installations were straightforward and completed by the City's staff electricians. Cree took care of the lighting commissioning work completely with their one-button setup.

(Top right) **A supplemental control module;** ***(Middle right)*** **Wireless dimmable switches**
(Bottom right) **Wireless plug load control modules.**

Shop area LED fixtures after retrofit, keep the space bright enough for bench work.



Privative office after retrofit.

- The integration between lighting network and HVAC controls network was not quite plug and play yet. Several issues related to hardware and software occurred during the integration process. Overall it took several months and multiple discussions among the City's IT staff, the Cree commissioning agent and technical support team, and the local HVAC controls contractor to resolve these network communication issues.
- The commissioning agent needed to make some adjustments to the designed light levels and lighting/plug load controls based on occupant feedback.
- Occupants need to be informed of both the purpose of the lighting controls and how they operate.
- In retrospect someone on the building owner's staff should have been trained as commissioning was taking place so that once it's done, there is someone local who knows how to make necessary adjustments.

PAYBACK INFORMATION

The following table describes the savings, cost, and resulting payback for this project. Electricity savings for lighting are shown as measured at the site; results for other end uses and the total results are still being calculated as of the time of this publication.

Lighting network POE switch and Link server.

PAYBACK	
Lighting savings	1.65 kWh/sq. ft. (52%)
System cost	$7.31/sq. ft.
Measure life	25 years

FOR MORE INFORMATION

info@slipstreaminc.org

ACKNOWLEDGMENT: "This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Building Technologies Office, Commercial Buildings Integration Program, Award Number DE-EE0001890."

Comparison of SOPO to Actual					
SOPO Task #	**T / M / D**	**Task Title or Milestone / Deliverable Description**	**Task Completion Date**		**Project Notes**
			Original Planned	**Actual**	
1.1	T	Pilot planning	1/20/18	2/10/18	Slipstream and Xcel determined eligibility requirements for sites, created marketing documents, and worked with Xcel's existing processes to establish this pilot's processes. We created an incentive structure and participation timeline.
1.1	D	Establish pilot scope with utility partner; DOE reviews pilot design	1/20/18	2/10/18	Slipstream and Xcel determined eligibility requirements for sites, created marketing documents, and worked with Xcel's existing processes to establish this pilot's processes. We created an incentive structure and participation timeline. *XCEL - Stage Gate visual v6_Markup_10.16.19.pdf*
1.2	T	Site recruitment	3/31/18	7/1/18	We developed a list of building owners and operators with potential pilot sites and began outreach to priority sites.
1.2	D	Identify 8 applicable sites for implementation; submit list to DOE	3/31/18	3/31/18	We developed a list of building owners and operators with potential pilot sites and began outreach to priority sites.
1.3	T	Site screening and establishment	4/20/18	5/15/18	Continued outreach. *AP pilot sell sheet.pdf; Integrated controls package pilot - final with option.pptx*
1.3	M	Have site list narrowed to 4 initial sites that are representative, feasible for the owner/operator, and generally project-ready	4/20/18	4/20/18	We coordinated site visits with 4 high-potential sites.
2.1	T	Project coordination and design	8/20/18	7/16/19	Work is underway with our technical partners and all 4 high-potential to provide final design of their site.
2.1	D	Complete design for 2 sites; submit key design drawings to DOE	8/20/18	12/31/18	Completed design for 2 sites. Participant agreements for all 5 sites were provided previously.
2.1	M	Complete design for 1-3 additional sites	11/20/18	7/1/19	All 5 demonstration sites have finalized design or have preliminary designs. Design documentation was provided previously.
2.2	T	Create a comprehensive M&V plan (completed by PNNL) that is consistent with our demonstration plans.	9/20/18	9/20/18	PNNL has conducted site visits of all 4 high-potential sites and completed a general measurement and verification plan for DOE review. All 4 measurement and verification plans have been established.

2.2	D	Have a comprehensive M&V plan for the first 2 sites completed by PNNL that is consistent with our demonstration plans; plan submitted to DOE for review.	9/20/18	9/20/18	PNNL has conducted site visits of all 4 high-potential sites and completed a general measurement and verification plan for DOE review. All 4 measurement and verification plans have been established.
GNG1	M	Go/no-go: Seventhwave has: 1. Met all deliverables. 2. Provided four owner/operator host site commitments.	10/20/18	10/20/18	Go
2.3	T	Complete retrofit for at least 2 sites; DOE invited to tour sites	3/20/19	1/15/20	Retrofits complete.
2.3	M	Complete retrofit for at least 2 sites; DOE invited to tour sites	3/20/19	1/15/20	DOE visited sites 12/4/2019.
2.4	T	Oversee commissioning of the system to maximize energy savings, ensure satisfied occupants, and improve persistence.	4/20/19	4/15/20	Commissioning at all 5 sites completed by Cree with Slipstream oversight.
3.1	T	Ensure that adequate data is being actively collected at initial sites (working with M&V team).	4/20/19	4/20/19	3 sites have M&V fully installed and captured data.
3.1	D	Ensure that adequate data is being actively collected at initial sites (working with M&V team); DOE verifies stream	4/20/19	6/30/19	3 sites have M&V fully installed and captured data; DOE decision that DOE review was unnecessary.
3.2	M	Complete retrofit for at least 1-3 more sites; DOE invited to tour sites	8/20/19	2/10/20	Retrofits complete.
3.2	D	Complete a case study document, including quantified cost and performance effects, for each installed site. Provide to DOE.	12/20/19	5/29/20	3 case studies submitted in May 2020. Some savings data was preliminary due to M&V delays because of COVID-19. Final versions provided with close-out reporting.
3.2	T	Submit a final report to DOE, Xcel Energy, and other stakeholders.	12/20/19	5/29/20	User guide/Final report submitted in May 2020. Some savings data was preliminary due to M&V delays because of COVID-19. Final versions provided with close-out reporting.

4.1	D	Develop full program	5/31/20	5/31/20	*XCEL - Stage Gate visual v6_Markup_10.16.19.pdf*
GNG2	M	Go/no-go: Seventhwave has: 1. Met all deliverables. 2. Delivered the Package Performance Report which covers the performance of the package at least 3-5 demonstration sites. 3. Delivered a plan, co-developed with our major utility partner, to implement a full program offering for the technology package.	9/20/19	5/21/20	Go. The COVID-19 pandemic impacted the timing of equipment and data collection at 3 sites, and the project received a 6-month NCE.
4.1	D	Develop and document a complete program offering including incentives, outreach plan, implementation plan, and evaluator and regulatory interactions. DOE reviews plan.	2/20/20	12/31/20	Will continue to support Xcel's plans to adapt existing program offerings to support integrated controls. Potential program pathways include Commercial Lighting, Custom, New Construction, Energy Management Systems. A series of four meetings/presentations occurred in Q4 2020 with several Xcel programs to discuss program support needs and share findings. *Integrated Controls_Xcel_12.02.20_v3.pptx*
4.2	T	Dissemination to other utilities and owner/operators	7/20/20	12/31/20	See below.
4.2	M	Direct outreach to 3 additional utilities, broad communication to utility audience	7/20/20	12/31/20	We are working with AESP topic committee to generate articles and webinar content for the National AESP Conference in January 2021. Will present a panel at ASHRAE National Conference 2021. National Grid will be moving forward with a field demonstration in 3-4 buildings in Rhode Island in 2021. We are assisting with identifying candidate projects.
4.2	M	Direct outreach to 3 additional large portfolio owner/operators, broad communication to utility audience	7/20/20	12/31/20	Have discussed findings with GSA. We did some lighting market research with ComEd in 2020 and submitted a proposal for a pilot offering to ComEd Feb. 2021. We will present at Xcel's Expo in early 2021.

PUBLIC RELEASES OF RESULTS

a. Publications, conference papers, other public releases of results during this project:

- Better Buildings Summit 2019 presentation
- ACEEE 2020 Summer Study paper
- ASHRAE 2020 Virtual Conference presentation on Preliminary Lessons Learned
- DOE Energy Exchange 2020 presentation
- EDS Zero Energy Buildings and Integrated Controls presentation 2020
- Light Fair lighting network controls presentation 2020
- Present to BTO Commercial Buildings Integration Spring 2021
- Seminar at ASHRAE National Conference 2021
- Presentation at AESP National Conference 2021

Upcoming presentations:

- Presentation at Xcel Energy Expo in 2021
- Panel for DOE's Better Buildings Better Plants Summit in 2021
- Panel presentation at NEEA Energy Efficiency Forum 2021

b. Website or other internet sites

- https://slipstreaminc.org/research/us-department-energy-integrated-controls-study

c. Networks or collaborations fostered

- Most of the presentations mentioned above have occurred at conferences and were therefore accompanied by significant audience exposure, discussion, and some follow-on conversations.
- We have communicated our progress and received input from other industry experts who are involved in building integrated control technologies and systems. This includes: NEEA, VEIC, DesignLights Consortium, DOD ESTCP, Honeywell, GSA Proving Ground, and RPI.
- Many lessons have been learned in implementation and M&V which we have shared with various stakeholders such as Better Building Alliance members, NEEP, and utilities such as ComEd, National Grid, Eversource, and Consumers Energy.
- National Grid Rhode Island has engaged Slipstream to assess how their Performance Lighting PLUS program could be enhanced with incentives for integration of lighting and HVAC controls. We conducted 22 market research interviews with customers, manufacturers, distributors, installers and controls technicians serving the Rhode Island market. The findings were presented to National Grid on 7/31/2020 and National Grid will be moving forward with a field demonstration in 3-4 buildings in Rhode Island in 2021.
- After completing some lighting market research ComEd requested a proposal for a pilot project from Slipstream; pending approval in April 2021.

d. Technologies/Techniques

- None.

e. Inventions/Patent Applications, licensing agreements

- None.

f. Other products, such as data or databases, physical collections, audio or video, software or netware, models, educational aid or curricula, instruments or equipment

- None.

PROJECT MATERIALS PRODUCED

Integrated Controls Recruitment Slide Deck

Integrated Control Retrofit Pilot

Photo courtesy of Cree


Photo courtesy of Cree

- Pilot overview
- Technology overview
- Site requirements
- Benefits of participation
- Measurement and verification process
- Participation timeline

Integrated Controls Retrofit Pilot

FUNDED BY

U.S. Department of Energy

PARTNERS

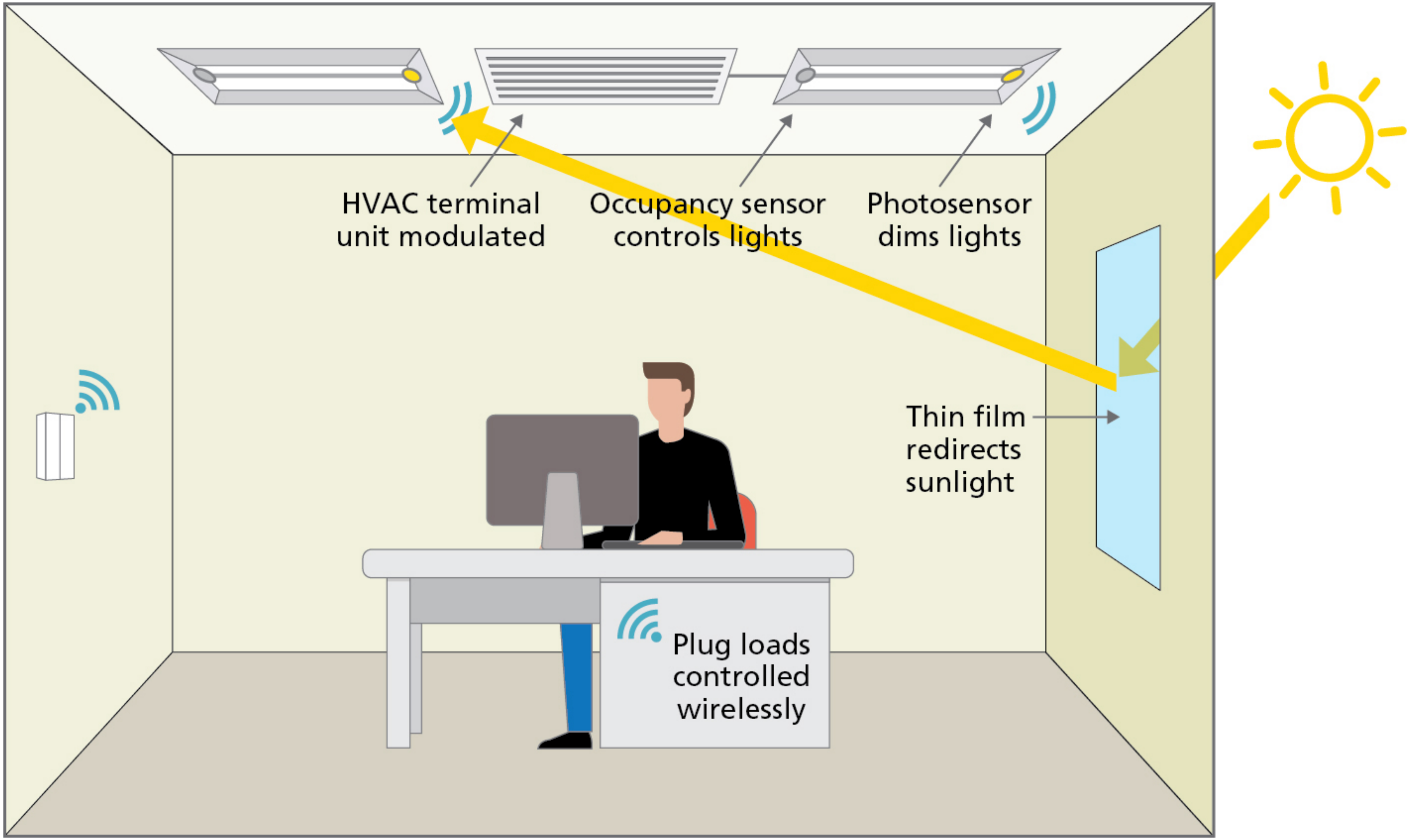
Xcel Energy — RESPONSIBLE BY NATURE™ | CREE | legrand | 10x technology — Microstructured Solutions

Inspire the retrofit market to go beyond basic fixture replacement

Spur market demand for an integrated controls approach

Transform the market with wide-scale adoption by energy efficiency programs

Traditional energy retrofit



Holistic: saves up to **85%** of lighting energy and **50%** of total energy in the space

Core technology: LED troffers with controls

Photos courtesy of Cree

Lighting tech partner: Cree

How to retrofit lighting controls

Design	Installation	Commissioning
Layout fixture locations	Install fixtures	Energize ltg. circuits at panel
Layout switch locations & zones	Install switches	Address all fixtures
Select control protocol/approach	Pull line voltage to fxt & switches	Group fixtures in zones
Determine daylight zones	Install occupancy sensors	Associate zones with switch
Select daylight sensors	Install daylight sensors	Associate zones w/dlight sensor
Locate daylight sensors	Connect fixtures to control bus	Associate zones w/occ sensor
Select occupancy sensors	Connect sensors to control bus	Verify occ sensor placement
Locate occupancy sensors	Connect sensors to power	Calibrate daylight sensors
Create one–line for submittal	Install and power gateway	
Create/review controls submittal	Connect control bus to hub	

