SELECTING LIGHTING CONTROL SYSTEMS

What's inside: A systematic approach to networked lighting controls

- Controls Objectives and Use Cases
- System Capability Considerations
- Networking and Communication Options
- Documenting a Lighting System

Introduction

The objective of this resource is to assist decision-makers in understanding how networked lighting control system attributes can satisfy project objectives at an appropriate cost and functionality. This resource is intended for members of the project team involved in the design and selection of lighting control systems, especially team members with limited-to-moderate controls experience.

Over the last five years, Pacific Northwest National Laboratory has conducted extensive research on the problems affecting lighting controls, from analysis and evaluation of a wide range of installations to dozens of interviews with industry participants. Some key challenges that have impacted successful lighting controls installations include:

- Failure to align lighting control system capabilities to project objectives
- Unclear or incomplete documentation of objectives, desired capabilities, and system features
- Misunderstandings in design and set up due to ambiguity in terminology.

These challenges can be compounded by reliance on the system architecture and vocabulary of individual manufacturers, which may limit one's understanding of lighting control systems. Developing a non-proprietary understanding of lighting control systems can offer broad options for achieving project objectives and desired performance while minimizing cost and complexity.

This document offers a systematic approach to establish objectives for lighting controls, identify relevant system capabilities, and narrow the choices in system architecture to those that support the desired system capabilities and availability of organizational resources during operation.

TABLE OF CONTENTS:

The Focused System Selection Process

The four steps below outline system selection to the point where the required characteristics of a system can be documented in terms of its capabilities and system architecture. From here, decision-makers can identify products that meet their requirements and select the system with favorable cost, resiliency, and support.

1 Identify controls-specific objectives based on the owner's project requirements (OPR).

Use cases can help to set priorities. Examples include:

- Energy Code Compliance (Required)
- Enhanced Lighting Performance
- Enhanced Energy Management
- Enhanced Facility Productivity

2 Define capabilities needed to support objectives. Capabilities will include those required for energy code compliance as well as those drawn from more than one use case.

- Consider risk factors and capability requirements

3 Understand how the structure and components of the system contribute to the desired capabilities and satisfy project limitations and owner preferences.

- System Scale
- Networking Options
- Wired and Wireless Networks
- System Components

4 Create documents that support accurate installation, configuration, and operation of the control system. The task of documenting begins with the Controls Intent Narrative and continues throughout the design process.

- Controls Intent Narrative
- Sequence of Operation
- Drawings and Specifications

Figure 1. Overview of the focused system selection process. Each step of the process is explained in detail in the following pages.

Objectives and Use Cases

Owners may provide direction for system performance, cost, occupant considerations, and project goals. Setting clear objectives with the project team helps to determine the functionality of the system; the four use cases below describe common objectives and can help prioritize system options.

Energy Code Compliance

Code compliance represents the minimum requirement for most projects and is generally the least costly. Local codes may vary and should be thoroughly understood. Code compliance alone may not satisfy owner objectives. Depending on local code requirements, supporting capabilities may include switching and local control, occupancy sensing, time scheduling, daylight-responsive controls, dimming, and plug load controls.

> All projects must comply with local energy codes. Simple projects may only need capabilities supporting this use case. Aspects of other use cases will likely be added to satisfy more extensive controls objectives.

Enhanced Lighting Performance

Enhanced lighting aims at improving workforce productivity, wellness, satisfaction, and facility appeal. Increasingly popular capabilities, such as tunable white and task tuning, can increase cost and programming complexities. Other supporting capabilities include scene control, motorized system control, and lumen maintenance.

Enhanced Energy Management

This use case looks for energy conservation and management beyond minimal code compliance by optimizing systems through granular feedback on energy usage and system performance. Some capabilities require additional communication infrastructure and will benefit from dedicated operational resources. Capabilities include measurement and reporting, external system integration, task tuning, plug load control, diagnostics and monitoring, demand response, lumen maintenance, and motorized system control.

Enhanced Facility Productivity

Enhanced facility productivity embraces greater spatial and asset efficiency, improved retail performance, and increased engagement, safety, and security. Capabilities typically require external analytics and application programs, which add cost and complexity. Examples include asset tracking, indoor positioning, occupant counting, external system integration, measurement and reporting, and diagnostics and remote monitoring to streamline maintenance.

Objectives and Use Cases

The first step in system selection is to identify specific system capabilities that will satisfy the project objectives and owner's requests.

