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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- Pacific Northwest National Laboratory measured energy impacts at the demonstration sites.

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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+.

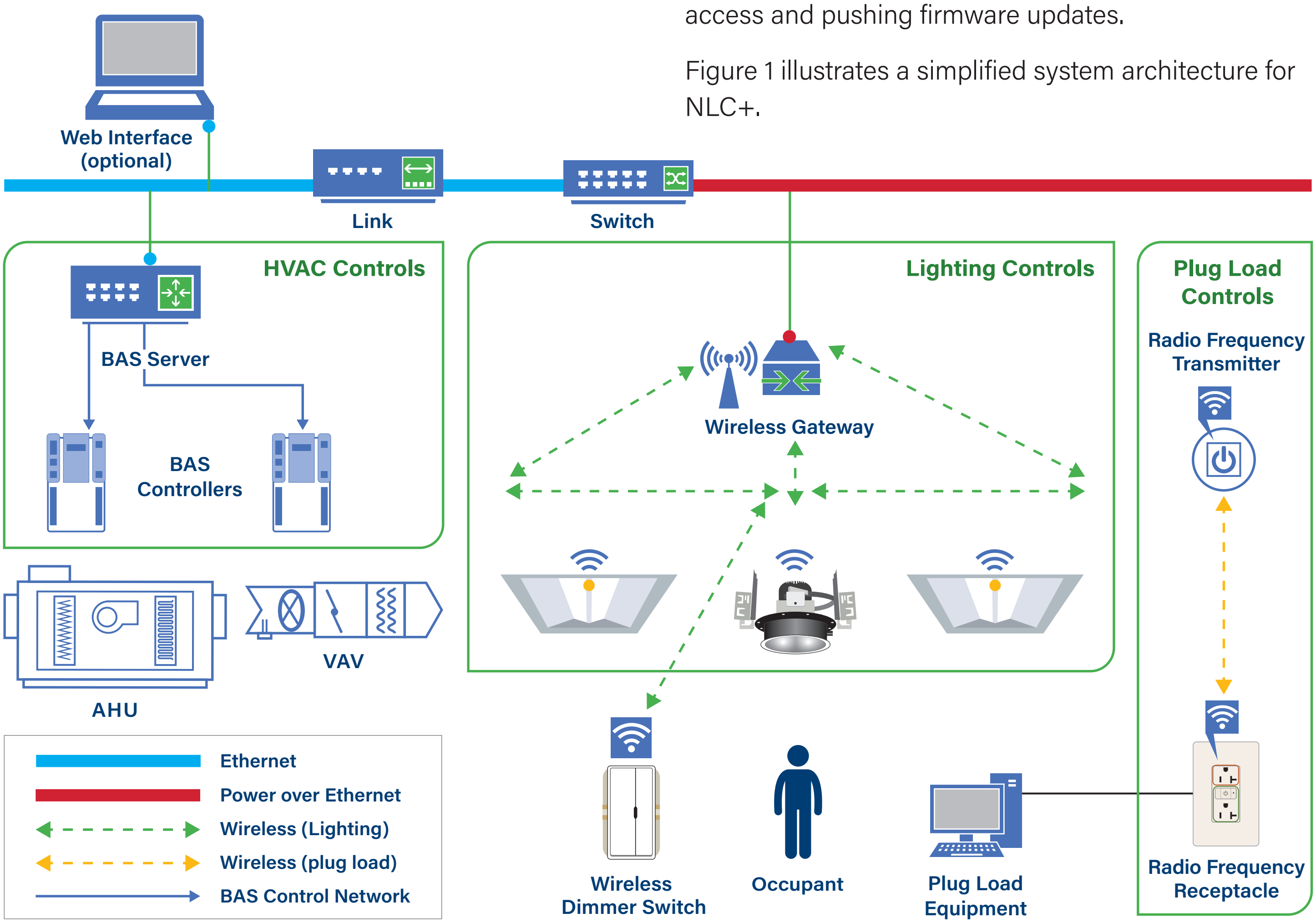


Figure 1: NLC+ system architecture.

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.

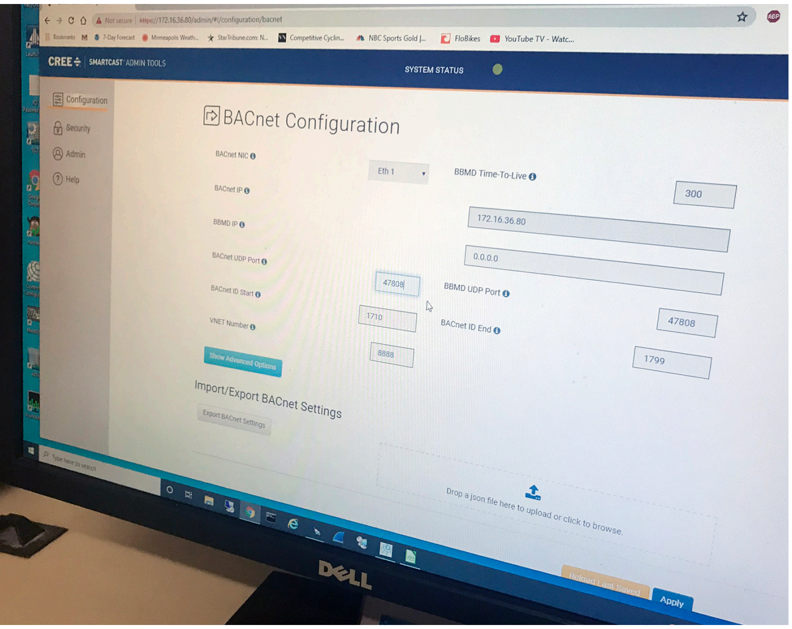
FOR NEW CONSTRUCTION

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.