How to retrofit lighting controls

Design

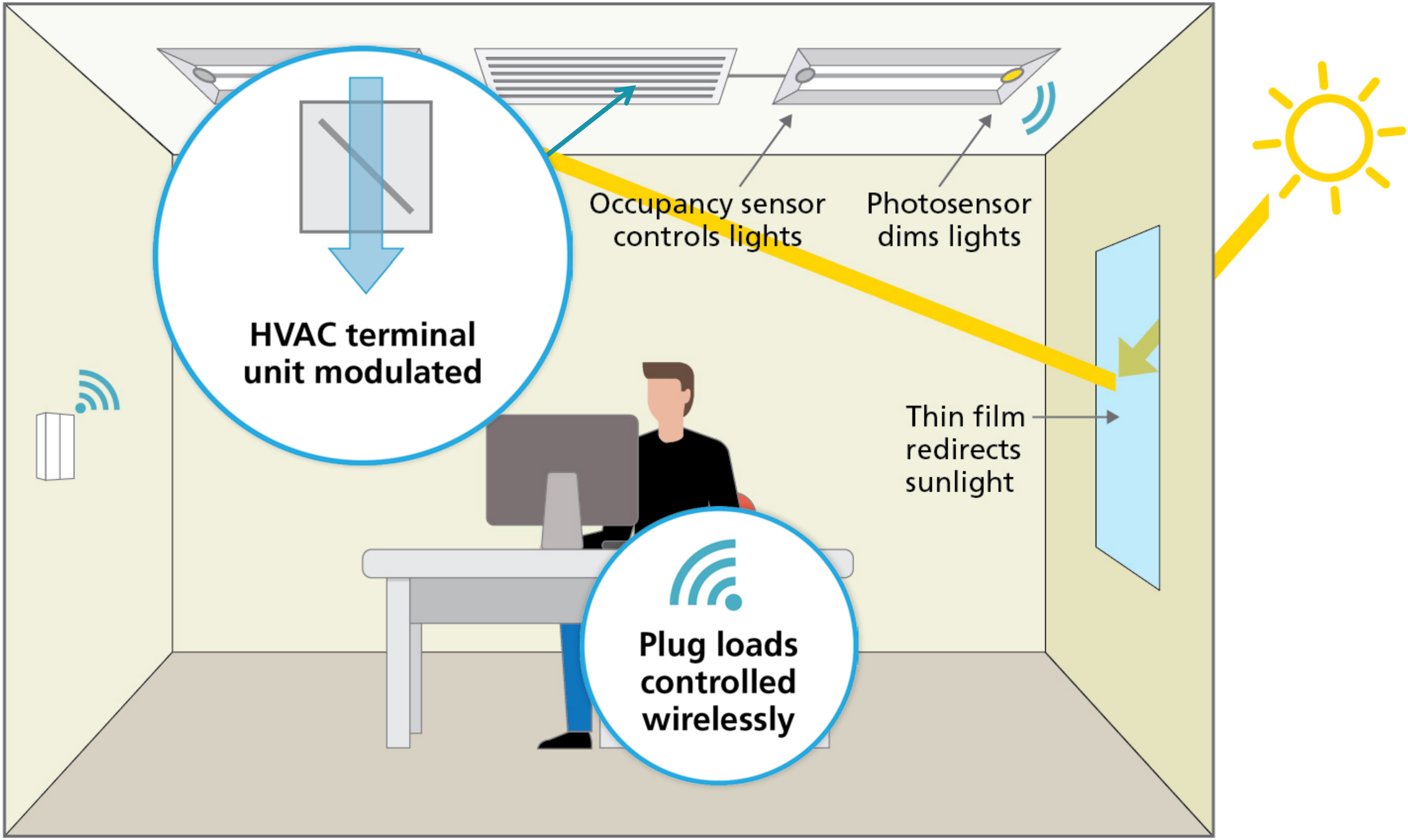
- Layout fixture locations
- Layout switch locations & zones

Installation

- Install fixtures
- Install switches
- Pull line voltage to fxt & switches

Commissioning

- Energize ltg. circuits at panel
- Automatic OneButton™ Setup

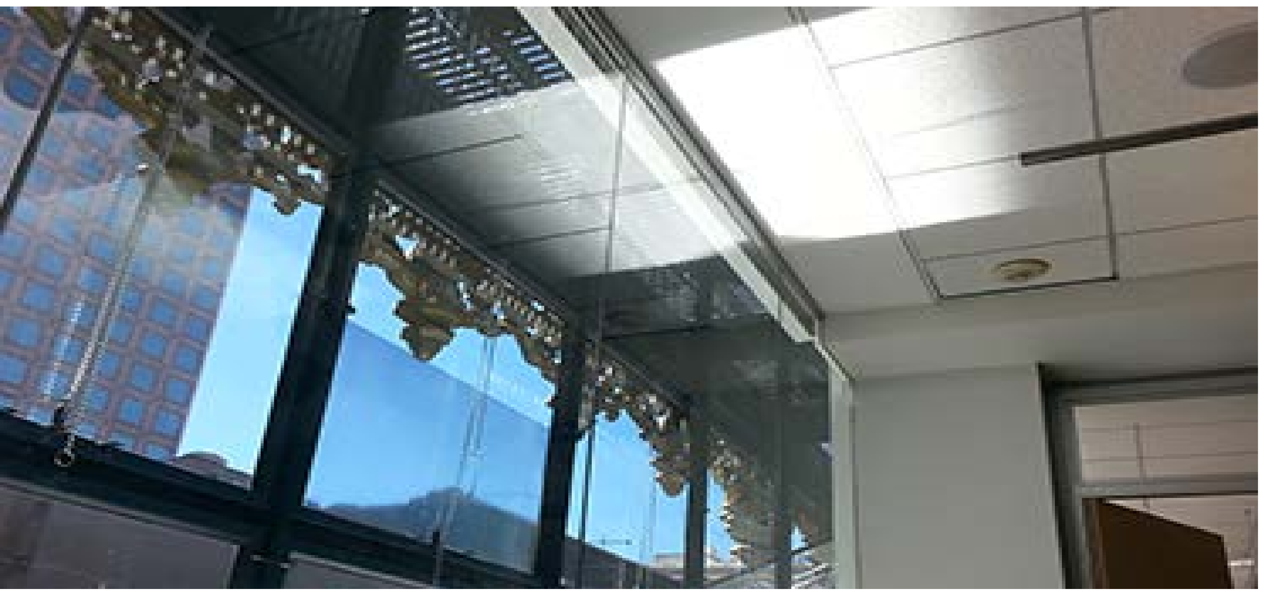


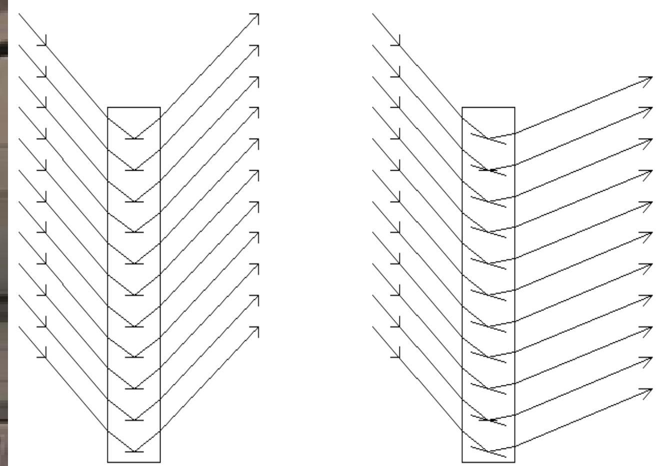
Controls tech partner: Wattstopper

OPTIONAL: daylight directing window film

Increase daylight penetration

Additional lighting control savings via daylighting





Window film partner: 10X

Site requirements

TYPE

Office space in any building type, outpatient healthcare or public spaces

LIGHTING

Presence of T8 or T12 fluorescent fixtures or other low-ceiling fixtures

SIZE

3,000 to 10,000 square feet (within any size building or stand-alone)

PREFERRED

- Some amount of daylight
- Direct digital control of HVAC

Photo by Warren Gretz, NREL 00145

Benefits of participation

- **Grant funding** to offset retrofit cost
- **First hand knowledge** of cutting-edge products
- **Hands-on experience** operating an integrated controls approach
- **National publicity** through case studies and other media
- **Free measurement and verification**


Photo courtesy of Cree

Free measurement and verification

ENERGY SAVINGS

OCCUPANT SATISFACTION | Light, controllability, comfort

COST EFFECTIVENESS | Labor, material, benefits

MAINTENANCE | Skill, time

PARTICIPATION TIMELINE

1. Identify possible spaces
2. Discuss with Seventhwave
   - Host a screening visit
   - **Accepted to program**
3. Receive funding estimate
4. Decide to implement the project

seventhwave

FOR MORE INFORMATION

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ACEEE 2020 Summer Study Presentation

Lighting controls: not just for lighting anymore!

Scott Hackel, Claire Cowan, Joe Zhou: Slipstream
Chris Wolgamott: Northwest Energy Efficiency Alliance
Michael Myer: Pacific Northwest National Laboratory

ABSTRACT

For the last few years, networked lighting control (NLCs) have promised significant energy savings beyond what is achieved through a basic light-emitting diode (LED) lighting retrofit. At the same time, NLCs can substantially increase the cost and complexity of the lighting retrofit. And as lighting system wattage declines because of the increasing efficiency of LEDs, advanced controls have less lighting energy to save and the cost-effectiveness of the NLC investment decreases. But NLCs can be leveraged to achieve significant energy savings and value by enhancing control of other building systems. Integrating NLCs with heating, ventilation and air conditioning (HVAC) controls, plug load controls, space utilization assessments, and grid services all enhance the value of your NLC investment.

There are already a few NLC products on the market that are capable of providing these enhanced benefits. Manufacturers and entrepreneurs are working hard to expand the impact of these products. But does system interoperability work? Can it be deployed at scale? Slipstream, NEEA and Pacific Northwest National Laboratory (PNNL) have all been attempting to answer these questions in recent pilot projects in a couple federal buildings, five different buildings in Minnesota, and one private building in the northwest. These projects incurred a wide range of costs, with the most typical result being about $7/ft^2. All pilot projects successfully integrated NLCs with HVAC, and most also incorporated plug load control. Each project did encounter challenges in ease of interoperability, commissioning of HVAC controls, and other items.

Introduction

The energy efficiency world has made major investments to improve lighting efficiency in commercial buildings, but the traditional approach to LED retrofits leaves energy savings on the table. Each retrofit that only improves lighting efficiency and under-utilizes daylighting and occupancy controls ignores a wealth of additional savings from deployment of an integrated control network across multiple building systems. NLC products deploy distributed sensors throughout a building to collect granular data on building operations—these can allow multiple building systems to respond to real-time feedback on occupancy, daylight, and in some cases even temperature and air quality. These sensor networks allow for optimization of lighting, heating, ventilation, and air conditioning (HVAC) and plug load control to achieve significant reductions in building energy consumption.

A number of recent initiatives and programs have promoted NLC systems for their ability to achieve deeper energy savings by advancing a more holistic approach to lighting retrofits. DesignLights Consortium (DLC) defines NLC as "the capability of individual luminaires and control devices to exchange digital data with other luminaires and control devices on the system." (Kisch, 2017). To promote broader deployment of advanced lighting controls in commercial buildings, DLC launched the Commercial Advanced Lighting Control Initiative in

2015 which included the first NLC Qualified Products List (DLC, 2020). Most programs that are incentivizing NLC today require that NLC projects be listed by DLC. Sacramento Municipal Utility District was among the first utilities to launch energy efficiency incentives for advanced lighting controls in 2012 (DLC, 2020), followed by AEP-Ohio, Consumers Energy, ComEd and others within the next several years.

Utilities in the Pacific Northwest like Puget Sound Energy (PSE) and Seattle City Light began offering incentives for luminaire-level lighting control (LLLC) in 2017 (Lane, 2019). LLLC systems can be a subset of NLC that offer more granular control and easier installation than some NLC products. Many NLC programs offer custom incentives on a per kW or per kWh basis, while some programs like Wisconsin's Focus on Energy offer incentives on a per square foot basis. PSE offers a per-fixture bonus on top of the per-kWh incentive (PSE, 2020).

As luminaires themselves become significantly more efficient there comes a limit to the cost that can be justified for advanced controls. Recent analysis of more than 4,000 projects found converting from conventional lighting to LED lighting resulted in greater than 50% average energy (kWh) savings from the equipment conversion (Myer, 2019). NLC system installed costs can be double the cost of standard lighting retrofits. These are major reasons that NLC programs have not grown as broadly as mainstream lighting retrofit programs.

One solution to the cost-effectiveness problem is integrating NLCs with other building systems. Lighting controls can now be readily integrated with Building Automation Systems (BAS) that control HVAC as well as systems that control plug load energy use. Some NLC systems offer open connectivity to building systems that provide security, space utilization and asset tracking functionality. Systems integration enhances the value delivered by each system, for example by increasing the granularity of occupancy signals to optimize HVAC performance. But it comes with a cost too – the time that is required to integrate complex systems.

This paper describes the collective experience of three different pilots around the country aimed at integrating NLC systems with HVAC and plug load controls. This year Slipstream, a non-profit that has implemented several lighting controls pilots, will be issuing the *Integrated Controls Implementation Guide* (Hackel et al, 2020) which will share more detailed guidance on how to successfully integrate NLC with other building systems.

The integration solution

The idea of a single BAS that controls all building systems has been around for many years. There have been many attempts in the past to use a single back-end control system using BACnet, LonWorks, or Modbus. Progress in the past two decades has been slow, as lighting controls generally prioritized a need for simplicity and specificity while HVAC systems prioritized a need for broad applicability. And plug load controls only became a commercially available solution in the last few years.

Historical barriers to deploying building-level control systems have included complexity, cost, and challenges with occupant interactions with the controls. Complexity must be reduced to a fairly straightforward plug-and-play connection between systems, requiring little additional labor for integration. User experience may lead to challenges with energy savings persistence; unhappy users will either turn the controls off or find a way to bypass or defeat the system. If the system does not continue to operate as intended then the energy savings made possible by the controls will never be achieved.

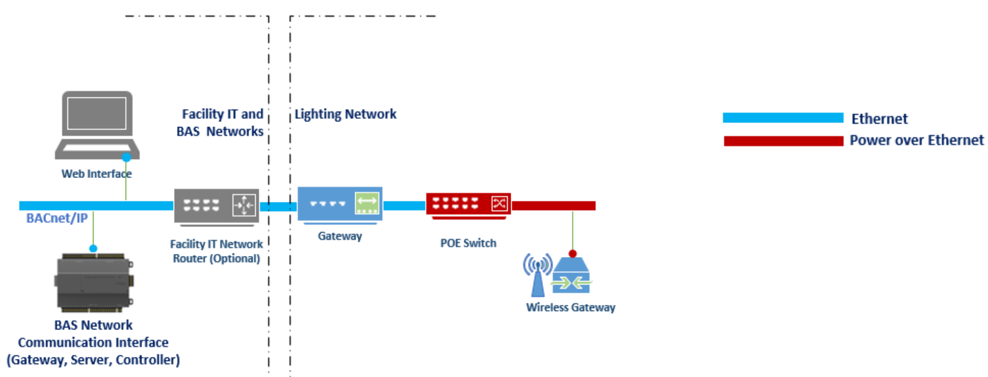
Recent technology developments

Two major shifts in technology have allowed for these barriers to be overcome: wireless LLLC and centralized system control made compatible with open protocols. These technologies developments are allowing for major improvements in how we can address the barriers of installing a whole building controls system.

Wireless LLLC are lighting products with integrated sensors and controllers that can be wirelessly networked with each other, with wall controls, and with a centralized control system. Controls strategies built into LLLC include occupancy sensing, daylight harvesting, task tuning and more. Retrofitting fluorescent lighting with LED retrofits and LLLCs achieves average energy savings of 70% (Schuetter, 2020). LLLCs are more straightforward to install than many NLC systems because sensors and control programming are already integrated into the fixture, are wireless, and include plug-and-play setup. Many products allow remote commissioning and control through an app or tablet. Available retrofit kits make this a simple install for those with existing linear fluorescent and recessed downlight fixtures. Control settings can be easily updated, so LLLCs reduce the cost of space reconfiguration or change-over to new tenants. Finally, LLLCs offer a much more granular occupancy sensing network, with a sensor in every fixture. This nearly eliminates false negative control signals (e.g., the lights turning off while the space is still occupied) which allows for more aggressive control of things like HVAC and plug loads.

LLLC systems also can be deployed with a centralized controller that observes system performance, centralizes system maintenance, and connects to other building systems (i.e. HVAC, plug loads, and non-energy systems like asset tracking). This allows most LLLC systems to be integrated with modern BASs. The general framework of integrating LLLC sensor information into a BAS is through a gateway device (Figure 1). This device can provide the BAS with an Application Programming Interface (API) and a compatible communication protocol. A public, open building controls protocol—BACnet—is the most commonly used protocol. Other protocols such as LonWorks, Modbus, or XML (eXtensible Markup Language) are also available for some systems. Through these methods, real-time luminaire-level sensor information such as occupancy, zone light level, luminaire power draw, etc. can be shared with the BAS for use in controlling other equipment, most often HVAC. Figure 1 shows an example of a typical network architecture for a LLLC system.

Figure 1. LLLC network architecture.



A number of LLLC manufacturers now deliver integration capability, and more products are in development. The product options that are currently widely available are listed in Table 1.

Table 1: More commonly used manufacturers of LLLCs

Manufacturer	Product Line	Networks	BAS Integration
Acuity Brands Lighting	nLight	Wired (nLight, Ethernet) and wireless (priopr ietary, nLight Air/Bluetooth Low Energy)	BACnet, Rest API
Cree Lighting	SmartCast	Wired (PoE) and wireless (proprietary, IEEE 802.15.4/ZigBee)	BACnet
Digital Lumens	LightRules	Wired (PoE) and wireless (proprietary, IEEE 802.15.4/ZigBee)	XML,BACnet, LonWorks, Modbus, Rest API
RAB	Lightcloud	Wireless	BACnet or Modbus
Eaton	WaveLinx	Wired (PoE) and wireless (proprietary, IEEE 802.15.4/ZigBee)	BACnet

Although BACnet, LonWorks, and Rest API protocols have allowed communication between a lighting network and a BAS, network communication protocol within the lighting systems remain nonstandard. This incompatibility prevents luminaires produced by different manufacturers from being used in the same lighting network and limits the flexibility of these applications. The DLC is currently evaluating different lighting network protocols with a goal of improving standardization in connectivity as well.