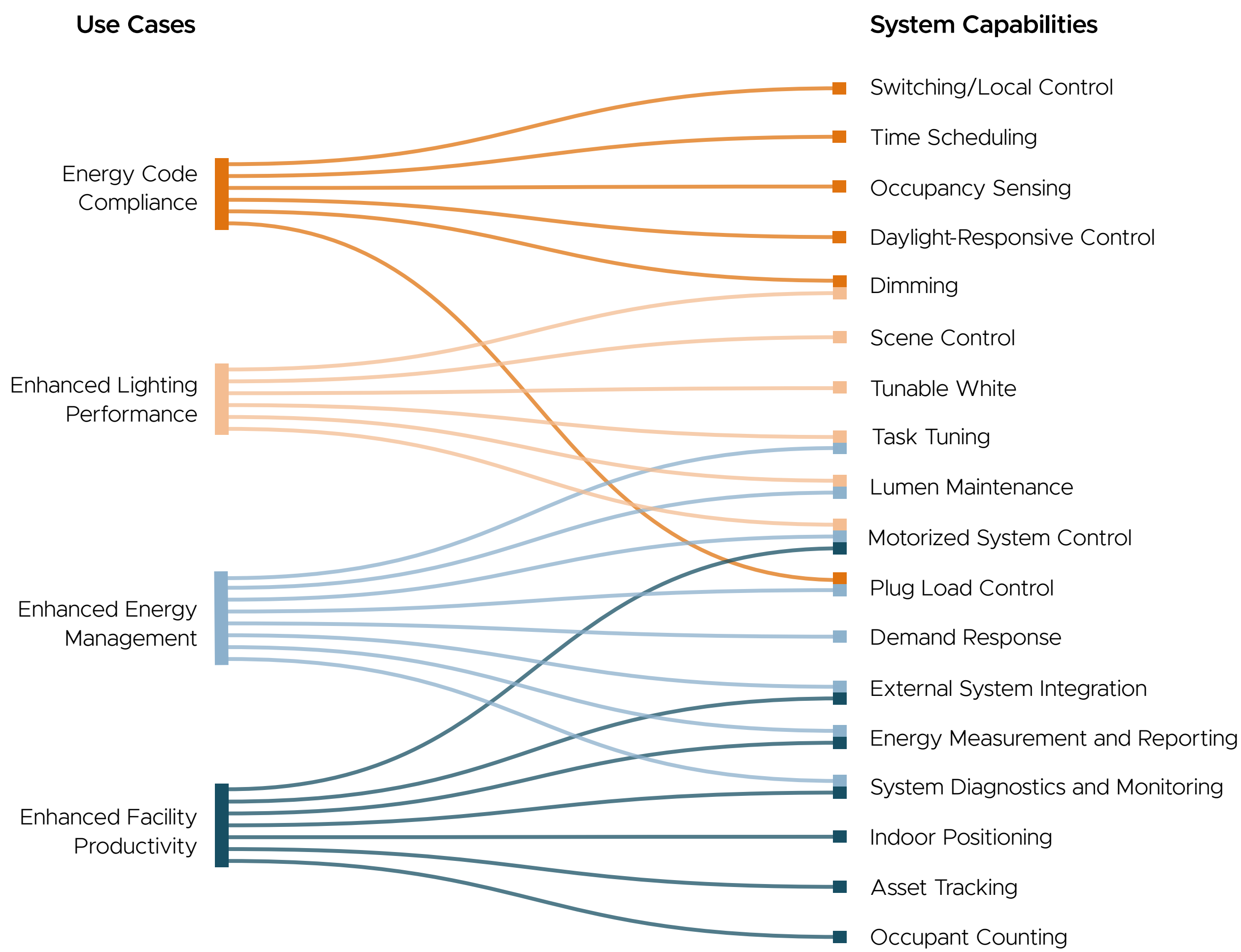


Figure 2. Common use cases (left) and the system capabilities (right) that functionally support organizational objectives.

Capabilities

Many common lighting control system capabilities are listed in Table 1, with associated use cases, design risk factors, and implementation issues. The legend explains the icons that represent common risk factors: the availability of the technology in the current networked lighting controls market and the level of communication required for each capability. These two factors can help decision-makers compare different capabilities in terms of overall risk and reliability.

Legend

Use Cases

- **CC** Energy Code Compliance
- **LP** Enhanced Lighting Performance
- **EM** Enhanced Energy Management
- **FP** Enhanced Facility Productivity

Risk Factors

Technology Availability (TA)

- ○ Capability is ubiquitous in lighting controls systems.
- ◐ Capability is offered in an upgraded tier of most controls systems.
- ● Availability in current market is limited to specialized or advanced systems.

Communication Requirements (CR)

- ○ Basic communication or does not require an exchange of data.
- ◐ Capability may require communication between devices within the lighting controls system. Standardized methods for data exchange may be required.
- ● Capability requires communication between devices or networks outside of the lighting controls system.