[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:

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

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.

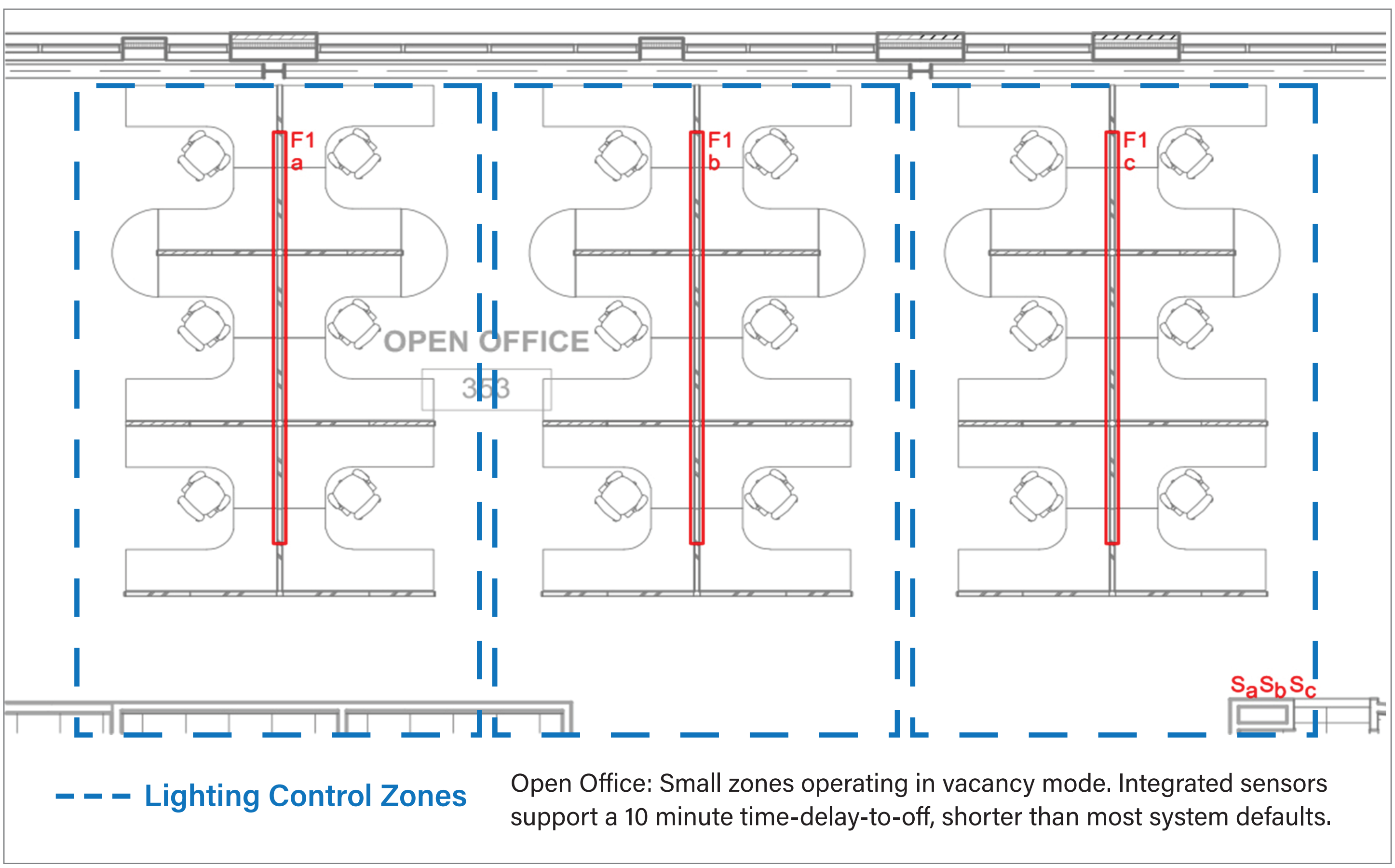


Figure 4: Lighting controls design diagram

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.