Current pilots

The remainder of this paper discusses lessons learned in using LLLC platforms to integrate multiple building systems, based on findings from three different pilots that are either recently completed or ongoing.

Energy efficiency pilot in the Midwest

Since 2018, Slipstream has been leading an integrated controls demonstration project co-funded by the US Department of Energy (DOE) and Xcel Energy. Five sites (5,000 – 15,000 ft^2 in demonstration area) were recruited in the Minneapolis/Saint Paul, MN area to use an NLC lighting retrofit as the basis of integrating lighting, HVAC, and plug load controls. The demonstration sites included: 1. a higher-education building, 2. Office building ("city operations site"), 3. Mixed-use facility ("Clinic/fitness"), 4. Office building ("Public works"), and 5. An outpatient clinic ("Clinic"). The foundation for each lighting retrofit was an LED troffer retrofit that combines energy efficient LEDs with LLLC. This solution uses wireless communication and allows for automatic setup for straightforward zoning and control programming. The integrated occupancy sensing functionality from the light fixtures is coupled to wireless receptacle-level controls to turn off plug loads when occupants are not present. Finally, each system communicates digitally with the BAS via the BACnet protocol to allow for a broad variety of HVAC efficiency measures. In 2020, Xcel Energy will use the results from this demonstration to inform development of a full-scale integrated controls incentiving program, provided cost-effectiveness and other program design criteria are met.

Federal building demonstrations

PNNL oversaw two federal building demonstrations; one by the U.S. General Services Administration's (GSA) and one by the US Department of Defense (DoD). From 2016 to 2020, the GSA GPG program evaluated the effectiveness of an LED lighting system with integral daylighting and occupancy sensors that could communicate with the building management system (Myer, 2020). Effectiveness was measured across broad criteria including energy, cost, and customer satisfaction. The study was conducted at the John C. Klucyznski Federal Building, a 43-story historic building, is located in Chicago, IL. A total of 60,000 ft^2 were retrofit.

The original lighting was a single-lamp fluorescent custom 4" wide x 4' long troffer. The lighting was replaced with custom-fit LED retrofit kit. The resultant LED system saved roughly 50% of the power compared to the original fluorescent system. Combined lighting control and internet-of-things (IoT) sensors were installed after installation of the retrofit kits. The HVAC system included a total of three different systems. The air-handling units served more than six floors. Perimeter units provided heat. Finally, some conference rooms had variable air volume units installed in the retrofit process.

The DoD Environmental Security Technology Certification Program (ESTCP) initiated in 2017 a series of evaluations of advanced lighting and controls at multiple DoD installations. ESTCP tests novel technologies for broarder integration across DoD facilities. One evaluation involved an LED system with lighting controls that interfaced with the plug loads and HVAC systems at Tinker Air Force Base in Oklahoma. The system was installed in a 21,000 ft^2 high bay space and a 5,000 ft^2 open plan office space (Davos 2020).

Market transformation initiative in the Northwest

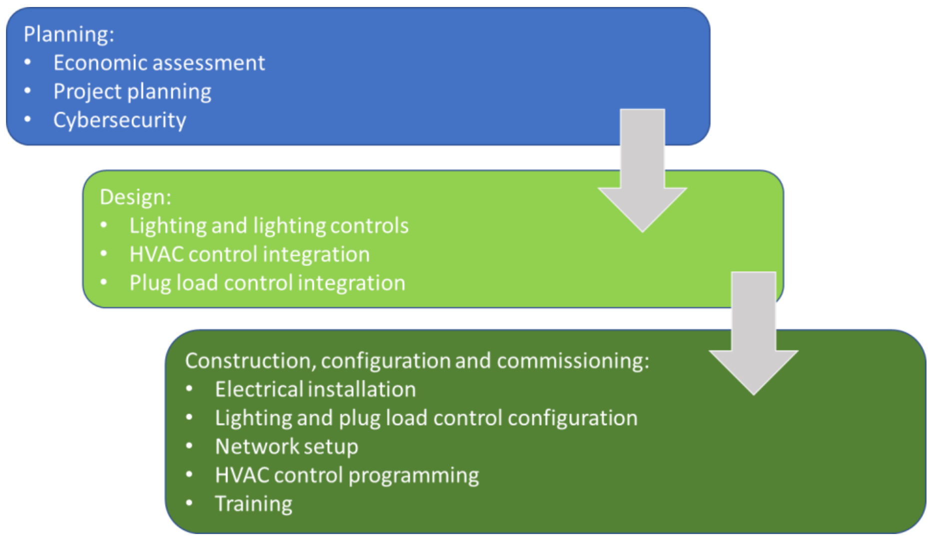
NEEA and the University of Oregon Integrated Design Lab teamed up to conduct a study an LLLC system in one building. Specifically, they were interested in using a network of temperature, illuminance, and occupancy sensors located at or near individual electric light fixtures for the purpose of localized system control, including HVAC integration. This study identified potential for LLLC and HVAC integration to reduce heating and cooling system energy consumption, improve ventilation control and resultant air quality, and improve occupant thermal comfort and workplace satisfaction through high spatial resolution of temperature and occupancy data from LLLC sensor networks.

This study occurred at a two-story 60,000 ft^2 office building with an LLLC system previously installed on one floor. Baseline performance metrics were established by documenting existing operational control sequencing, monitoring HVAC energy use and CO_2 levels, and surveying occupants. Controlled receptacles were also installed to study the energy use reduction possible from plugged equipment using this technology. Integrated HVAC and lighting control sequences were developed using LLLC temperature and occupancy data to control HVAC delivery systems, and these proposed modifications were tested against existing HVAC usage data to estimate energy and comfort improvements. A proposal to deploy and evaluate the integrated control sequence was developed and a lifecycle evaluation of the proposal was conducted. NEEA plans to use these outcomes to inform their ongoing LLLC market transformation initiative.

Barriers and lessons learned from the field

The steps that we generally followed in pilot projects are outlined in Figure 2, and can serve as a guide for others undertaking an integrated controls projects. More details on each sub-step follow in the remainder of the section (though note that design and construction steps organized by system and not process order).

Figure 2. The steps in an NLC+ retrofit project.



Economic assessment

A comprehensive economic assessment can help justify the higher cost of an NLC and systems integration investment as compared to a standard retrofit of LEDs and basic controls (actual cost data is provided in the results section). Given the broader reach of these integrated controls projects, a number of benefits are identified that should be quantified and included in the economic assessment: energy cost savings, maintenance impacts (from having remote access to zonal lighting control), space utilization or asset tracking benefits (if applicable), energy efficiency incentives, and improvements in occupant satisfaction.

Similarly, there are new add-on costs related to integration that must be accounted for: materials for lighting and controls, labor for lighting and control installation, HVAC control revision labor, and software license costs for some vendors.

Project planning

An NLC plus integrated controls (NLC+) retrofit project has a similar flow to a lighting retrofit project, but there are a number of additional steps. Given the interdisciplinary nature of these projects, its important to identify the major project roles up front, and define which steps will be led by which role. In addition to a lighting professional and electrical contractor (which are the traditional roles on a lighting retrofit), projects will also need to identify who will fill a few other roles. An HVAC control contractor is needed; we have found that this is easily filled by whoever services the BAS updates and revisions. Some institutional owners fulfill this role with internal staff; on many projects the role is provided through a service contract. A lighting commissioning technician is also needed. Many lighting vendors offer this service now and sometimes include it with the cost of the controls systems. Owners can start by checking with the lighting vendor to determine the level of support that will be provided.

One final role to fill is that of “integrator”, who will ensure that the different disciplines are collaborating, especially when it comes to troubleshooting the interface between lighting, HVAC, plug loads, IT, or other systems. Without integrator involvement we have noticed that interface issues lead to finger pointing and significant delays. With the integrator, it is easier to get everyone communicating: joint conference calls with screen shared BAS work well to resolve issues. Though Slipstream and NEEA filled that role on our pilots, its possible that energy efficiency program technical assistance providers, owner’s representatives, or ESCOs would all be able to fill this role at scale.

One last step in project planning that serves as a bridge to the design stage is to check for compatibility of two items. Key questions include:

- **Is the BAS compatible with most lighting products?** We found most systems to use BACnet communication, so the HVAC system needs to be capable of communicating via BACnet, even if this necessitates adding a gateway.
- **How might the lighting, HVAC, and plug load zones map onto each other?** We determined a method to control every HVAC system we encountered, but granularity (and therefore performance) does depend on how HVAC is zoned and whether each zone is in digital communication with the BAS.

Network design and integration

Network design. Whether the lighting control platform is wired or wireless, it will at some point need to connect to the wired networks serving other building systems. Early in design, determine which building networks will be connected to the lighting controls. The BAS network is of course the minimum requirement. We had some sites that also connected to an additional VLAN to better facilitate connection to the BAS and the cloud. Regardless, project teams should determine whether these network connections will require IT support for either access or to meet cybersecurity protocols; both of these interactions should begin as early as possible in the process.

The connection itself may only require a simple CAT cable, but it is important to confirm that the BAS gateway (e.g., a JACE) has open ports and is in a reasonable location for connecting the cable. We did need to install additional networking hardware on some sites (and on at least one site we ran into compatibility issues with that added hardware). In general, though, the physical connection was easy in pilot sites.

Cybersecurity. Introducing NLCs that communicate with other building systems will involve some level of cybersecurity review. In planning any integrated controls project, this issue should be discussed with building owners up front, and any IT constraints should be identified early. At a bare minimum, the system must include an operational technology (OT) connection to the BAS. Beyond that, there is some flexibility in system design.

For example, both the GSA and DoD projects were intending to utilize a cloud-based IoT energy management system. However, for cybersecurity reasons, the systems were "islanded" meaning a server on-site, without an internet connection out of the building, to act as a "cloud" and on-site staff had to interface with the server for information or to modify the system. Islanding was only one cybersecurity step in the process. Both the GSA and DoD conducted security tests of both the devices as well as software. The GSA has a significant testing protocol, which took roughly a year to pass. Not all of the software could address GSA's requirements and therefore could not be deployed on site. This type of testing could possibly be a barrier to other sites, especially if testing has to be repeated for the same vendor or if an organization has to test three vendors in a multi-name specification. Federal agencies may be able to re-use the same manufacturers on such systems, but that limits multi-name specifications, flexibility, and competition.

Interoperability. Once the network is set up and secured, the various building systems must begin talking to one another. The most common protocol for communication is BACnet. However, not all BASs use BACnet and manufacturers are developing additional APIs to assist with integration. Regardless of protocol, this is where interoperability issues between systems will come to light.

One common issue is a bad CAT cable installation. Common failure points with CAT cables are at the plug ends due to incorrect placement of the plug or a physically broken connection. The cables should also be tested. Software and ports can also be potential sources of failure. At one of the demonstration sites, the switch was not compatible with the lighting system. During the installation at a few of the sites, the firmware version needed to be updated on BAS or lighting units to the latest version.

The GSA site's HVAC integration was affected by some routine HVAC system upgrades. Following the initial lighting and HVAC integration, JACE devices were replaced without notifying the demonstration evaluation team. The JACE devices and the HVAC integration device communicate with each other via BACnet over IP. Months after lighting and HVAC integration, the project was conducting an analysis as part of the field evaluation and discovered that for one floor the BACnet property that defines the port had nothing selected and for another floor, the incorrect port was selected. Similar events occurred elsewhere. During the installation of the first sites in Minnesota, the port names were not consistent with the BACnet assumptions of the BAS. Thus, the ports for the lighting system had to be renamed to allow for BACnet communication.

If utilizing BACnet, there may be issues related to the BACnet license. At one of the field sites, adjustments to the existing BACnet license were necessary, which added time and cost. As stated earlier, not all systems will be IoT, however, some might need access to the internet during the integration process. Not all IT networks allowed access to the internet because of security concerns.

Lighting control design and configuration

The design process for integrated controls systems differs depending on whether the project is large enough to include a lighting design professional or if the electrical contractor is handling that role. Lighting design professionals are usually involved in new construction projects; either approach is common in renovations and retrofits.

Regardless, the first step is a conversation with the owner or user of the space to understand expectations and plan proper sequence of operations for the spaces. The manufacturer of the controls system should also be consulted to ensure they are aware of the expectations for the controls, identifying any expectations outside the norm. If possible, prior to construction a small test mockup of the lighting and controls should be done to verify that lighting and controls operate as expected, though this is not always possible due to cost. In some cases, especially retrofits, a lighting design professional will not necessarily be part of the project. In this situation, hopefully both design and installation cost can be saved by making it a 1:1 retrofit and allowing either contractor or distributor to handle the minimal design tasks that are necessary.

The controls design tends to be simple as well, consisting of determining the occupancy, daylighting, and high-end trim settings for each of the major zone types. The high-end trim setting is best determined using photometric analysis prior to installation, as opposed to trying to measure light levels in the space afterward. Often the lighting distributor or manufacturer's representative can help with photometrics.

Finally, some thought is needed as to how to zone the control system. Individual private offices make for clear zoning, but many larger spaces such as open offices, corridors, large classrooms, and others need additional consideration. To maximize energy savings, lighting zones should align well with HVAC zones, and be as small as possible while remaining efficient. At one of the field sites, this required some considerable coordination, where there weren't even drawings that clearly showed the HVAC zoning. But it was surmountable.

For both new construction and retrofit work, more fixtures in a space means more programing and startup related challenges. For example, at the GSA facility (500 fixtures in each 20,000 ft^2 floor), it was believed that each sensor was commissioned. Yet a data visualization process helped to determine that a few of the sensors were responding to daylight signals when no daylight really existed.

Configuration and commissioning. Once lighting and controls hardware is installed, it will not be fully operational until the system is configured. The following control parameters must be configured after installation:

- Luminaire and wall control grouping (smaller zones are usually best)
- High-end trim (with possibly different levels for auto-on and manual)
- Occupancy parameters (vacancy mode, timeout)
- Daylighting tuning

Vendors supplying the configuration service are not necessarily motivated to maximize energy savings, so the lighting professional should prepare a "controls matrix" defining each of these parameters for each of the major zones. An example controls matrix is shown in Figure 3.

Figure 3. Controls matrix for communicating proper configuration of lighting zones

Space Name	Control Mode	Occupied Level	Unoccupied Level	Occupancy Timeout	Task Tuning Percentage	Notes
Office	Manual On, Auto Off	100%	0%	10 mins	75%	
Procedure	Auto On, Auto Off	90%	5%	10 mins	100%	*auto on to 50 fc*
Circulation	Occupancy	100%	0%	10 mins	100%	
Nurse Station-desk (north)	Manual On, Auto Off	100%	0%	10 mins	95%	
Nurse Station (north)	Manual On, Auto Off	100%	0%	10 mins	60%	
PT Exam	Auto On, Auto Off	100%	0%	10 mins	80%	
Office (records)	Manual On, Auto Off	100%	0%	10 mins	100%	
Office (room 1073)	Manual On, Auto Off	100%	0%	10 mins	70%	

The configuration process and reasoning behind the settings should be taught to the building operators both so they can make future adjustments and so they do not disable important control parameters. Furthermore, materials should be provided to educate the occupants of the spaces about the NLC+ system, around the time of control configuration.

Examples of configuration issues. At the DoD site that PNNL field validated, the occupancy sensors in just one of the new types of luminaires installed were not commissioned properly and yielded false positive readings in the middle of the night when the space was unoccupied. Because the lighting occupancy sensor is also communicating with two other systems, the false positives were not only resulting in increased energy usage of the lighting system, but also the HVAC and plug load systems. Once this issue was discovered, the sensors were adjusted and behaved properly. This is especially notable because other equipment installed by the same vendor worked fine. This building had greater scrutiny as part of a field validation, but similar configuration issues can occur on any job. As a result, we would recommend spot checking all control parameters to ensure they are fully commissioned.

At the higher education field site, the high-end trim was set relatively aggressively for energy savings. Their strategy was to save as much energy as possible, and make adjustments for any users with resulting issues. The lighting controls technician simply returned to the site after the system was in operation for a period of time and adjusted the high-end trim in a few spaces where occupants had related concerns, leaving the aggressive settings in most places. This strategy may only work for certain types of organizations.

HVAC control

The intent of integrating the LLLC system with HVAC controls is to utilize the LLLC's granular occupancy sensing capabilities to better control HVAC equipment based on occupancy status or level. New sensing capabilities such as air temperature, relative humidity, and carbon dioxide levels may be added to LLLC products in the future, further improving the granularity of data available to inform HVAC control strategies and optimization of energy performance. HVAC integration can occur with just about any system type with a compatible modern BAS (see *Project* planning section in this document for more detail on system compatibility).