System Capabilities	Use Cases	Risk Factors TA	Risk Factors CR	Implementation Notes
Time Scheduling	CC	○	○	
Occupancy Sensing	CC	○	○	Sensor location and coverage are critical.
Daylight-Responsive Control	CC	○	○	Zoning and sensor placement are critical.
Dimming	CC LP	○	○	
Scene Control	LP	○	○	
Tunable White	LP	◐	◐	Digital control is recommended for best performance.
Task Tuning	LP EM	◐	◐	
Lumen Maintenance	LP EM	◐	○	
Motorized System Control	LP EM FP	○	○	
Plug Load Control	CC EM	◐	○	An alternative option uses a clock not integrated with the lighting system.
Demand Response	EM	◐	●	Communication with external utility is required.
External System Integration	EM FP	◐	●	A gateway and/or server are typically required.
Energy Measurement and Reporting	EM FP	◐	◐	Requires an additional measurement device, a digital driver, or a digital load controller.
System Diagnostics and Monitoring	EM FP	◐	◐	Requires an additional measurement device, a digital driver, or a digital load controller. Diagnostic capabilities differ between systems.
Indoor Positioning	FP	●	●	Additional devices, server, analytics, and communication required.
Asset Tracking	FP	●	●	Additional devices, server, analytics, and communication required.
Occupant Counting	FP	●	●	Additional devices, server, analytics, and communication required.

Table 1. Common lighting control system capabilities functionally support one or more use cases, including energy code compliance and enhanced facility productivity. Technology availability (TA) and communication requirements (CR) can assist in deciding if the capability is appropriate for the project. Guidance for implementing certain capabilities is also provided; for more information see the **Capability Details (p. 16-18)** section.

System Architecture

During system selection, it is helpful to understand common system architectures and network topologies as they relate to specific capabilities, project conditions, and scale. While controls products typically identify their capabilities, system architecture is often less clear in product literature. The following information may help decision-makers identify the architecture of different products, along with their strengths and limitations.

System Scale

System architecture can be influenced by project characteristics, such as the scale of the project and whether it is new construction or a renovation.

Regardless of system capabilities, communication needs will increase with the scale or scope of the project. Some capabilities require advanced communication or control strategies regardless of the system scale.

Retrofit or renovation projects may have different code requirements than new projects, as well as significant challenges installing the equipment. Wireless control systems may save substantial labor cost and installation time for most projects, but particularly for retrofit scenarios.

SINGLE SPACE

A single-space system provides local control of a single room and does not communicate externally. Internal communication can be wired or wireless. These systems may also be referred to as room-based or stand-alone systems. Multiple room-based systems can be applied across multiple spaces, although each control system will operate independently.

Many capabilities supporting enhanced energy management or facility productivity cannot be practically supported by systems that control rooms independently and do not communicate externally.

SUITE, FLOOR, OR BUILDING

A larger scale, networked system can control a suite of several rooms or an entire floor using gateways (wired or wireless) or large-area wireless mesh networks. Connection to other local or external servers and systems, such as HVAC and building automation systems (BASs), are possible with a gateway.

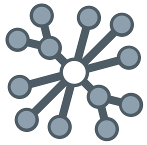
Systems at this scale may also take a hybrid approach with some local, room-based controls and some communicating with a central processor, gateway, or server. For example, room-based (non-networked) systems within a suite may implement occupancy sensing independently, while all of the corridor lighting is networked and programmed to follow the same operating schedule. Full functionality, especially with capabilities for enhanced energy management and facility performance, usually requires a fully networked system.

CAMPUS OR PORTFOLIO

A campus-wide or portfolio-managed lighting control system is largely the same as a floor- or building-scale system with an additional layer of communication for building-to-building interaction. Given the physical distance involved, the control systems are connected using intra/internet and report to a central server (physically located on-site or cloud-hosted) that allows the facility staff to remotely monitor and control building systems.

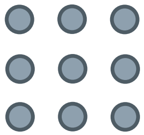
Network Options

Networked lighting controls allow for remote monitoring and adjustment as well as user-initiated or automated demand response. While a campus or portfolio of properties require networked lighting controls for remote access, some capabilities, such as demand response, require networked controls regardless of the project scale in order to communicate with systems outside the lighting controls. Networked systems typically use centralized intelligence (or processing), distributed intelligence, or some combination of the two. For example, luminaire-level lighting controls (LLLC) utilize distributed intelligence at the fixture to enable local capabilities, but can process higher level capabilities, such as scheduling, at the central processor. Characteristics of two common network designs, a centrally-controlled system and a LLLC, are described to the right.



Central Control

A system with centralized intelligence uses a system-wide processor (i.e., central processor) to signal the networked components, such as user interfaces, sensors, and controllers, and to receive status reports from them. A centrally networked lighting control system may be configured to communicate with the building's primary control network. Some systems may use a gateway as a central processor, which will also translate control signals between the building's control network and the lighting control network. Large-scale central control systems tend to use wired communication at the building scale and may transition to wireless communication at the floor or suite level.



LLLC

With independent control (i.e., a load controller and sensor) located in each luminaire, LLLC provides maximum granularity with more options for creating lighting effects, reducing energy consumption, and collecting information. Distributing intelligence to the luminaire level can protect the lighting control system against widespread faults and failures and increase system resiliency because the devices can operate autonomously. Sensors in LLLC systems typically operate as continuous data streams with frequent status updates that increase the quantity, and therefore granularity, of the data that is collected compared to other methods (see the Digital subsection in the Wired Communication Networks section). An LLLC can use a gateway or central controller to communicate to system-wide control schemes or to external systems.