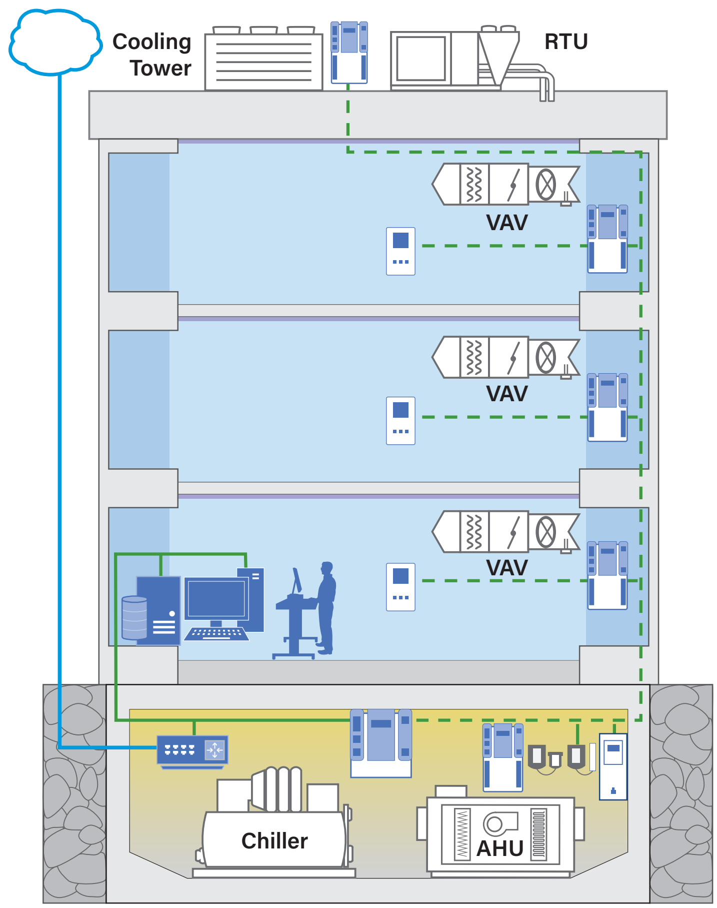


Figure 5: BAS schematic

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.