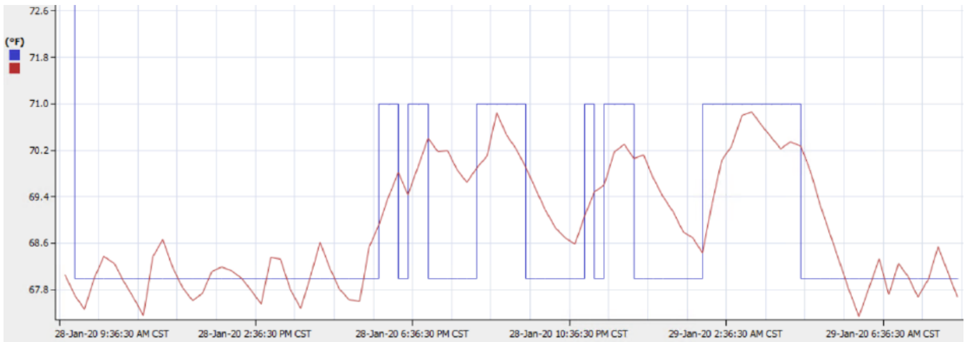
The first step in HVAC control integration is making sure the new LLLC control zones match the existing HVAC control zones. The HVAC control zones are largely driven by existing HVAC system design and thermostat or terminal unit locations. The new LLLC control zones, which can be relatively easily configured based on luminaire and light switch locations and space usages, should be designed to match up with the existing HVAC control zones as closely as possible. Zone matching need not be on a one-for-one basis. Multiple lighting control zones can often be part of a larger HVAC control zone, and effort should be made to maximize the use of the granularity of the LLLC sensors.

The next step is custom HVAC control sequence design. The control sequences can be written by a design consultant if desired, but it may be more cost-effective to have them written by a mechanical or controls contractor who is responsible for HVAC system maintenance. The goal of designing custom HVAC control sequences is to fully utilize the available luminaire-level sensor signals. A useful reference for air-handling unit (AHU) + VAV systems is ASHRAE Guideline 36, *High-Performance Sequences of Operation for HVAC Systems*, which provides specific sequences for integrating occupancy signal, window switch, or CO_2 signal (future capability) for demand-controlled ventilation (ASHRAE, 2019). The integrator should first review the existing HVAC system design, control system schematics and sequences, and incorporate demand-controlled logic and LLLC sensor signals to customize the existing control sequences. At a minimum, basic measures such as zone airflow and thermostat adjustment should respond to occupancy signals.

In HVAC control integration utilizing BACnet, an additional BACnet license may be needed on the BAS side. Some LLLC manufacturers also will charge a subscription or license fee for each BACnet object (one sensor signal counts as one BACnet object). This may impact the project cost and future operating and maintenance costs if additional objects are needed. One option is to combine multiple sensor signals in one lighting control zone into one BACnet object, reducing the total number of BACnet objects needed for HVAC control, though this creates a trades off with additional programming requirements. The custom programming of the new control sequences should be done by a trained or certified controls technician who is familiar with the existing BAS, the proprietary BAS programming tool, and the HVAC equipment.

Commissioning. The integrator or project manager should oversee commissioning or functional testing of the HVAC system. It should not be assumed that the HVAC system is operating entirely as expected; often changes like reset schedules are needed even after the controls contractor stated they were complete. One simple method we used for commissioning was to request screen shots of trend data or BAS graphics once systems were operational (see Figure 4).

Figure 4. Example trend chart for verifying HVAC response to occupancy signals.



Depending on system size and complexity, the commissioning process may require significant labor. The GSA facility that PNNL measured, with a large number of parts included, was an example of a scenario in which it was very difficult to verify operation of each control element.

Plug load control

In an integrated system, receptacles (i.e., outlets) in a space can be controlled based on occupancy. When the NLC system shows that the space is unoccupied, it sends a signal to the receptacles, shutting them off. Similar to lighting design, conducting a site visit is the first step in designing plug load controls. During the visits we determined which receptacles should be controlled. Our site contacts were helpful here, especially identifying receptacles that should not be controlled such as desktop PCs, refrigerators, and critical battery chargers. Information gathered during the visit allowed us to create drawings showing the location of each controlled receptacle and notes identifying whether a given receptacle should be half- or full-controlled receptacles, receptacle color, etc. The drawing also helps to identify which control zone each receptacle is being connected to.

The cost-effectiveness of a controlled receptacle is heavily dependent on the wattage of devices installed that are likely to be left on overnight. Good candidates for control include: monitors, printers, water coolers, exercise equipment, and any equipment with large parasitic energy loads. Low-wattage equipment are generally not cost-effective candidates for plug load control. The DoD project was an extreme example, where plug load controllers had an approximate installed cost of $669 per unit including material costs ($155) and labor ($513). The yearly energy savings per plug load unit averaged only 1.7 kWh, resulting in a measure where the costs could never be recovered. But the DoD site only implemented plug load control on a limited number of receptacles in the space and allowed occupants to self select the loads to connect to the controlled receptacles. The receptacles were also more labor intensive than normal at this site. More discerning plug load selection limited to only very high wattage receptacles would improve the cost-effectiveness assessment.

In the future we would also give more consideration to whether wired or wireless control is more cost effective for each situation. Wireless receptacle controls make retrofits easier and improve future flexibility, but powered cubicle furniture is simpler to retrofit directly at the power drop; one circuit leg of each furniture feed can be controlled (most such furniture has two or more circuits), controlling multiple cubicles.

Installation and configuration of plug load controlsPlug loads may be the simplest (from a technological point of view) of the three building systems to control, but there are still some challenges to overcome. In a retrofit scenario, adding controls will require some level of rewiring the existing receptacles. The same electrician performing the lighting retrofit can also install controlled receptacles, at an increase in their labor time for the job. Installation of the plug-load controllers involved re-wiring each receptacle that was connected to a controller and configuring the schedule and behavior of the plug-load control in energy manager software.

The plug load control retrofit process also involves extensive communication with the space occupants. Occupants need to be informed about the process because certain devices will be unplugged, receptacles re-wired, and then the loads plugged back in. This can cause resetting of clocks or other disruptions that, without adequate communication, can lead to frustration and dissatisfaction.

Identifying controlled receptacles is paramount. Consider purchasing different colored receptacles to indicate which ones are controlled versus not controlled so occupants can easily distinguish between them. Some manufacturers provide stickers indicating that the receptacle is controlled. Beyond indicating that the receptacle is controlled, it is beneficial to provide information about what equipment should ideally be installed in a controlled receptacle. At all sites in the Minnesota pilot, the plugs were labeled “controlled” and “uncontrolled”. An explanation was provided as to the differences between these type of plugs. However, more and permament information (e.g., a flyer in communal areas) indicating which equipment should be ideally on each type of plug was not provided to the occupants.

Plug load controllers are introducing another level of complexity to the space beyond simple physical on/off switching. At the DoD installation there was an initial firmware issue with the plug load controllers connecting the larger control device. This was discovered and resolved (2 hours of electrician labor time), but firmware could create new levels of integration than simple wiring.

Future potential

This is an ongoing area of research. Our few pilot projects suggest some direction for the future, but do not yet offer a definitive conclusion on overall cost-effectiveness. We are able to offer conclusions in three areas: economics, scaling of this market, and recommendations for efficiency programs.

Current economics

First cost. At the present time we do have more data on the first costs of these systems, but annual cost savings data will not be available until energy savings data are complete. Table 2 contains cost data for seven buildings that have been observed across the three authors’ organizations.

Table 2. First costs for integrated controls retrofits.

	Area (ft^2)	Installed cost, per ft^2					
		Lighting material	Lighting labor	Plug load materials	Plug load labor	HVAC	**Total**
Higher education	25,000	$2.27 (43%)	$2.37 (45%)	$0.21 (4%)	$0.07 (1%)	$0.37 (6%)	**$5.30**
City operations	13,100	$2.95 (36%)	$4.02 (49%)	$0.25 (3%)	$0.08 (1%)	$0.88 (11%)	**$8.18**
Clinic / fitness	7,300	$4.41 (40%)	$4.52 (41%)	$0.42 (4%)	$0.14 (1%)	$1.60 (14%)	**$11.08**
Public works	11,300	$2.93 (39%)	$4.07 (54%)	$0.15 (2%)	$0.05 (1%)	$0.38 (5%)	**$7.58**
Clinic	12,400	$3.01 (51%)	$1.99 (34%)	$0.16 (3%)	$0.06 (1%)	$0.64 (11%)	**$5.86**
GSA - Chicago	60,000	$3.86 (40%)	$4.89 (51%)	N/A	N/A	$0.83 (9%)	**$9.58**
DoD - Oklahoma	26,000	$2.65 (56%)	$1.29 (27%)	$0.13 (3%)	$0.30 (6%)	$0.38 (8%)	**$4.77 (100%)**

There is recent pilot cost data available from much broader pilots of LLLC programs (Kisch 2019 and NextEnergy 2020) that suggests LLLC systems with integration capability can be installed for between \$4-5/ft^2. This aligns with a few of the sites in the table, but suggests that Clinic/fitness and GSA-Chicago are potentially outliers on the cost of their lighting system alone (integration aside). This is not directly related to the technology, but also the nature of the sites. The Clinic / fitness site and GSA – Chicago both required work during off-hour periods which is more expensive. The average total cost of integrating the three control systems across the remaining five sites (without the outliers) was \$6.38/ft^2.

Lighting cost. The lighting portion of these projects should cost \$4-5/ft^2, but may be as high as \$7-8/ft^2. Lessons learned about lighting costs:

- *Materials:* Keep lighting retrofits to 1:1 fixture replacement wherever possible. Where spaces are simple and 1:1 replacement is possible, it is possible for the contractor and distributor to handle the lighting design to save on soft costs.
- *Labor:* Four sites had labor rates of $ 4 / ft2 or greater. This is not directly related to the technology, but also the nature of the sites. The Clinic / fitness site and GSA – Chicago both required work during off-hour periods which is more expensive.

Plug load control cost. For clarity, Table 2 used the same site size across all building technologies to calculate the costs per square foot. However, plug loads were selectively deployed and the actual costs were actually much greater than \$0.20-0.45/ft^2. For example, the

DoD facility only had 15 receptacles in a 5,000 ft^2 portion of the space. Thus the actual cost is closer to $2.00 / ft^2 for labor and materials. The plug load labor in the DoD facility is likely an outlier. The firmware communicating between the controlled receptacle and the lighting system required an update at each receptacle adding more than two labor hours per receptacle.

Lessons about related to plug load costs:

- *Materials:* Plug load controls are generally on the order of $100-200 per unit for materials. Target receptacles with large power devices in your space.
- *Labor:* Plug and play receptacles is necessary to reduce labor costs. The firmware at the DoD facility was out of date and required update at each receptacle adding more than two labor hours per receptacle.

HVAC integration cost. There is also a cost for the HVAC controls component of the work. This cost is primarily contractor-related labor (e.g., electrical contractor connecting lighting and mechanical system, HVAC control technician simply accepted the new data points and revised control sequences to incorporate them, per our specifications) and not HVAC equipment. As shown in Table 2, the HVAC component of projects cost anywhere from $0.4/$ft^2$ to over $1/$ft^2$ in the worst case. Costs near and greater than $1.00/$ft^2$ negatively affect the cost effectiveness of the project. This cost is primarily mechanical contractor-related labor and not equipment. At five of the sites, this category represented almost 10% of the total costs.

Integrating lighting with HVAC is somewhat novel, therefore it is still hard to determine what type of cost will be normal. In most of these seven sites, limited equipment was needed to integrate the lighting with the HVAC. Therefore, the costs are mostly driven by labor. Labor times varied heavily depending on the system and the sophistication of the contractor. If the facility has smaller HVAC zones, responsive equipment (e.g., VAVs), and a contractor with integration experience, shorter payback periods should be typical.

Lessons about related to HVAC costs:

- *Materials:* Most sites did not require equipment for integration. The DoD facility's HVAC integration process required some hardware that cost roughly $3,300 to integrate with two air-handling units.
- *Labor:* Some large owners took on this task using their own in-house control technicians, which eliminated any direct labor component to the project; though there is an opportunity cost associated with dedicating that person's time to the integrated controls project instead of another organizational priority. In contrast, the GSA facility's mechanical contractor required hundreds of hours of labor related to the integration.

Energy cost savings. The energy and maintenance cost impact from our pilots is still being measured.[1] Energy savings has only been fully established at the DoD site. There, the lighting-driven systems integration process reduced HVAC energy use by 30% in the high bay and 12% in the office spaces. The retrofit saved 70% of the energy for the lighting system and reduced plug load energy use by 4%. The specific devices connected to the controlled and uncontrolled receptacles were not recorded in the pre and post phases. However, the metered

[1] Note that some of this will hopefully be available by the time of the final version of the report.

data did indicate an increased load to the non-controlled receptacles in the post-phase. Active on-site device management of controlled and uncontrolled receptacles could have resulted in greater energy saivngs. Total annual energy saved from the controlled receptacles was 25 kWh. Typical savings from controlled receptacles came in the off-hours and weekends when the space was not occupied.

Cost Effectiveness. The energy and maintenance savings from many of the sites is still being measured. Energy savings has only been fully established at the DoD site. There, the lighting-driven systems integration process reduced HVAC energy use by 30% in the high bay and 12% in the office spaces. The retrofit saved 70% of the energy for the lighting system and reduced plug load energy use by 4%. The specific devices connected to the controlled and uncontrolled receptacles were not recorded in the pre and post phases. However, the metered data did indicate an increased load to the non-controlled receptacles in the post-phase. Active on-site device management of controlled and uncontrolled receptacles could have resulted in greater energy saivngs. Total annual energy saved from the controlled receptacles was 25 kWh. Typical savings from controlled receptacles came in the off-hours and weekends when the space was not occupied.

The DoD facility had below national averae utility rates. Using national average rates, (U.S. Energy Information Administration, $0.1041 average commercial electricity, $7.78/MMBtu average commercial delivered to consumers natural gas price), the total savings at the site is $15,206 ($6,935 from lighting, $8,269 from HVAC, and $3 from plug loads). The monetary savings generated from the HVAC energy savings lowers the overall simpe payback of the project by almost half (14.8 years lighting energy only → 8.2 years lighting + HVAC energy). This demonstrates that including the HVAC integration into the lighting system increased the cost-effectiveness of both systems.

Scaling the Approach

LLLC cost-effectiveness may improve in the future, as hard and soft costs decrease and project implementers learn to capture more savings with each system. A number of developments should contribute to an improved economic outlook in future:

- System architecture becomes increasingly plug-and-play
- Electrical and mechanical contractors grow more comfortable with integration tasks
- Cost premiums for LLLC decrease
- More complete HVAC control retrofits are established using tools such as *ASHRAE Guideline 36*

Of course this technological approach will suffer from the typical hurdles of the early part of the innovation adoption curve. Additional demonstrations, pilots, and supporting educational activities will be required to reach a significant level of scale such as:

- Market transformation to train contractors and lighting professionals and to work with manufacturers on simplicity and cost

- Establishment of specifications for new construction and tenant build-outs (Mathew, 2020)
- ESCO adoption of the measure
- Procurement programs to increase scale and reduce cost
- Energy efficiency program support and incentives (see next section)

If NLC+ projects are made to be broadly cost-effective, there is large savings potential from such holistic retrofits, given how broadly applicable this opportunity is in commercial buildings. Slipstream estimated the *technical* potential nationwide to be over 300 TBtu per year. This is based on the percentage savings seen in our initial projects discussed above, applied to CBECS baseline energy usage for applicable building types (EIA, 2012).

Energy efficiency program considerations

Energy efficiency programs have traditionally helped to increase the adoption of energy efficient products in commercial buildings. Past program interventions have tended to be widget-based, with lighting, controls, and HVAC addressed through siloed incentive offerings. In order to move beyond LED lighting savings, programs will need to shift away from paying for widgets and move to paying for improvements in system or building-level performance. Some programs are experimenting with pay for performance approaches, such as an incentive rate per kWh saved by new equipment or operational changes. This kind of program strategy has more flexibility to combine multiple measures to achieve deeper savings. Holistic system-based solutions, such as the integrated controls approach discussed in this paper, is another path to deeper savings. System-based program offerings are rare, but integrated controls retrofits are one possible example of an energy efficiency opportunity that could change this paradigm through a standalone program offering or inclusion in existing programs such as lighting controls, new construction, or energy management.

Finally, the timing of energy use is also going to become a more important driver of savings than the amount of energy saved. Program administrators may focus more on incentive programs for peak kW, demand response, load shifting, or load shaping. Integrated control systems have the ability to satisfy a few of these needs through a single intervention. Broader deployment of lighting-based integrated controls projects is an opportunity to drive the systemic change needed for large-scale carbon reduction.