LUMINAIRE ZONING

Zoning is a key system design consideration. A zone is a set of luminaires that respond together to a control signal. The smaller the zone, the more refined the lighting and energy management. The larger the zone, the simpler and less costly the set up. With LLLC, each luminaire can be its own zone (the ultimate in granularity) for certain capabilities (e.g., daylight responsive controls) as well as part of larger zones for others (e.g., occupancy sensing, time scheduling). Zones should consist of one luminaire type to ensure compatibility between the luminaire driver and other control devices.

Wireless Communication Networks

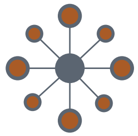
Wireless communication eliminates the need for controls wiring in fully networked as well as independently controlled room-based systems. Wireless systems are particularly useful in renovation applications and where ceiling access is difficult. Wireless components can also easily be reconfigured for future renovations. Wireless control systems use digital radio frequency (RF) communication to transmit data and are typically structured as hub, mesh, or point-to-point topologies, or some combination of the three.

While some systems employ genuinely open communication protocols, most systems today are proprietary to some extent. The proprietary nature ensures interoperability between devices within the ecosystem; however, communication among devices from different manufacturers can be inconsistent and product compatibility is key. RF communication protocols can be applied in a variety of topologies, as product and manufacturers determine.

Wireless RF signals are not limited to line-of-sight, but individual devices are limited in signal range (typically specified in manufacturer literature) and can be affected by building materials. Networks also have limits on the number of nodes they can support, which varies by system. Common wireless protocols include Zigbee and qualified Bluetooth mesh.

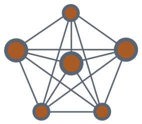
WHAT IS A NODE?

In wireless and wired systems, nodes facilitate communication between devices and can send and/or receive a control signal. In a hub network, nodes typically communicate to the gateway, while in a mesh network, nodes communicate with each other. Nodes may be standalone devices; however, they are typically integrated with controllers, sensors, switches, or gateways. As a result, many devices in a mesh network are often referred to as nodes because they are necessary for communication in each device.



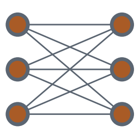
Hub

A central access point, often housed in a hub or gateway, sends and receives signals from other nodes in the networked components, which do not communicate to each other. The hub or gateway(s) should be installed in locations that will provide RF coverage for all devices communicating with the device. In some cases, luminaire controllers may have the ability to act as boosters or repeaters to extend signal strength. Providing more hubs may increase communication speed and reliability, but will also increase the cost. This topology may also be referred to as a “star” network.



Mesh

In mesh networks, all devices communicate as nodes in the network and multiple, redundant paths between devices exist to sustain communication when a single device fails. Employing a mesh network can improve system resilience, increase the signal strength shared between devices, and increase the expanse of the network. Mesh networks can exist without a gateway if a connection to a central server, external building systems, or applications is not needed.



Point-to-Point

Unlike hub and mesh networks, point-to-point network signals are typically limited to a single space. Nevertheless, such systems may be connected to one another by using a gateway. Often, point-to-point connections may be utilized for communication between components within larger systems or to incorporate battery-powered devices (e.g., audio/visual controls, local controls, etc.).

Wired Communication Networks

Against the costs and limitations of running wires to the control system, wired systems offer a degree of cybersecurity compared to wireless systems due to the need for on-site access. Wired systems transmit control signals using analog or digital communication protocols. A comparison is provided in Table 2.

Analog

Analog communication sends a control signal over low-voltage conductors wired to each luminaire. Two common analog control methods used in lighting systems, phase dimming and 0–10V, only support one-way communication which limits system feedback and reporting. Analog control zones are determined by the control wiring; changing control zones requires rerouting the control wires, which can be quite costly.

0–10 V is a commonly used analog control signal, widely supported by manufacturers and familiar to most commercial installers. For luminaire control, 0–10 V load capacities limit the number of fixtures that can belong to a single group. 0–10 V controls require 0–10 V compatible drivers and other components.

Some advanced capabilities are not compatible with 0–10 V luminaires, but can be successfully implemented with a digital load converter. These include lumen maintenance, external system integration, demand response, energy measurement and reporting, system diagnostics and reporting, wayfinding, asset tracking, and occupant counting.

SYSTEM ATTRIBUTE	ANALOG	DIGITAL
Data Exchange	One-way	Two-way
Luminaire Addressability	No	Yes
Zoning Flexibility	Determined by wiring	Can be reconfigured in software

Table 2. Analog and digital wired system comparison.

Digital

Digital communication also requires dedicated low-voltage conductors. Importantly, digital networks can provide a one-way or two-way transfer of information, including system commands and data reporting. Addressable devices permit granular data collection and communication as well as reconfigurable zones of control. Rezoning is typically implemented from a software application.

Data exchange may occur in a continuous or repetitive scheme, or a command-and-response scheme in which the data are sent once and are not resent until there is a change in the conditions or a different response is received. Trade-offs in data quantity and quality should be considered for capabilities that require data capture from lighting equipment.