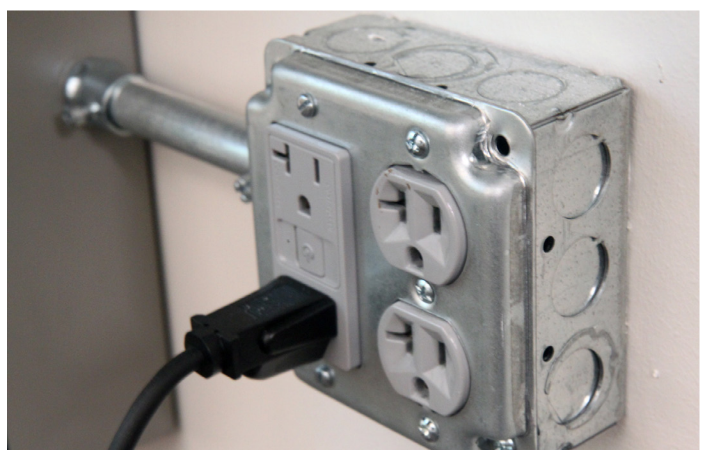
FOR OTHER HVAC SYSTEMS

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

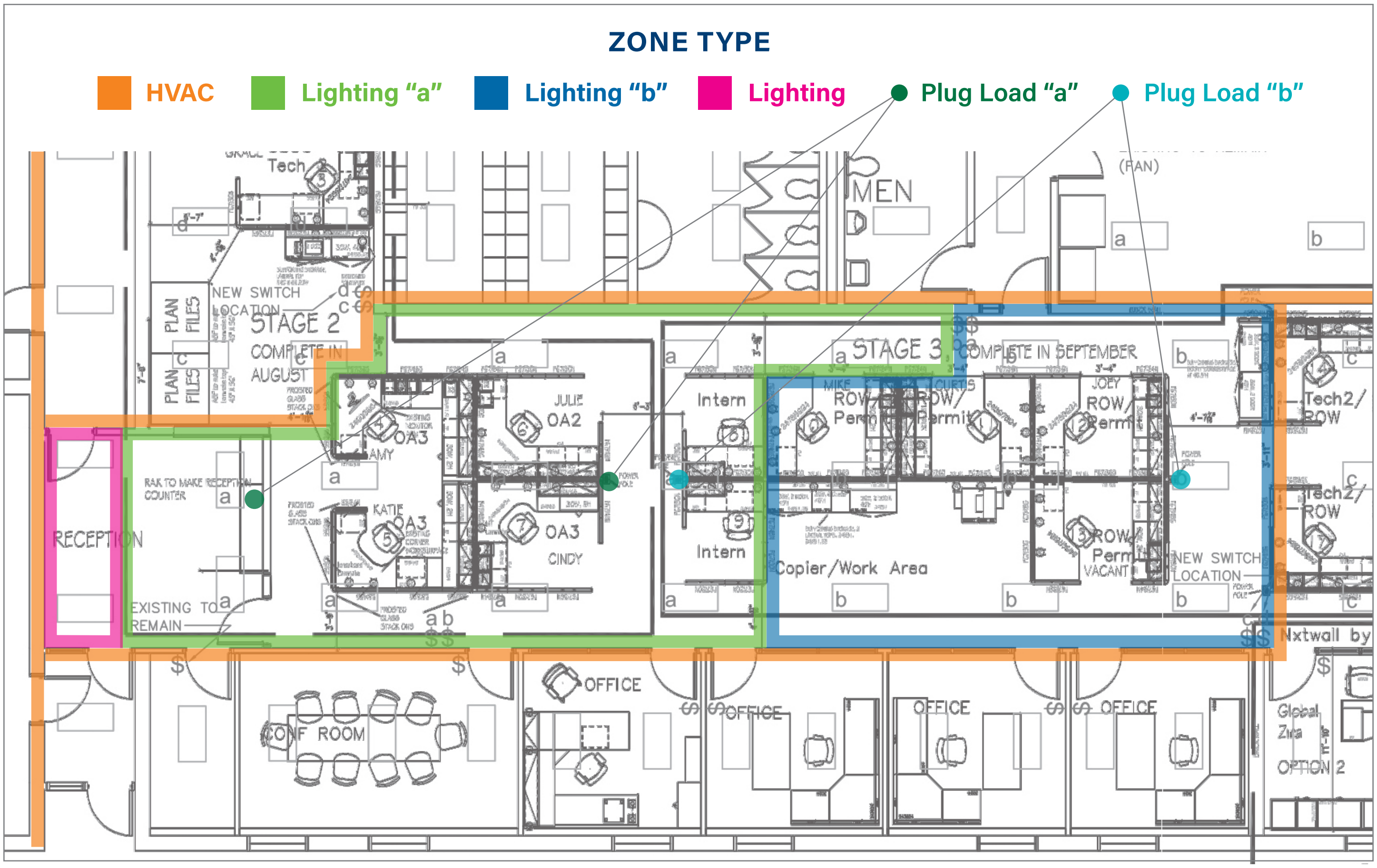


Figure 6: Mapping control zones

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.

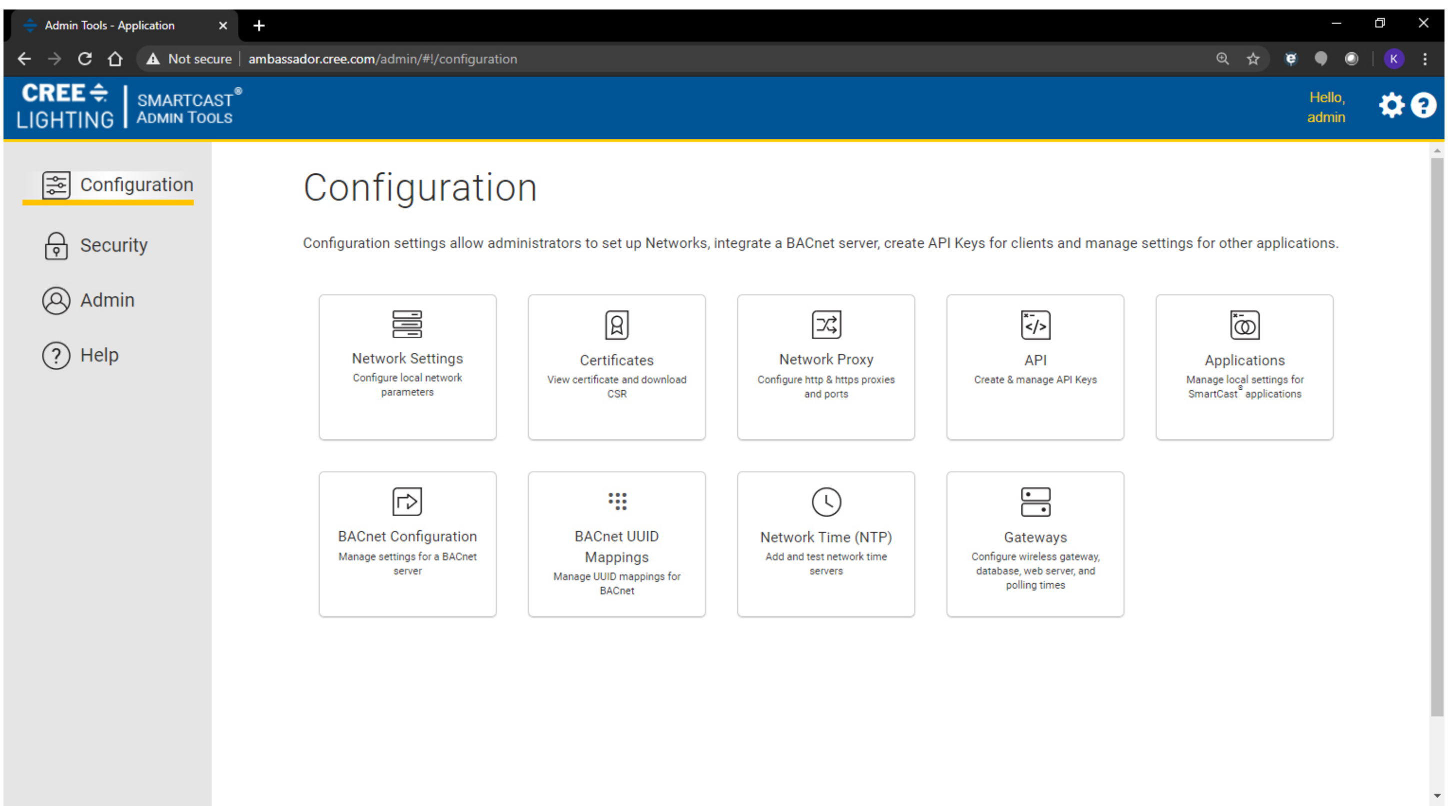
One benefit of NLC+ systems is the ability to easily make changes to system programming any time after initial commissioning. Because individual preferences vary, one strategy to maximize energy savings would be to start with reasonably stringent control settings in most zones, and simply back off the 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.