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Xcel Stage Gate Flow Chart

For certain types of projects, the decision can be made to walk through stages at accelerated rate and only have 1 Go/ No go decision Gate at the end

Ideation → Gate 0 Ideation → Define the Problem → Gate 1 → Define the Solution → Gate 2 → Develop Business Model → Gate 3 → Build the Product → Gate 4 → Launch the Product → Post-Launch Review

Ideation

Primary Question
Is this idea the next best product to invest in?

Ideation Deliverables
- Idea description
- Strategic fit
- Cost to develop
- Benefits at steady state
- Business confidence
- Technology confidence

Gate Keeper
- Portfolio Management Board

Decision Criteria
- On an approved roadmap?
- Resource availability
- How much time/money to spend in stage 1 and 2?

Stage 1

Primary Question
Do we understand the true customer problem enough to generate possible solutions?

Product Deliverables
- Target Market Analysis
- Problem definition
- user stories

Activities
- Targeted customer and stakeholder discovery on identified problem(s)
- Refine / define new problem statements ideation process
- Define and analyze the target customer market
- Test problem statements with customers
- Define customer user stories

Project Management Deliverables
- Risk Assessment
- Project Charter
- Scoring Summary update
- Updated Workplan

Gate Keeper
- One level up from PO

Decisions made:
- Approval to move to stage 2
- Resource approval for stage 2

Time/Effort Consumed: 10%
Percentage of Total Project Cost: 5%
Resources Assigned: PD, PM, EEE, Customer Insights, CX

Stage 2

Primary Question
Do we have solutions that solve the customer or market problem?

Product Deliverables
- Value Proposition Canvas

Activities
- Generate solutions
- Create prototypes
- Test solutions with customers
- Develop truth statements
- Work breakdown for stage 3

Project Management Deliverables
- Risk Assessment
- Project Charter
- Scoring Summary update
- Updated Workplan

Decision Maker
- Cross-functional management team (EEE, PM, DSM Reg, PD)

Decisions made:
- Approval to move to stage 3
- Resource approval for stage 3

Time/Effort Consumed: 10%
Percentage of Total Project Cost: 10%
Resources Assigned: PD, PM, EEE, Customer Insights, CX

Stage 3

Primary Question
Is our selected business plan able to achieve initial objectives?

Product Deliverables – not all deliverables required for a no-go recommendation
- Solution Prototype
- Define Name
- Portfolio Fit
- Business Model Canvas
- Financial Analysis
  - Potential Forecast
  - Draft TAs
  - Costs/revenues

Activities
- Test hypotheses in order through prototypes and customer interactions and/or analysis
- Build out business model components using BMC
- Compile financial Analysis
- Name the product and determine portfolio fit

Project Management Deliverables
- Risk Assessment
- Project Charter
- Scoring Summary update
- Updated Workplan

Gate Keeper
- Cross-functional management team (EEE, PM, DSM Reg, PD)

Decisions made:
- Approval to move to stage 4
- Resource approval for stage 4

Time/Effort Consumed: 30%
Percentage of Total Project Cost: 20%
Resources Assigned: PD, PM, EEE

Stage 4

Primary Question
Are we ready to launch?

Product Deliverables
- Final Customer Journey Map
- Sourcing
- Marketing Plan
- Final Operations Plan
- Regulatory Filing
- IT Systems Build
- Training
- Website development

Activities
- Execute product plan
- Web Development
- Collateral Development
- IT Architecture build (including SFDC calc)
- Testing with customers
- Regulatory Filing
- Update metrics for success
- Update ops plan & go-to-market strategy

Project Management Deliverables
- Risk Assessment
- Project Charter
- Scoring Summary update
- Launch Plan
- Post Launch Work plan including reporting
- Project post mortem/lessons learned on process

Gate Keeper
- Cross-functional management team (EEE, PM, DSM Reg, PD)

Decisions made:
- Approval to move to launch
- Resource approval to launch

Time/Effort Consumed: 40%
Percentage of Total Project Cost: 45%
Resources Assigned:
PD, PM, EEE, SMEs as needed from reg, IT, etc

Stage 5

Primary Questions
Is the product delivering projected benefits?

Timing – decided in Gate 4

Product Deliverables
- Report on metrics, test plan, results, issues
- Updated processes and biz model components

Activities
- In-market testing
- Customer feedback
- Clarify/refine processes based on feedback
  - Training
  - Monitor metrics

Project Management Deliverables
- If needed, new development workplan

Gate Keeper
- Cross-functional management team (EEE, PM, DSM Reg, PD)

Decisions made:
- Any changes or adjustments needed?

Time/Effort Consumed: 10%
Percentage of Total Project Cost: 20%
Resources Assigned: PD, PM, EEE, SMEs as needed from other orgs

Build – Test – Design – Gather Customer / Stakeholder Feedback in Iterations

Xcel Stage Gate Flow Chart

Last Update: 5/16/2018

Xcel Presentation of Preliminary Results

Minnesota integrated controls demonstration

Lighting, HVAC and plug load control

Scott Hackel, Jennifer Li, Joe Zhou, Claire Cowan

December 2, 2020

slipstream

Agenda

- Presentation
  - Demonstration overview
  - Energy savings impacts
  - Project economics
  - Lessons learned
- Workshop
  - Program integration opportunities
  - Marketing/outreach strategies
  - Incentive strategies
  - Resources to support program delivery

Integrated Control Retrofits:

Lighting + HVAC + Plug loads

Research goals

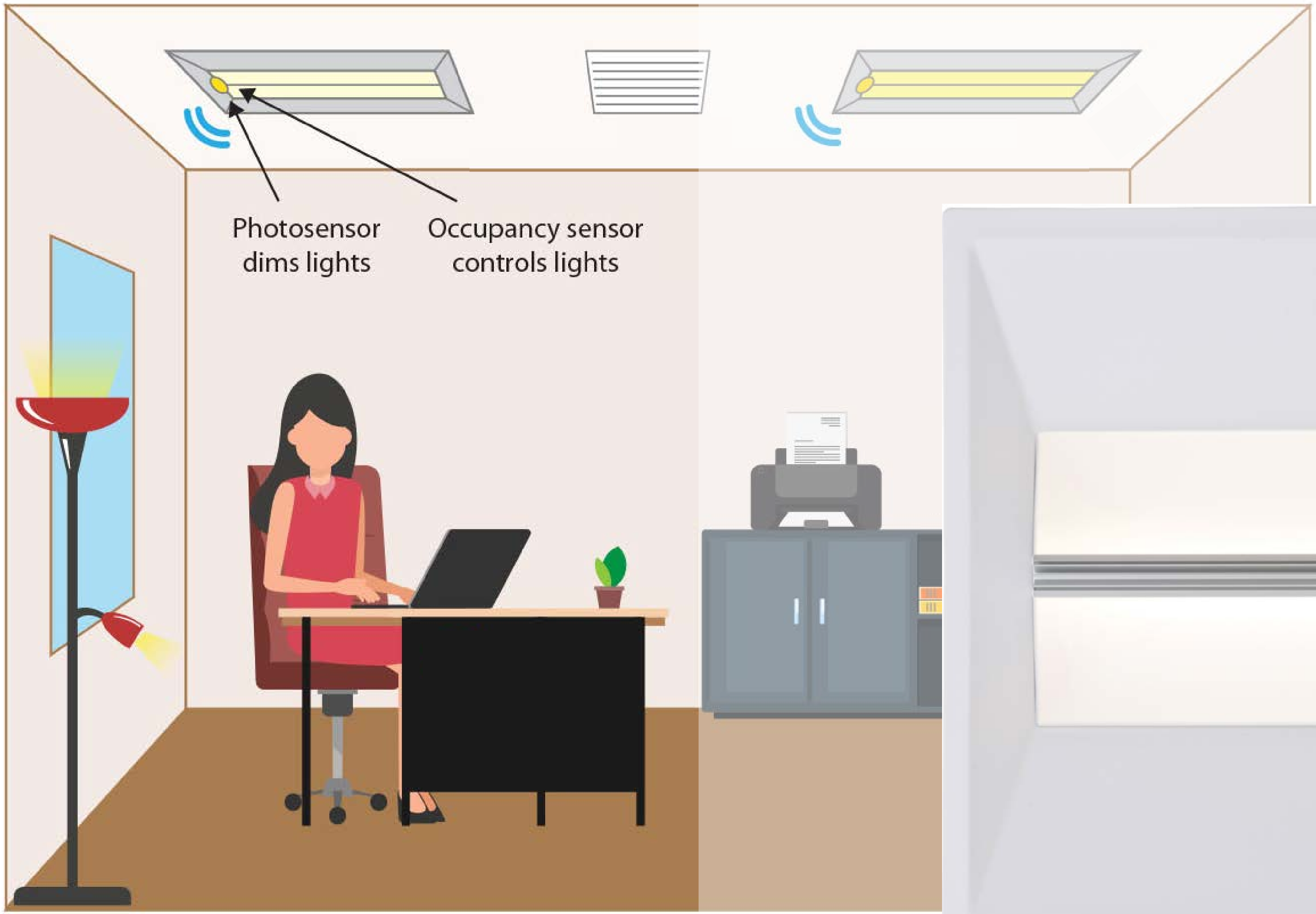
- Develop and test a retrofit approach for integrating networked lighting controls (NLC) with HVAC controls and plug load controls
- Quantify energy savings impacts and project economics at five sites
- Distill barriers and lessons learned
- Assess opportunities for integrating this approach into energy efficiency program delivery

Traditional Energy Retrofit

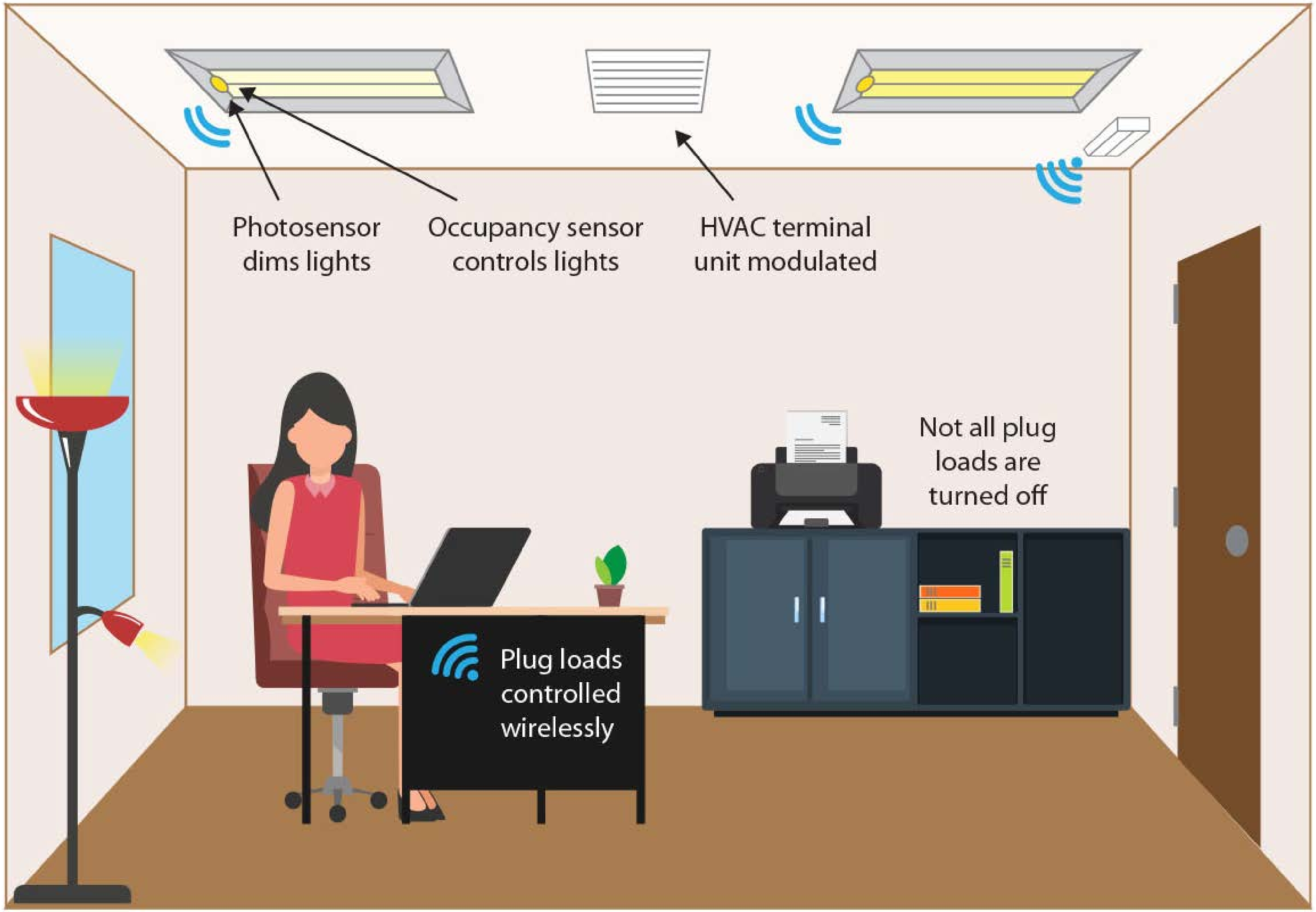
~50% lighting savings

3-8% total building energy savings

Luminaire Level Lighting Controls



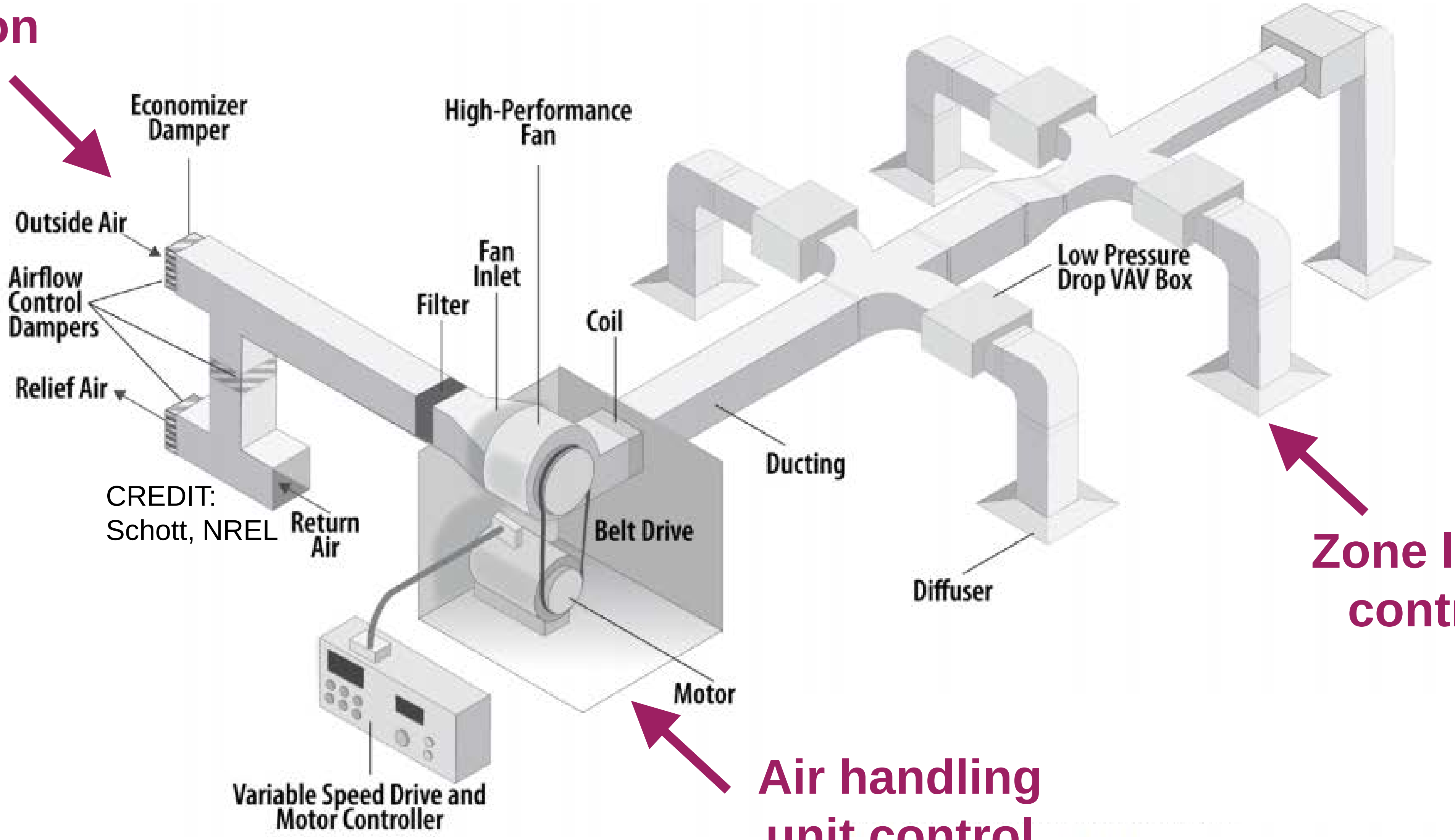
Fully Integrated Controls



25-35% total building energy savings

HVAC Control: VAV

Ventilation control



CREDIT: Schott, NREL

Zone level control

Air handling unit control

HVAC Control: Basic single zone equipment

Non-energy benefits

- Occupant satisfaction
- Improved IEQ and health
- Simplified maintenance
- Better space utilization