Wired digital protocols include the Digital Addressable Lighting Interface (DALI) standard, manufacturer-specific protocols, proprietary variations, and the entertainment-oriented DMX512, which is widely used for multi-channel color mixing.

As a network technology, low-voltage direct current (DC) systems with digital controls can send and receive data from each connected unit or device.

DC power and control signals can be delivered independently or in a single ethernet cable, as in a Power over Ethernet (PoE) system. These systems can support Wi-Fi access points, security cameras, and telephones, as well as light-emitting diode (LED) luminaires and sensors. PoE systems require a network device, called a switch, for signal and power, as well as DC luminaire drivers.

System Components and Functions

System components have different communication strategies depending on the scale of the system and the task at hand. Some control devices can facilitate one or more functions depending on the specific system, as summarized below. Each manufacturer or controls system may use unique language or terminology for the same controls components; see the **Component Details** section for examples.

Servers store and share data captured by sensors or other building systems and house the programming information for the lighting system. A local or cloud-hosted server typically acts as the central controller and houses most of the intelligence for a centrally controlled lighting system.

In some systems, the function and intelligence of the server is integrated into the gateway itself, eliminating the need for a server unless there is a requirement for storing and sharing data or remote monitoring.

Gateways (also known as a hubs or bridges) translate between networks with different protocols. The gateway may also house network routing and access points, which create the network and enable communication. The location of the gateway(s) in wireless systems should be considered to ensure adequate signal strength to communicate with other devices.

User Interfaces include wall switches, touchscreens, computers, and mobile devices. They send commands to load controllers and some can display system information.

Sensors detect occupancy, light levels, or other environmental conditions. More advanced sensors may be employed to track assets or personnel, count occupants, or assist with wayfinding capabilities. Sensors can be installed on the ceiling or wall, in a luminaire, or in a wall switch.

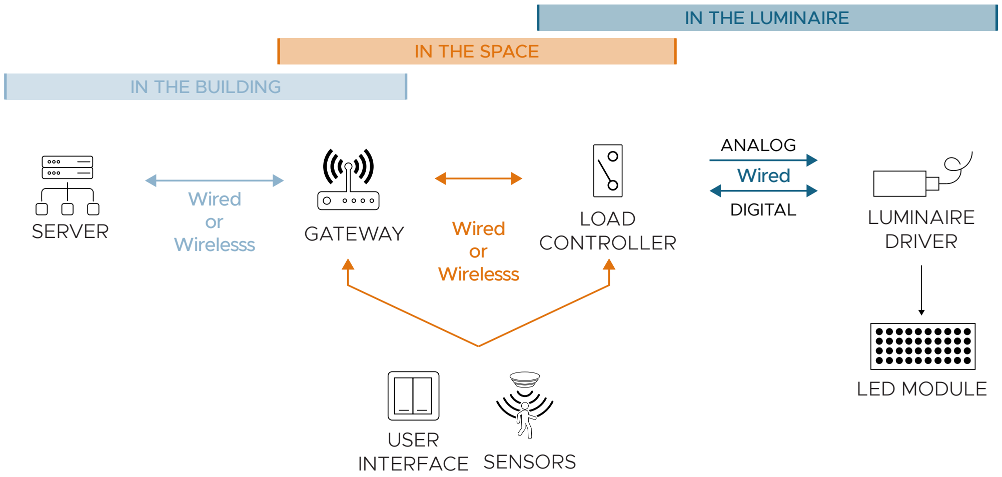


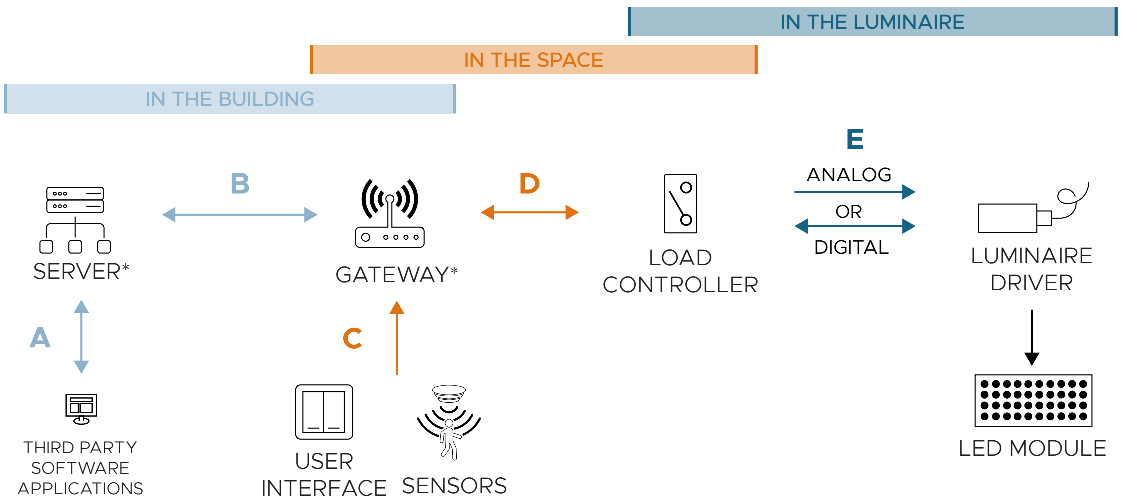
Figure 3. Schematic system architecture describing the location of each controls component and the possible communication methods used for data exchange.