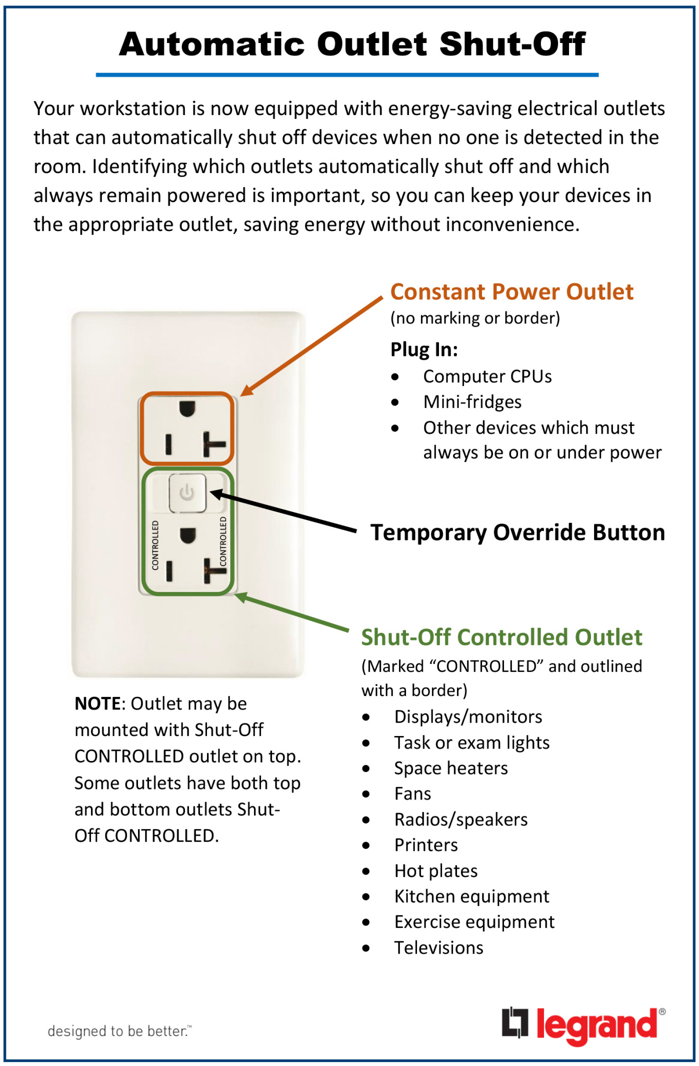


Figure 7: Plug load control instructions

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.

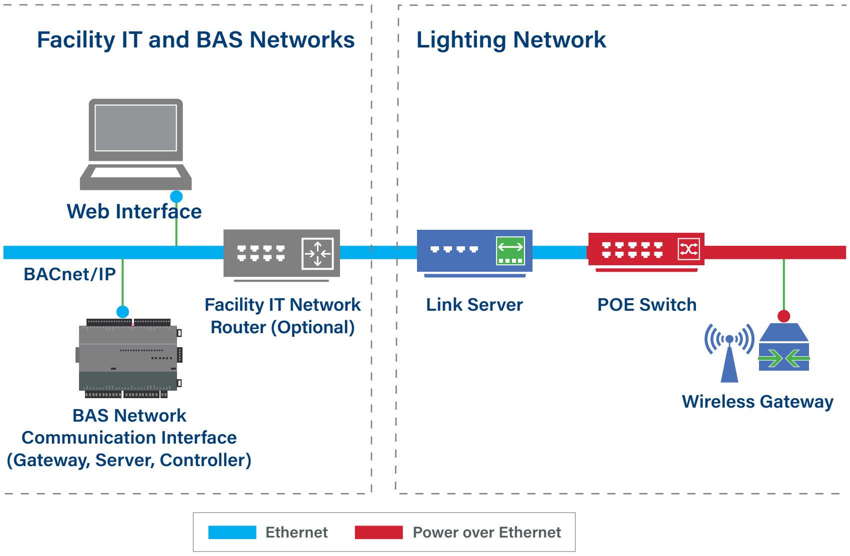


Figure 8: Network integration

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.