Minnesota Sites

Demonstration overview

Timeline: 9/2017 – 12/2020

5 retrofit sites

1. MN DOT truck facility
2. CentraCare clinic
3. City of St Paul office
4. Hennepin County clinic/fitness center
5. University of Minnesota

Partners

Xcel Energy® RESPONSIBLE BY NATURE™

CREE™

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Pacific Northwest NATIONAL LABORATORY

Retrofit sites: University of Minnesota

Pre-retrofit

Retrofit sites: University of Minnesota

Post-retrofit

Retrofit Sites: Hennepin County clinic / fitness center

Pre-retrofit

Retrofit sites: Hennepin County clinic

Post-retrofit

Retrofit sites: City of St. Paul

Pre-retrofit

Retrofit sites: City of St. Paul

Post-retrofit

Retrofit sites: AHUs

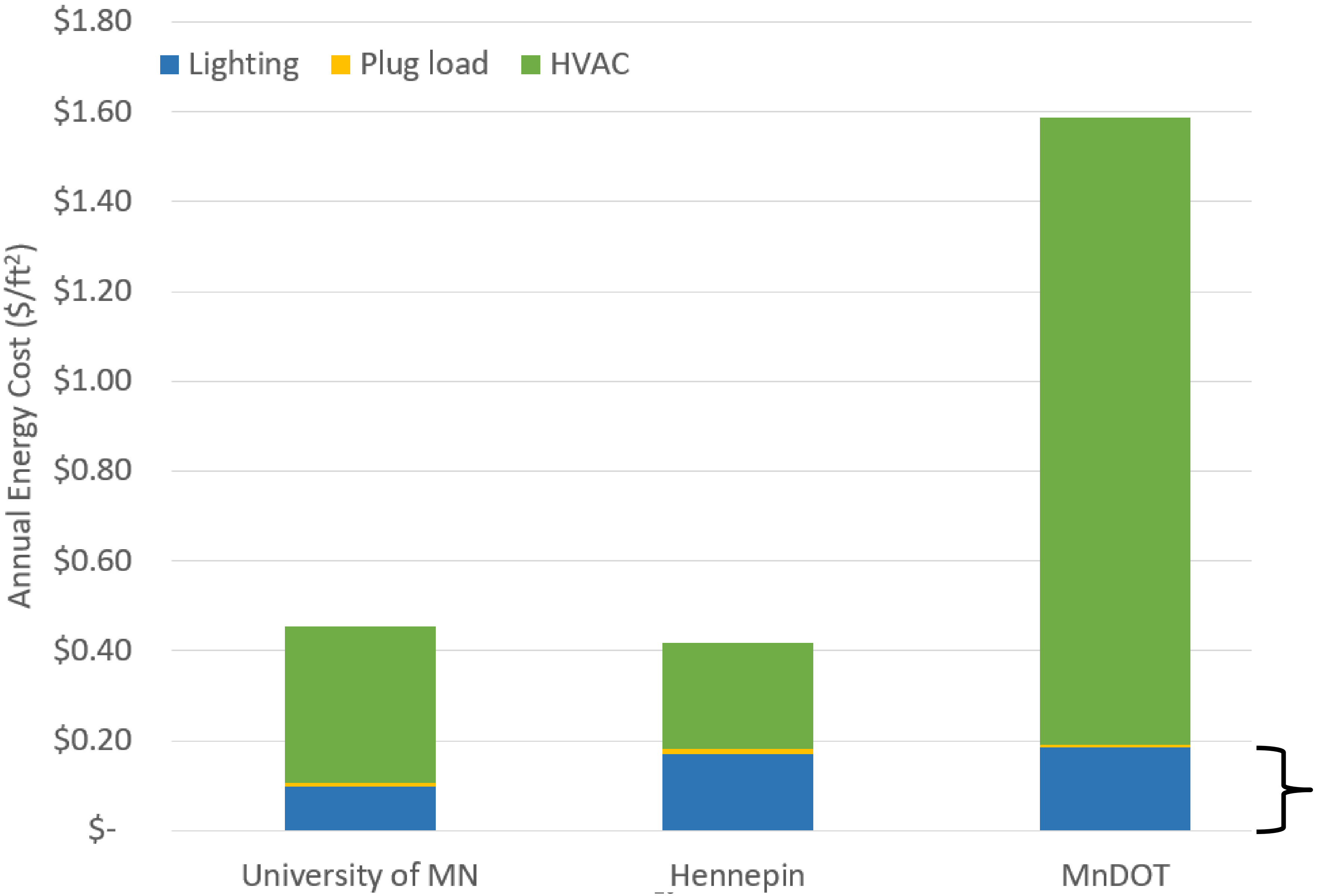
Retrofit sites: RTUs

Energy Impacts

Energy Savings

Type	Measure
Traditional Lighting Retrofit	Efficient LED Lighting
Advanced Lighting Control	Occupancy / Vacancy
	Daylighting
	Task Tuning
	Personal Tuning
Integrated Control - Plug	Workstation Plug Load Control
	Common Area Equipment Control
Integrated Control - HVAC	Thermostat Setback (Airside, Waterside, Baseboard)
	VAV Box Turndown (including off)
	Aggressive Pressure/Temperature Reset
	Ventilation Reset
	Demand Control Ventilation

Energy cost savings: three sites so far



Lighting savings smaller than in other studies due to better baselines

Energy savings: three sites so far

Average savings for first three sites

	kWh/ft^2	$therms/ft^2$	Pct.
Lighting	1.4		67%
Plug load	0.1		N/A
HVAC	5.6	0.07	47%
All end uses	**7.1**	**0.07**	**48%**

Lighting savings contributions: NEEA + DLC research

Table 8. Summary of estimated control factors by LLLC and control strategies.

LLLC Presence	Total Buildings	Control Factor (% Savings)			
		Average	25th–75th Percentile	High-End Trim Contributions	Other Control Strategies
NLCs w/ LLLC	98	0.63	0.50 - 0.79	0.37	0.41
NLCs w/o LLLC	96	0.35	0.17 - 0.48	0.17	0.22
All NLCs	194	0.49	0.35 - 0.69	0.27	0.32

Note: The numbers in this table are meant to provide a high-level overview of average savings trends. Additional study is needed to control for potentially confounding variables, and thus at this time the data does not imply that LLLC is universally superior or applicable to all building types.

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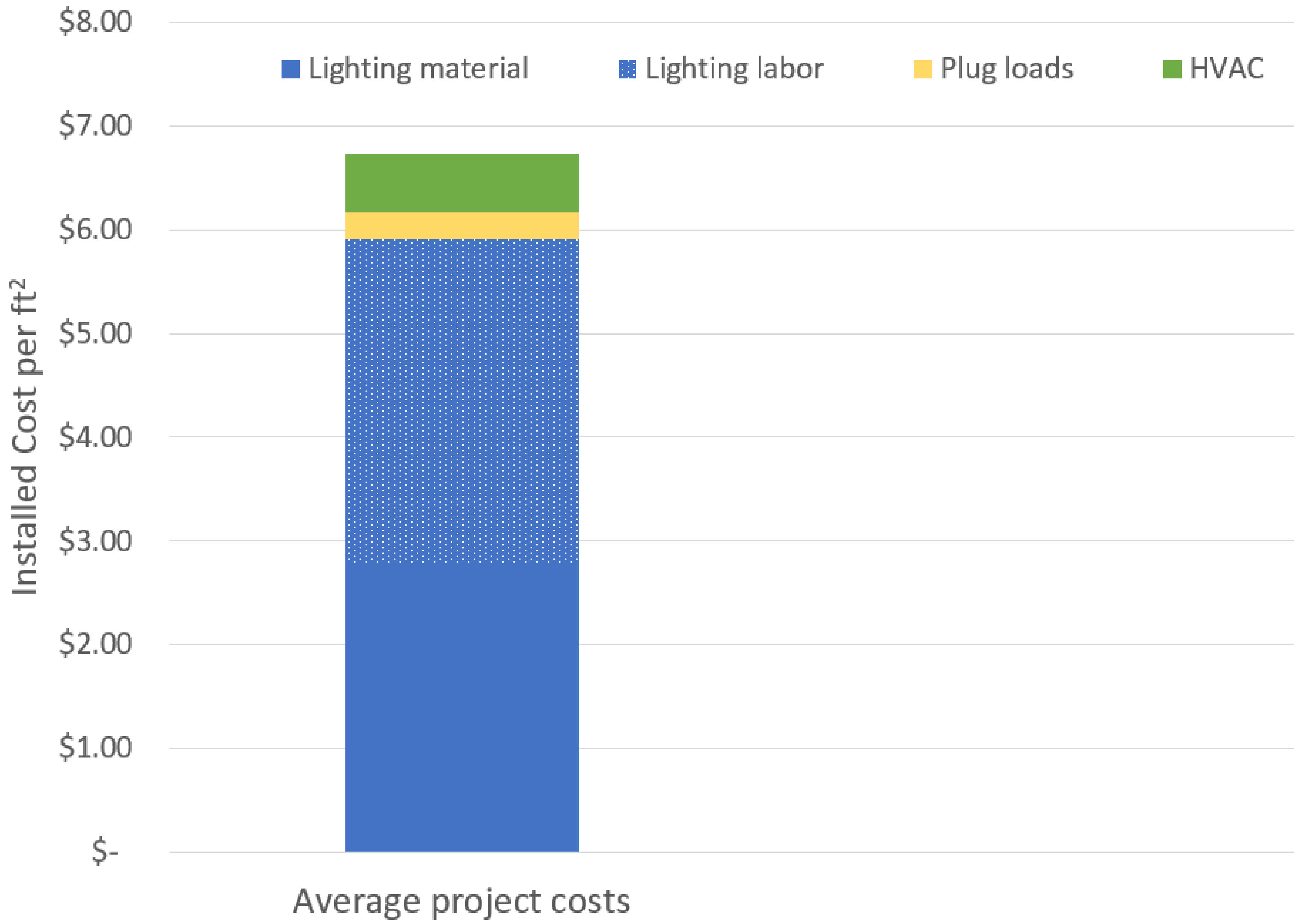
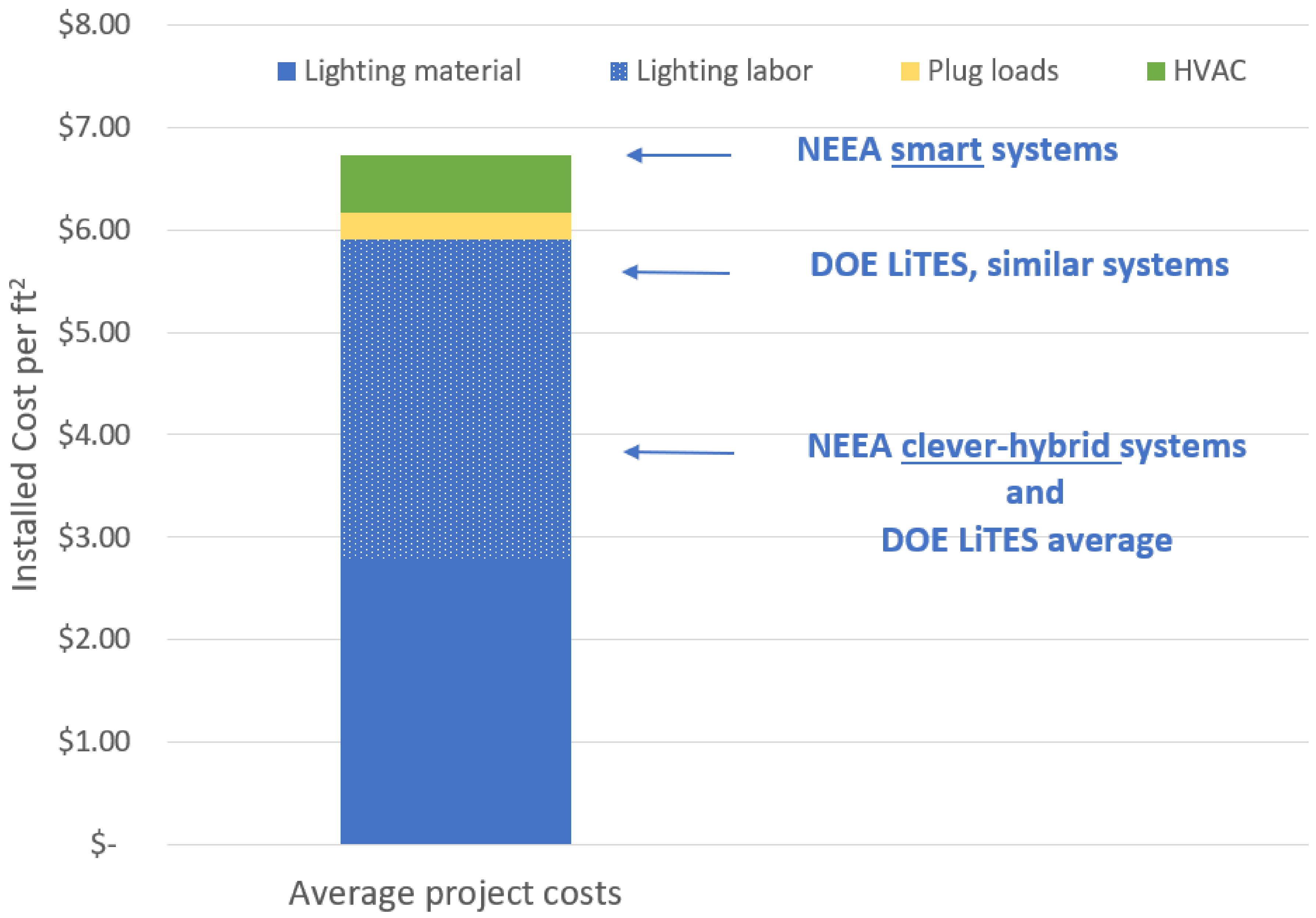
Project Economics

System costs



System costs



[NEEA] Kisch, et al., "Incremental Cost of Luminaire Level Lighting Controls (LLLC)", prepared for the Northwest Energy Efficiency Alliance, December 2019.

[DOE LiTES] NextEnergy, "Lighting Technology Energy Solutions Final Technical Report", prepared for the Department of Energy, February 2020.

Payback: pilot data

	Cost per ft^2	Payback
Full retrofit	$6.73	8.4 yrs
Without plug control	$6.47	8.0 yrs

Payback: cost in more mature market

	Cost per ft^2	Payback
NLC only	$4.50	30 yrs*
Full retrofit	$5.33	6.6 yrs
NLC+HVAC	$5.07	6.2 yrs
NLC+HVAC, w/ incentives	$4.19	5.2 yrs

* Conservative compared with other studies

Payback: just adding HVAC

	Cost per ft^2	Payback
Adding HVAC control*	$0.57	0.9 years

* With Slipstream acting as integration coordinator, a role that a program could play.

Non-energy benefits

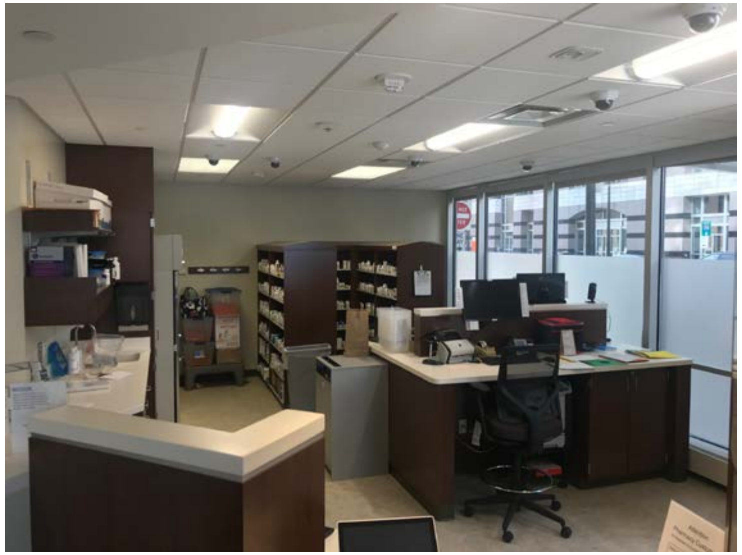
- Occupant satisfaction
- Improved IEQ / health
- Simplified maintenance
- Better space utilization
- Other future NEBs?