Load Controllers, typically relays, power packs, or dimming modules, send and/or receive commands to execute a lighting change. Load controllers may be separate devices or packaged with a driver, user interface, or sensor.

Luminaire Drivers, together with the LED array(s), are part of the load. Critically, the signal or protocol of the control system and that of the driver must be compatible.

Schematic Example - Centralized Intelligence

The following schematic diagrams depict how distinct lighting control components communicate with one another and where each component is typically located: within the luminaire itself, within the room or space, or within the building. They are examples and will not represent all lighting control systems.



A Internet

B HARD-WIRED:
Ethernet

WIRELESS:
Wi-Fi

C HARD-WIRED:
Ethernet

WIRELESS:
Bluetooth Low Energy (BLE), Zigbee, Thread, etc.

D HARD-WIRED:
Ethernet

WIRELESS:
BLE, Zigbee, Thread, etc.

E HARD-WIRED:
Low-voltage wiring

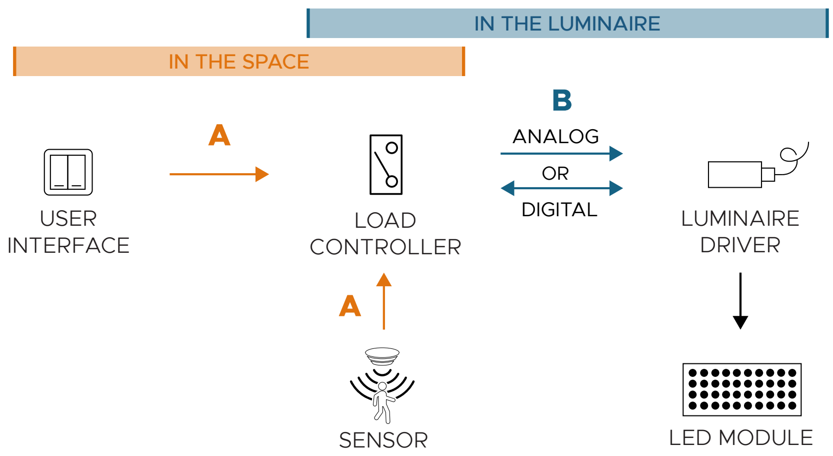
Analog (one-way) - 0-10V
Digital (two-way) - DALI 2, DMX 512, manufacturer specific, etc.

*In most systems, the gateway or a local server will act as the central controller.

Not all systems will require a connection to external applications or other building systems via a gateway or server. In some systems, the load controller may be integral to the driver, the sensors, or the user interfaces.

Figure 4. Schematic diagram of lighting control system components and possible communication strategies for a networked system with centralized intelligence.

Schematic Example - Room-Based System



A HARD-WIRED:
Ethernet

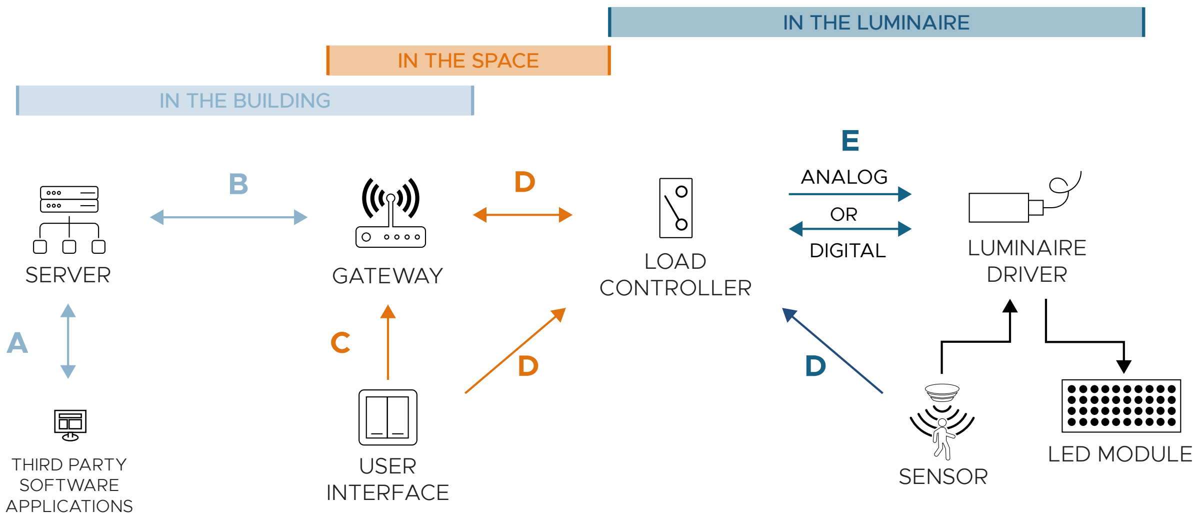
WIRELESS:
BLE, Zigbee, Thread, etc.