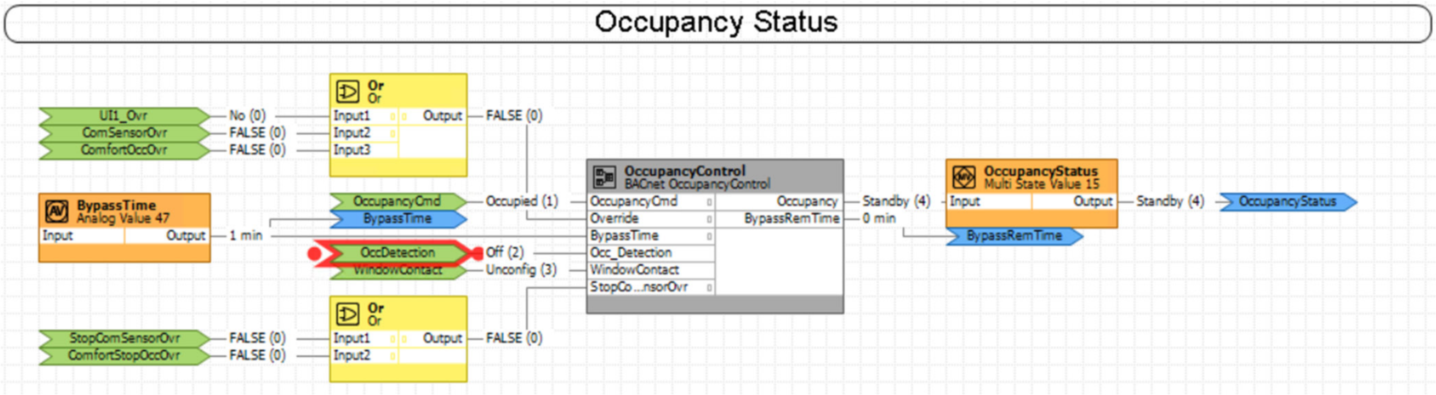


Figure 9: A sample custom HVAC programming code

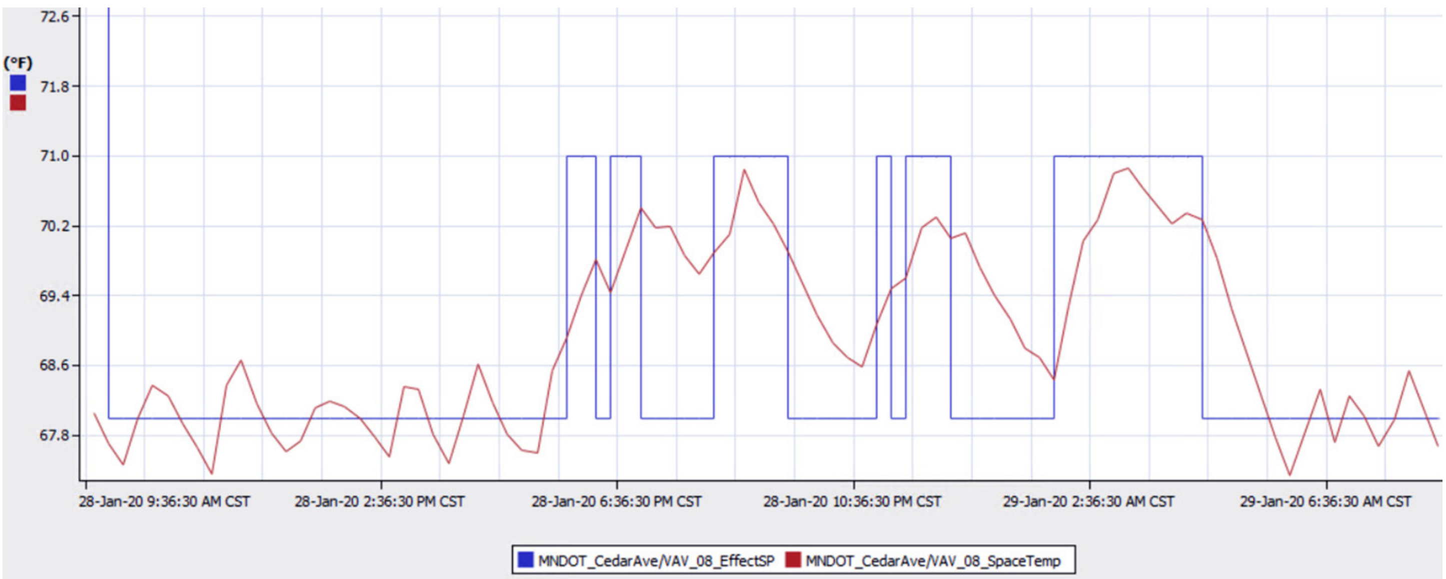


Figure 10: A sample trend chart for commissioning verification

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).

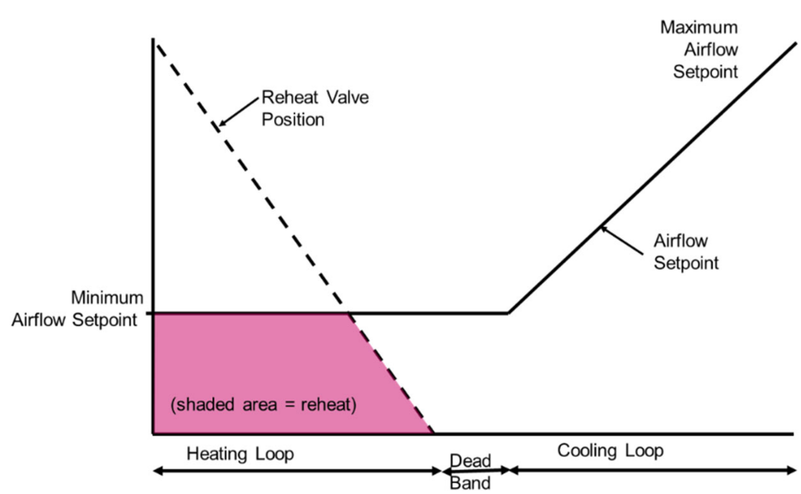
d. Active maximum and minimum heating and cooling airflow setpoints shall vary depending on the Mode of the zone (Figure 1):