Payback: cost in more mature market

	Cost per ft^2	Payback
NLC only	$4.50	30 yrs*
Full retrofit	$5.33	6.6 yrs
NLC+HVAC	$5.07	6.2 yrs
NLC+HVAC, w/ incentives	$4.19	5.2 yrs
+ space utilization benefit	$4.59	2.0 yrs

Payback: cost in more mature market

* Reminder: the energy portion of payback results are based on only three sites so far.



Lessons Learned

Process

Planning

- Economic assessment
- Project planning
- Cybersecurity

Key Role:

Integration Manager

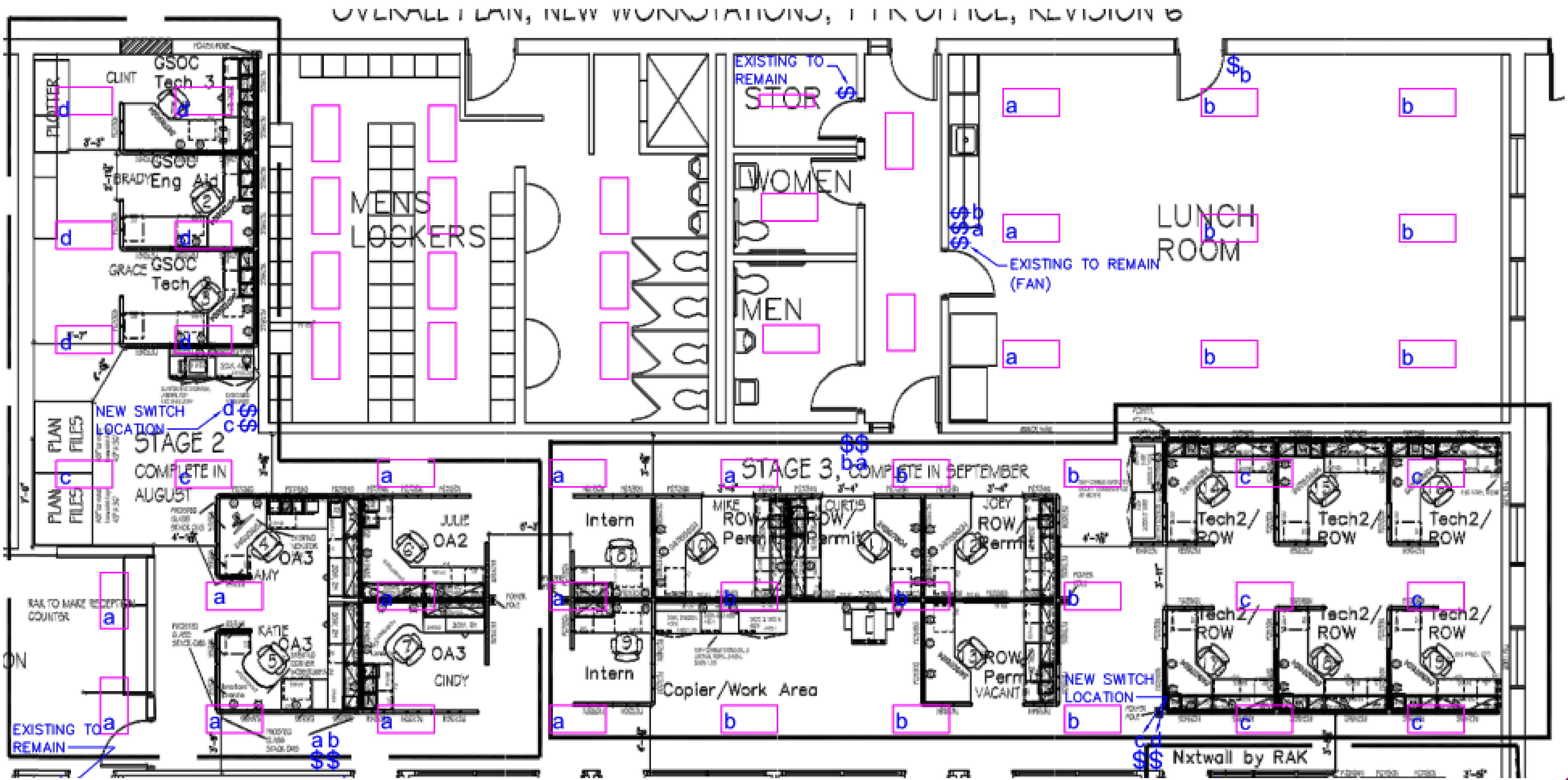
Process

Key Role:
Integration Manager

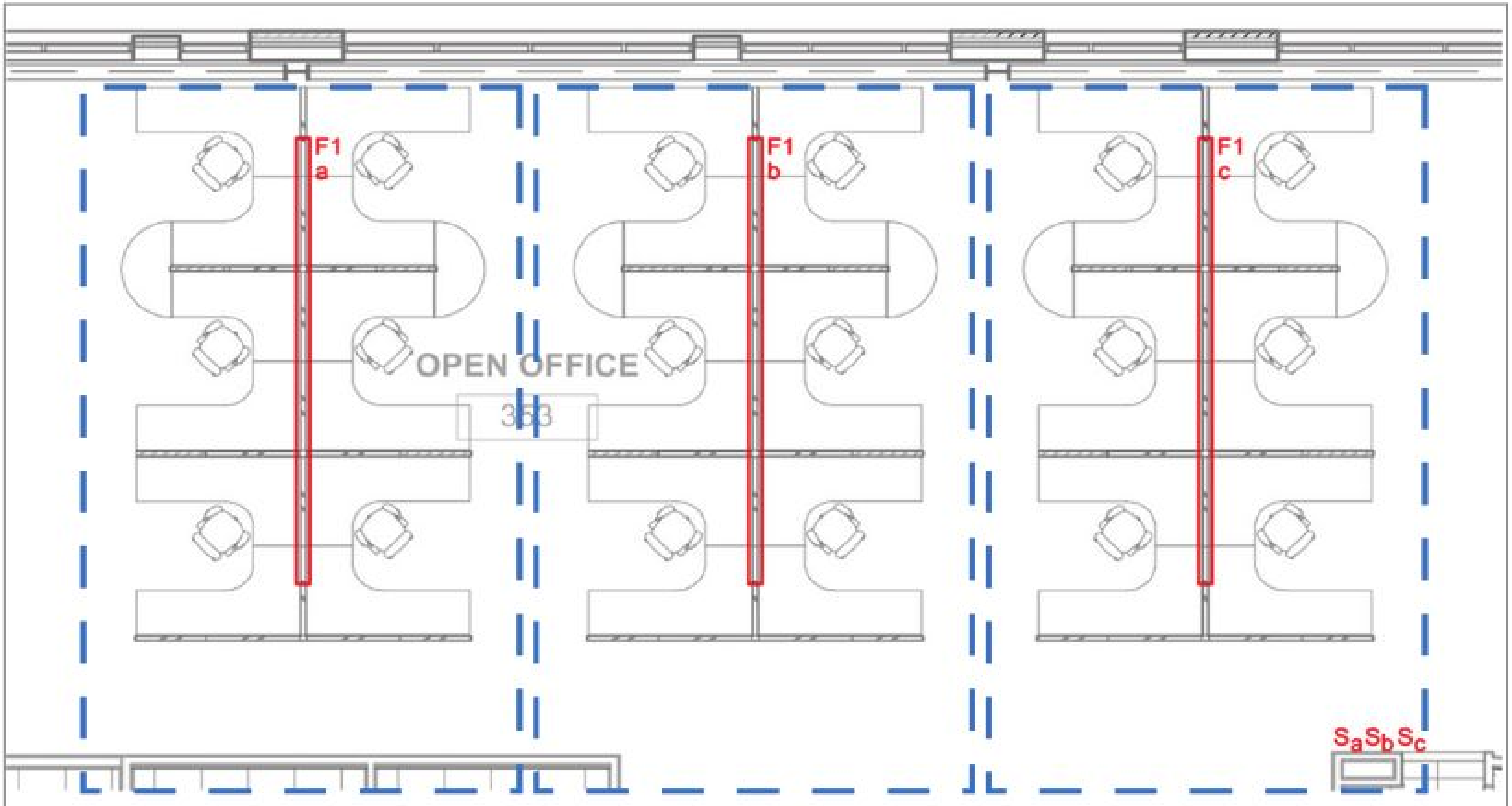
Planning
- Economic assessment
- Project planning
- Cybersecurity

Design
- Lighting and lighting controls
- Plug load integration
- HVAC integration

Design: Lighting Plan



Design: Advanced Lighting Control Strategies



- - - Lighting Control Zones

Open Office: Small zones operating in vacancy mode. Integrated sensors support a 10 minute time-delay-to-off, shorter than most system defaults.

Design: Control Matrix

$$Tuning\ \% = \frac{Target\ illuminance}{Calculated\ illuminance}$$

Space Name	Local Control	Control Mode	Occupied Level	Unoccupied Level	Occupancy Timeout	Calculated Average Illuminance	Target Illuminance	Task Tuning Percentage
Private Office	Y	Vacancy	100%	0%	10 mins	41	30	75%
Open Office	Y	Vacancy	100%	0%	10 mins	34	30	90%
Conference Rm	Y	Vacancy	100%	0%	10 mins	47	30	65%
Break Room	Y	Occupancy	50%	0%	10 mins	47	30	65%
Waiting	N	Occupancy	100%	0%	10 mins	35	30	90%
Nurse Station	Y	Vacancy	100%	0%	10 mins	50	30	60%
Exam Rm	Y	Occupancy	100%	0%	10 mins	49	50	100%
Procedure	Y	Occupancy	90%	5%	10 mins	57	50	100%
PT Exam	Y	Occupancy	100%	0%	10 mins	65	50	80%
Lab	Y	Occupancy	50%	0%	10 mins	52	50	100%
Clean Storage	Y	Vacancy	100%	0%	5 mins	41	30	75%
Vestible	N	Occupancy	100%	0%	10 mins	32	20	65%
Circulation	N	Occupancy	100%	0%	10 mins	24	30	100%
Toilet Rm - private	Y	Occupancy	100%	0%	10 mins	32	30	95%
Toilet Rm - partitions	Y	Occupancy	100%	0%	10 mins	34	30	90%

Design: HVAC control sequences

ASHRAE Guideline 36

i. **Zone minimum primary airflow (Vmin)**

a. Select Vmin to be the existing design zone minimum outdoor airflow rate, for use when space is occupied

b. The occupied minimum airflow Vmin* shall be equal to Vmin except if the zone has an occupancy sensor and is unpopulated, where Vmin* = 0.

c. Use existing design values for cooling airflow setpoint (Vcool-max) and heating airflow setpoint (Vheat-min).

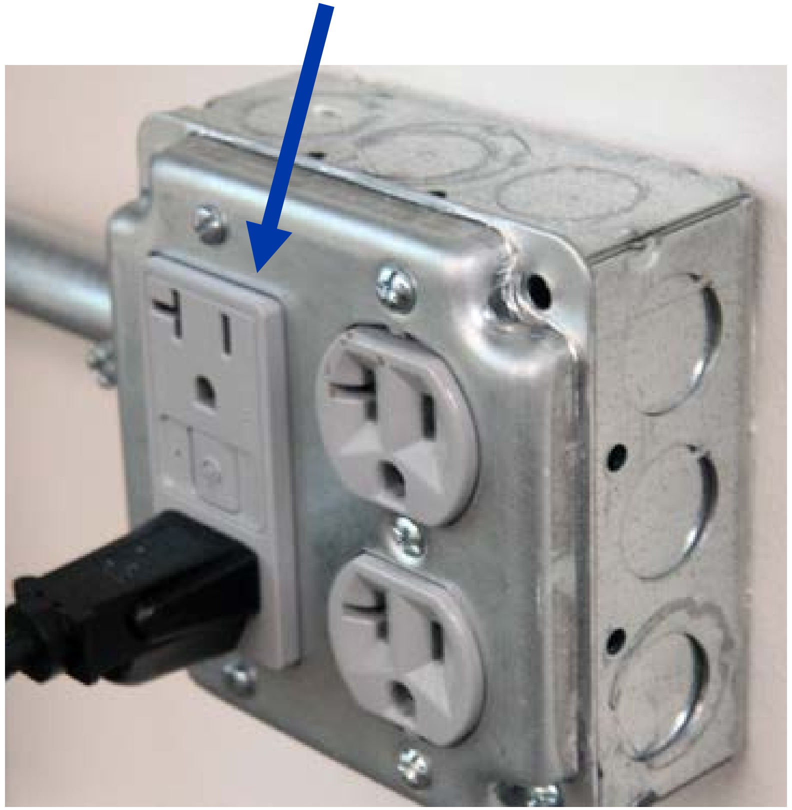
d. Active maximum and minimum heating and cooling airflow setpoints shall vary depending on the Mode of the zone:

Setpoint	Occupied	Standby or Unoccupied
Cooling maximum	Vcool-max	0
Cooling	Vmin*	0

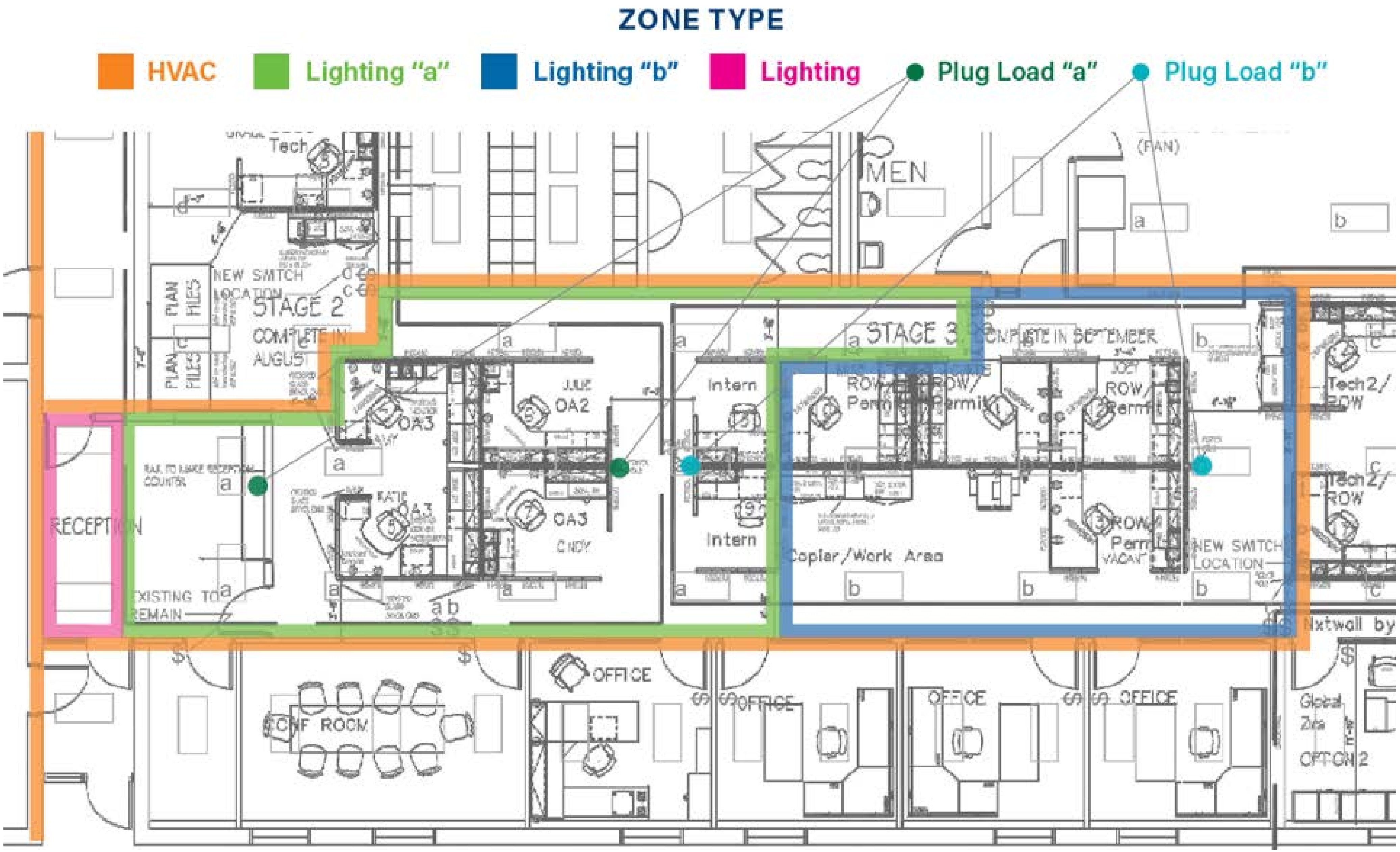
Design: plug load selection

- Loaded workstations – task lights, monitors, heaters/fans
- Furniture feeds
  (1 of several circuits)
- Printers/copiers
- Computer labs
- Beverage equipment
- Fitness equipment

Recommend color or label to mark the controlled outlets



Design: coordination of zoning



Process

Key Role:
Integration Manager

Planning
- Economic assessment
- Project planning
- Cybersecurity

Design
- Lighting and lighting controls
- Plug load integration
- HVAC integration

Construction
- Electrical installation
- Lighting and plug control configuration
- Network setup
- HVAC control programming
- Training

Construction: Lessons Learned

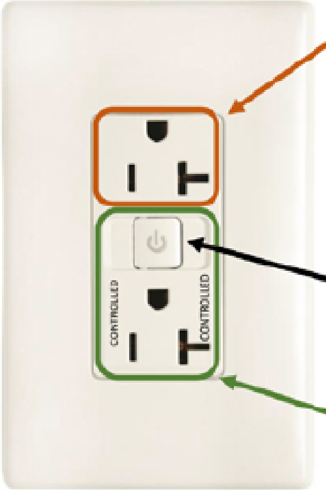
- Maintain one-for-one fixture replacement
- Meaningful space names
- Controls contractor familiarity
  - Affects install quality and cost
- Clear scope of work

Construction: More Lessons Learned

- Educating occupants is important
  - Reduce complaints
  - Savings persistence
  - Office manager - important resource
- Care needed to ensure occupant satisfaction
  - Light levels
  - Computer/printer availability
  - Temperature recovery

Automatic Outlet Shut-Off

Your workstation is now equipped with energy-saving electrical outlets that can automatically shut off devices when no one is detected in the room. Identifying which outlets automatically shut off and which always remain powered is important, so you can keep your devices in the appropriate outlet, saving energy without inconvenience.