B HARD-WIRED:
Low-voltage wiring

Analog (one-way) - 0-10V
Digital (two-way) - DALI 2 (including D4i drivers), DMX 512, manufacturer specific, etc.

Figure 5. Schematic diagram of lighting control system components and possible communication strategies for a room-based system.

Schematic Example - Luminaire Level Lighting Control System (LLLC)



Not all systems will require a connection to external applications or other building systems via a gateway or server. In some systems, the load controller may be integral to the driver, the sensors, or the user interfaces.

A Internet

B HARD-WIRED:
Ethernet

WIRELESS:
Wi-Fi

C HARD-WIRED:
Ethernet

WIRELESS:
BLE, Zigbee, Thread, etc.

D/D HARD-WIRED:
Ethernet

WIRELESS:
BLE, Zigbee, Thread, etc.

E HARD-WIRED:
Low-voltage wiring

Analog (one-way) - 0-10V
Digital (two-way) - DALI 2 (including D4i drivers), DMX 512, manufacturer specific, etc.

Figure 6. Schematic diagram of lighting control system components and possible communication strategies for an LLLC system. Lighting control systems may not contain each component described; however, it is important to understand how each component interacts with the rest of the system.

Control Intent Narrative (CIN)

The earliest version of the **CIN** is typically developed during Schematic Design and translates the owner's objectives into the general control capabilities that will be applied to each space or function of the project.

Control capabilities above and beyond owner requests that are implemented to satisfy code requirements should be documented explicitly to avoid misunderstanding. The design should reflect the interpretation of local enforcement authorities (i.e., authority having jurisdiction [AHJ]), as well as the written code requirements.

During Design Development, the next iteration of the CIN should also include the intended approaches to system scale, networking, building integration, communication, and user-interfaces. Decisions, such as the use of digital protocols or integral sensors that support luminaire-level lighting control, are also incorporated into the CIN.

Although the CIN often benefits from the clarity of minimal detail, the intent and desired outcome should be unambiguous. The CIN should be written in plain language to clearly communicate the design objectives to all members of the project team.

WHAT SHOULD BE INCLUDED IN A CONTROL INTENT NARRATIVE?

The CIN is typically organized by space type. Include an overview of the control strategies and capabilities deployed in each space to satisfy project objectives and code requirements.

- System scale
- Networking and communication requirements
- Existing conditions (where applicable)
- Sensor functionality requirements
- User interface and local control intent
- Application of automatic and/or manual lighting control
- Accent or specialized lighting features
- Emergency lighting approach

Sequence of Operations (SOO)

The SOO provides installers and commissioning personnel with the detailed instructions necessary to set up the system so that it can realize the expected outcomes of the use cases and CIN. Like the CIN, the SOO applies to each space or function. The SOO is typically written during Design Development.

After the final system has been selected, review the specific terminology and forms used during programming to ensure all items are addressed and clearly stated in the SOO. Be sure to align the description of desired behaviors within the scope or operation of the specific, final system.

Specifications and Drawings

Specifications and drawings also provide critical information necessary for the unambiguous implementation of the controls system. These may include specifications for controls equipment, protocols, and single-line diagrams for wiring. Directions for system integrators and user training also form part of the specification document. Maintaining a comprehensive record of decisions, including why a certain system or luminaire was not selected, will help resolve questions as design progresses; it will also strengthen the specification.

Locations for control equipment are typically shown on electrical drawings, along with single-line wiring diagrams. Directions for labeling user interfaces may be located on schedules, incorporated in the SOO, or added as notes on drawings. As long as repetitive information in documents is not inconsistent, placing information in multiple documents can reinforce helpful information and respond to the varying practices of installers and other members of the project team.

All materials in the controls design and specification need to be complete and consistent. Gaps and conflicts in the various documents often leave installers and commissioning personnel uncertain as to what is desired or how to accomplish general objectives and who may be contractually responsible for any additional labor required to address system performance shortcomings.

WHAT SHOULD BE INCLUDED IN A SEQUENCE OF OPERATIONS?

The SOO should document specific behaviors and settings described in the CIN. Language should be prescriptive and contractually enforceable.

- Light levels
- User interface engraving and functionality
- Scene programming
- Occupancy or vacancy sensor setpoints and methods
- Time-based controls and schedules
- Daylight-response setpoints and methods
- Night lighting and emergency lighting methods, zoning, and triggers

Capability Details

The functional capabilities of a lighting system determine the range of outcomes it can deliver and the use case(s) it supports. Some capabilities are mandated by state energy codes; others are discretionary. The task and use of the space typically drives the need for control functions. Most spaces will employ several control strategies and control system capabilities.

Risk Factors

Technology Availability (TA)

- ○ Capability is ubiquitous in lighting controls systems.
- ◐ Capability is offered in an upgraded tier of most controls systems.
- ● Availability in current market is limited to specialized or advanced systems.