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**

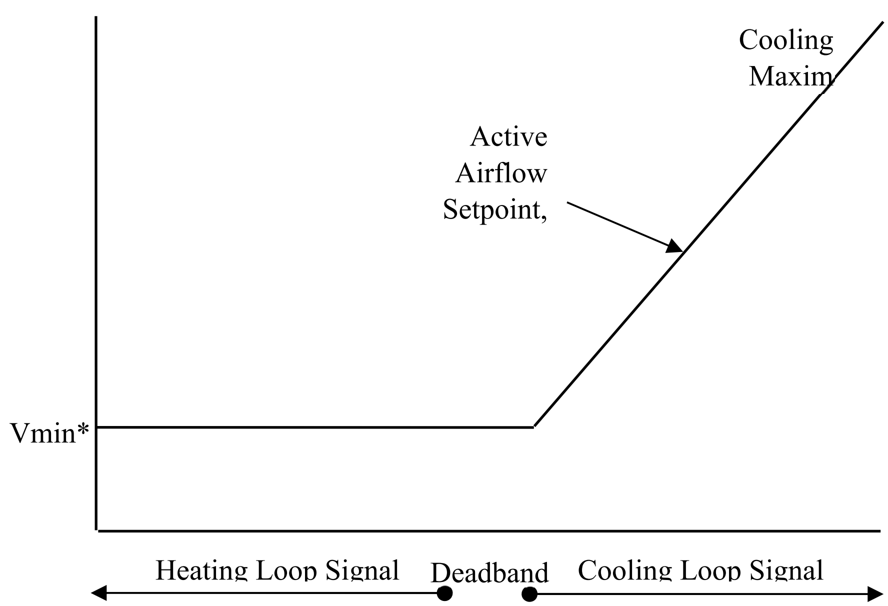
a. If the VAV heating water (HW) valve position is greater than 95%, send 1 Request until the HW valve position is less than 85%,

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

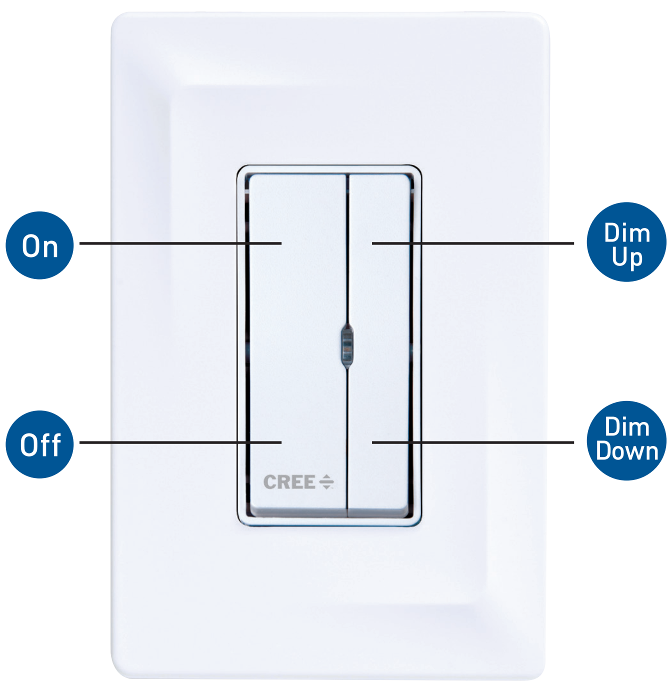
While you were gone, your office underwent a lighting makeover. Each room is now equipped with Cree LED lighting enabled with the SmartCast Intelligence Platform™. It's intelligent lighting aimed at improving your workday experience while saving money for your company. It's lighting so intuitive and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



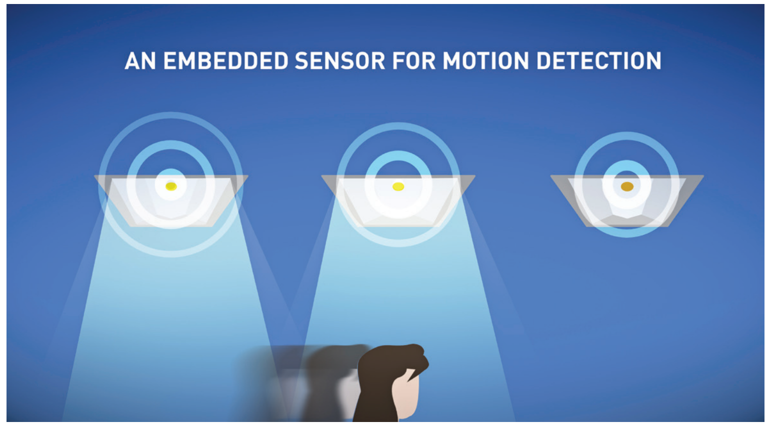
DIMMING

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.