Constant Power Outlet

(no marking or border)

Plug In:

- Computer CPUs
- Mini-fridges
- Other devices which must always be on or under power

Temporary Override Button

Shut-Off Controlled Outlet

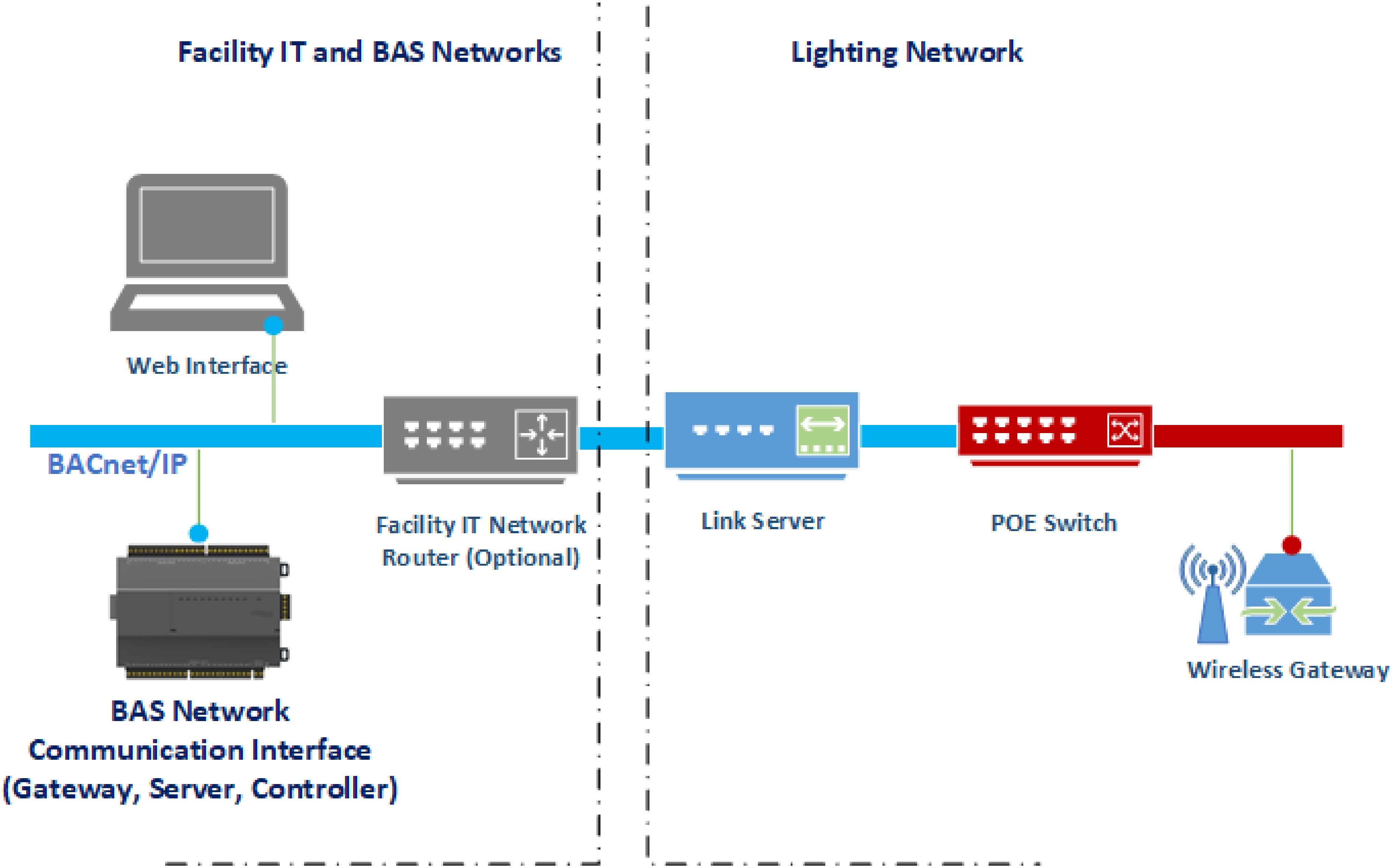
(Marked "CONTROLLED" and outlined with a border)

- Displays/monitors
- Task or exam lights
- Space heaters
- Fans
- Radios/speakers
- Printers
- Hot plates
- Kitchen equipment
- Exercise equipment
- Televisions

NOTE: Outlet may be mounted with Shut-Off CONTROLLED outlet on top. Some outlets have both top and bottom outlets Shut-Off CONTROLLED.

designed to be better.™ legrand®

Integration: BAS, IT and Lighting Networks



Internet → Cybersecurity

Avoid the "Inter<u>NOT</u> of Things"!

Have secure internet access for:

- Updating device firmware
- Updating software
- Updating security profiles (cybersec best practice)
- Remote access, setup, troubleshooting
- Remote diagnostics

Workshop and discussion

Program integration opportunities

- Xcel questions from supply chain discussion 10/14
  - What is magnitude of cost barrier?
  - What is cost-effectiveness & payback for lighting vs HVAC?
- Questions for Xcel
  - How does the payback info shared today influence your consideration of this opportunity?
  - How are you thinking about role of NEBs in customer motivation and/or cost-effectiveness calcs?

Program integration opportunities

- Service provider education/training
  - What strategies are currently employed?
  - What is working and where do challenges lie?
  - Are lighting and HVAC trade ally networks separately managed?
  - How are you viewing the need for program-provided technical assistance?
  - Where do you see the biggest knowledge gaps around advanced controls?

Program integration opportunities

- Xcel questions from custom calc discussion 10/21
  - Interest in isolating savings from each control strategy (lighting and HVAC)
  - Interest in getting service providers to implement a wider array of control strategies
- Questions for Xcel
  - How can data from these 5 sites help to refine HVAC calcs?

Program integration opportunities

- Demand response/GEB discussion 10/30
  - For building with integrated lighting and HVAC controls, where will ADR signal be sent?
  - We are demonstrating lighting DR next year
- Questions for Xcel
  - Let us know if there is any additional help Slipstream can provide

Marketing/outreach

Program integration opportunities

- Where could integrated controls projects be supported in Xcel's portfolio?
  - Lighting program
  - Custom program
  - Energy Management Systems program
  - New Construction program

Incentive strategy

Incentive	Paid To
Performance Lighting Plus (PL+) incentive of ~$1/sf plus demonstration project bonus of $0.50/sf = ~$1.50/sf (based on M&V area)	Owner
PL+ lighting “designer” incentive at 20% of owner incentive up to $15,000	Lighting contractor
HVAC integration costs up to $10,000	Owner
Integration service provider incentive of $2,000	HVAC controls contractor

Incentive strategy

- How well do existing Xcel incentives serve integrated controls projects?
- Are there existing service provider incentives that could be applied to integrated controls projects?
- Are there barriers to serving integrated controls projects with a more prescriptive incentive approach?

Questions?

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Project Sell Sheet Used for Marketing to Utilities

seventhwave | **ACCELERATE** PERFORMANCE

YOU BENEFIT WHEN DESIGN TEAMS COMPETE ON BUILDING PERFORMANCE

PILOT PARTNERS

Xcel Energy® RESPONSIBLE BY NATURE™

CSBR Center for Sustainable Building Research

B3 SB 2030 ENERGY STANDARD

In today's environment, energy efficiency is key in owning and operating any facility. New building projects include a focused investment on energy efficiency in anticipation of operational savings throughout the building's life. What energy performance do you expect to see? How does a building owner ensure that performance and return on investment will be achieved? Accelerate Performance empowers you to achieve advanced energy performance goals for new buildings and major renovations by enhancing the way you 'buy' your building.

Through this process, our energy experts will work with you before the design team is selected. We help you determine and prioritize project goals, which includes an energy performance target. The goals become a critical part of the selection process for the design team and the contractor. You select the design team based on their ability to deliver your goals for the building.

Seventhwave, the Center for Sustainable Building Research and Xcel Energy have partnered to offer a pilot that incorporates performance-based procurement with Enhanced Energy Design Assistance and with B3 Sustainable Building 2030 Standards. The limited time offering brings energy efficiency into the project scope from the very beginning to the end of the project.

BENEFITS OF ACCELERATE PERFORMANCE

- Reduce owner's risk in buying a high performance or net zero building
- Achieve superior energy performance within construction budgets
- Maximize energy savings and control costs
- Deliver the energy performance predicted during design
- Establish measurable success criteria
- Maintain energy-efficient design intent during building operation
- Improve construction quality

FEATURES

- Technical assistance to establish project energy requirements and evaluate team submittals
- Procurement language that integrates into existing RFP and contract documents
- Easy-to-use processes from RFP through operations
- Training and resources that allow owners to replicate this procurement approach across a portfolio of buildings

TO PARTICIPATE PROJECTS SHOULD BE:

- Projects looking to achieve 40% to 75%+ energy reduction, including zero energy buildings
- Projects in pre-planning phase before design team or contractor is under contract
- New construction, additions or renovation projects of 50,000 sq ft+

To find out more or to submit an application, contact:

Dave Vigliotta
Seventhwave
608.712.7143
dvigliotta@seventhwave.org

This material is based upon work supported by the Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), under Award Number DE-EE0007068.

National Grid Recruitment Flyer

nationalgrid

Rhode Island

Opportunity to participate

National Grid's Advanced Lighting and HVAC Controls Demonstration

A holistic approach to drive greater energy savings

National Grid has partnered with Slipstream, an independent nonprofit, to test the integration of networked lighting control (NLC) systems with HVAC controls to achieve deep energy savings in commercial buildings. A total of four sites will be selected for this demonstration. Facilities that meet the eligibility criteria have an opportunity for enhanced incentives and other benefits described below.

Demonstration Overview

PURPOSE

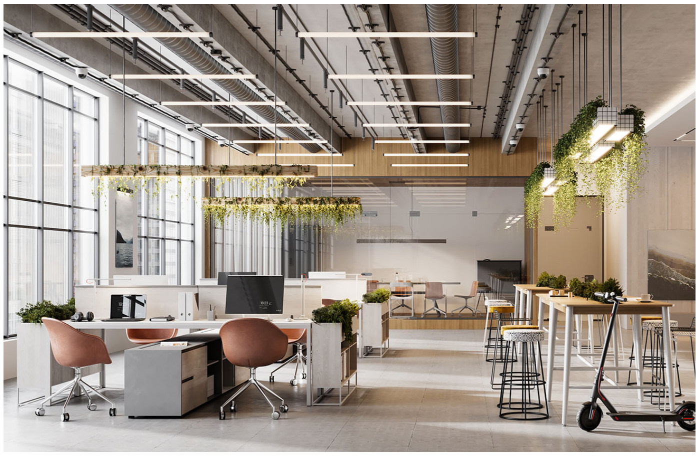
Encourage a deeper, holistic approach to advanced lighting retrofit projects. Demonstration sites will be retrofitted with LED fixtures that have embedded occupancy sensors and controls capable of connecting to building automation systems (BAS) for enhanced HVAC control. Occupancy signals from the lighting are sent to the BAS, facilitating energy efficient strategies like temperature setbacks, VAV box turndowns and demand control ventilation.

BENEFITS

- Enhanced incentives to offset project costs
- Gain first-hand experience with cutting edge technology and advanced control strategies
- Receive free technical assistance to support project implementation
- Free measurement and verification services to quantify energy savings impacts and return on investment
- Publicity through National Grid case studies

ELIGIBILITY

- Offices, healthcare, K-12 schools, higher education, government
- Existing lighting is low-bay fluorescent fixtures or NLC
- Interest in installing NLC system or connecting existing NLC with HVAC controls
- Direct digital control of HVAC units with open communications protocol like BACnet
- Any common HVAC system type
- Facility must be located in Rhode Island



ENHANCED INCENTIVES

- $0.50/sq. ft. bonus on top of National Grid Performance Lighting Plus incentives (based on M&V area)
- HVAC integration costs covered up to $10,000
- Lighting designer incentive of 20% of owner incentive, up to $15,000
- Integration service provider incentive of $2,000

Want to learn more?

If you are interested to learn if your facility is eligible to participate, please contact Slipstream:

Claire Cowan
Director of Program Design & Delivery
608.210.7117 | ccowan@slipstreaminc.org

slipstream

National Grid Recruitment HVAC Demo

NLC + HVAC Demonstration

NATIONAL GRID RHODE ISLAND

slipstream

Agenda

RESEARCH GOALS

SITE REQUIREMENTS

BENEFITS OF PARTICIPATION

M&V PROCESS

PARTICIPATION TIMELINE

Research Goals

- Test NLC+HVAC integration at up to 4 Rhode Island sites
  - One site with NLC or LLLC previously installed
- Measure end use energy impacts
- Quantify economic value proposition
- Assess barriers to integration with different lighting products
- Evaluate customer experience
- Recommend program design

Occupancy signal from lighting improves HVAC performance

- Temperature setback
- VAV box turndown/off
- Aggressive pressure/temperature reset
- Unoccupied unit shutdown
- Ventilation reset
- Demand control ventilation

Site requirements

BUILDING TYPE
Office, healthcare, K-12 school, higher education, government

LIGHTING
Low-bay fluorescent or NLC installed

BAS
Open communications protocol

HVAC
Any common system type

SIZE
Any size building; M&V will focus on representative 15-25,000 sq. ft. area

LOCATION
Rhode Island

PREFERRED
Daylighting control opportunity

Photo by Warren Gretz, NREL 001

Incentives for demo projects

Incentive	Paid To
Performance Lighting Plus (PL+) incentive of ~$1/sf plus demonstration bonus of $0.50/sf = $1.50/sf (based on M&V area)	Owner
HVAC integration costs up to $10,000	Owner
Lighting service provider incentive at 20% of owner incentive up to $15,000	Lighting controls tech
Integration service provider incentive of $2,000	HVAC controls tech

National Grid will discuss & finalize incentive offerings on a project-by-project basis.

Incentives

Free M&V

ENERGY SAVINGS | Usage and peak reduction

OCCUPANT SATISFACTION | Light, controllability, comfort

COST EFFECTIVENESS | Energy cost reduction

OPERATIONAL EFFICIENCY | Integrated control strategy

M&V process

- Develop M&V plan
  - Review documentation (plans and specifications), site visit*
- Install monitoring equipment
  - Electric power meters in lighting and HVAC subpanels*
  - Set up building automation system trending
- Monitor systems pre- and post-retrofit
  - Also implement occupant surveys
- Collect utility billing data
- Uninstall monitoring equipment
- Quantify energy and occupant satisfaction impact

Research timeline

SEPT 2020 – MAR 2021

Project outreach/recruitment

JAN – DEC 2021

Pre-install M&V (6 months)

Installations (3 months)

JAN – SEP 2022

Post-install M&V (6 months)

PARTICIPATION TIMELINE

1	2	3	4
Identify potential sites	Discuss with Slipstream Host a screening visit **Accepted to program**	Receive funding estimate	Decide to implement the project

PARTICIPATION TIMELINE

5
Pre-installation M&V

6
NLC installation

7
HVAC controls integration

8
Initial incentive payment

PARTICIPATION TIMELINE

9
Post-installation M&V

10
Final incentive payment

11
M&V equipment removal

12
Final energy savings analysis

Questions?

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