CREE | SMARTCAST® TECHNOLOGY

OCCUPANCY SENSING

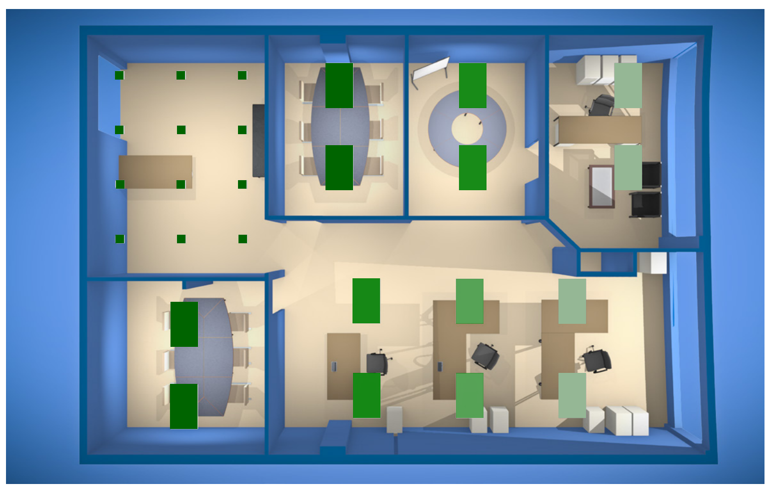
Whether you noticed your office's updated lighting or not, it noticed you. For many businesses, lighting can be 40% of their energy costs. Cree has solved that problem with Cree SmartCast® Technology with Motion Sensing. Each light comes with an embedded sensor for motion detection to sense changes in 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.



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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.

Rev. Date: 11/07/2017

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.

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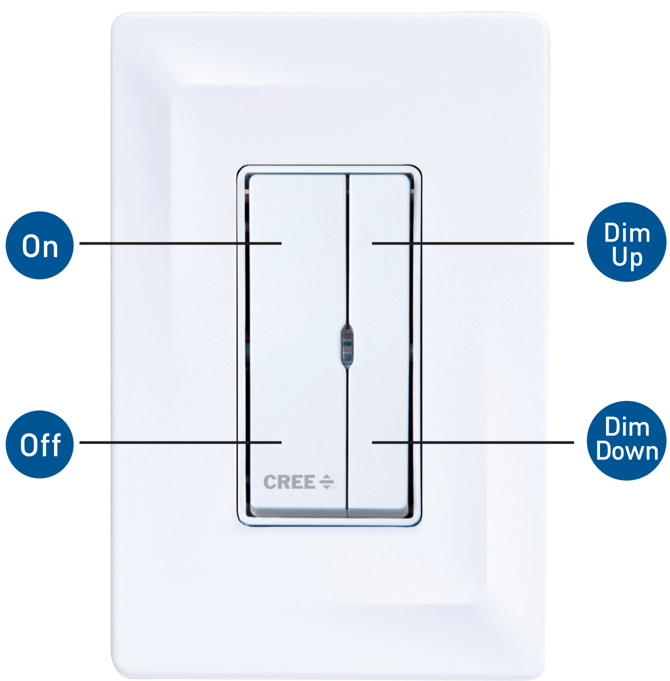

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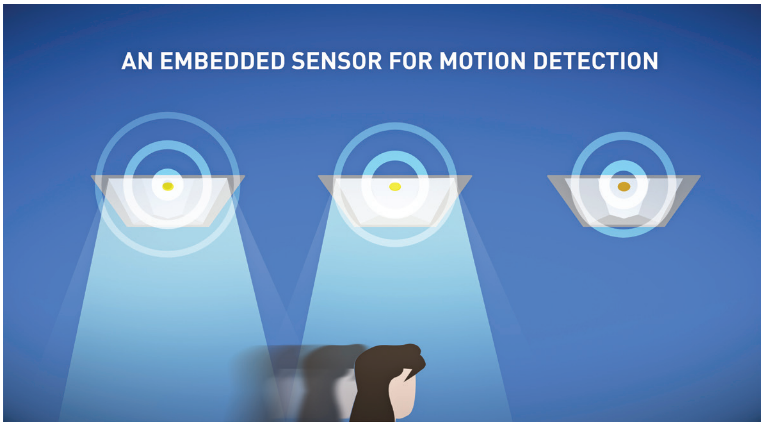

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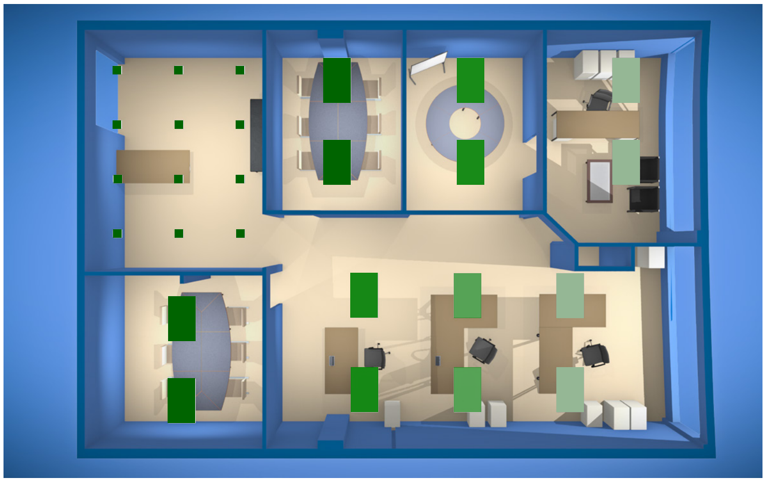

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