Communication Requirements (CR)

- ○ Basic communication or does not require an exchange of data.
- ◐ Capability may require communication between devices within the lighting controls system. Standardized methods for data exchange may be required.
- ● Capability requires communication between devices or networks outside of the lighting controls system.

TIME SCHEDULING ○ ○

CODE COMPLIANCE

A programmable clock signals lights to turn on or off, dim, or change color, according to the hour or day of the week. Astronomical clocks adjust for seasonal, latitude-related differences in sunrise and sunset. As an alternative to sensor-based control for automatic shutoff, time-based control provides lower savings and requires override capability for interior spaces.

IMPLEMENTATION NOTES: In non-networked systems, scheduling can be easily implemented with timeclocks that control lighting circuits or switchlegs at the panel. Hybrid or fully networked lighting control systems use computer software or the building management system to implement time scheduling.

OCCUPANCY SENSING ○ ○

CODE COMPLIANCE

Turning lights on, off, or dimming automatically when a space is occupied or unoccupied is one of the simplest and most cost-effective strategies for localized energy savings. Lighting that is controlled in occupancy mode will automatically turn the lights on when an occupant is sensed and off when the space is unoccupied; vacancy mode will turn the lights off when the room is unoccupied and a manual switch is required to turn lights on. False triggering that turns lights off in occupied spaces is a major source of user complaints, which often leads users to disable the sensor, contributing to energy inefficiencies. Inadequate coverage, poor location, and inappropriate sensitivity settings all contribute to false triggering. The sensitivity of some sensors can be adjusted in the field to improve performance.

DAYLIGHT-RESPONSIVE CONTROL ○ ○

CODE COMPLIANCE

Also Known As: Daylight-Responsive Dimming and Daylight Harvesting

Daylight-responsive control – prioritizing daylight by dimming electric light – is mandated by energy codes for many interior spaces. Photosensors with closed-loop logic adjust electric lighting to maintain the contribution of electric light and daylight so that the horizontal illuminance does not drop below a target level. Open-loop logic, typical for exterior lighting, switches lights on and off, or dims to preset levels, based only on incident daylight or time of day. Some systems use both open- and closed-loop logic in the same system depending on the application.

DIMMING ○ ○

CODE COMPLIANCE
ENHANCED LIGHTING PERFORMANCE

Adjusting lighting levels (and power) for different visual tasks, personal preference, or environmental conditions both improves the luminous environment and saves energy. The quality of dimming (range, curve, consistency, and cost) varies with drivers and dimming protocols.

SCENE CONTROL

ENHANCED LIGHTING PERFORMANCE

The light output (or color) of multiple luminaires is adjusted to create different overall lighting effects. Each effect is configured as a preset in the control system and is recalled by pressing a button on a user interface or a signal from a clock, sensor, or external device. Preset scene control provides conveniently initiated lighting effects for different activities or times of day.

TUNABLE WHITE

ENHANCED LIGHTING PERFORMANCE

Light-emitting diode (LED) arrays of different colors can be separately dimmed to create a blended color of light at different levels of light output. Color tuning can be used to stimulate both visual and physiological responses. "Tunable white" generally combines two arrays: one with warm color temperature and the other with cool. Two control channels and two-channel drivers (or two drivers) are required.

Warm dimming, which emulates the dimming of incandescent sources, is a simplified approach where a single channel provides a preset combination of color and light output.

Three or more LED arrays offer more color options but require more complex and generally costly controls than for static white lighting; current experience suggests that problems are more common as well.

IMPLEMENTATION NOTES: Tunable white control can be handled by either familiar analog or digital signals. If analog controls are used, response to the same signal may vary between luminaire manufacturers. Color mixing, on the other hand, typically requires special digital control, such as digital multiplex (DMX; see System Architecture).

TASK TUNING

ENHANCED LIGHTING PERFORMANCE
ENHANCED ENERGY MANAGEMENT

Also Known As: High-end Trim and Institutional Tuning; related to Personal Tuning

Luminaires are configured by the control system to operate at a dimmed level (until reconfigured), setting a lower maximum output than the luminaire can otherwise deliver. High-end trim is a popular energy-saving strategy where the lighting system in its full-output mode exceeds light level requirements. Task tuning at the room, floor, or building level is also called institutional tuning. Personal tuning is a more complex approach that refers to individual luminaire control often manipulated by end users via a mobile app or other software interface.

LUMEN MAINTENANCE

ENHANCED LIGHTING PERFORMANCE
ENHANCED ENERGY MANAGEMENT

To compensate for the loss of light output over LED lifetimes, luminaires may be selected that initially provide higher light levels when the system is new, so that when the light levels depreciate over time, there is still adequate light. The control system can be programmed to reduce this "excess" light output at the outset to match the target light level and save energy, and then gradually increase luminaire output as light output depreciates.

IMPLEMENTATION NOTES: Lumen maintenance can be programmed into capable drivers, monitored by photosensors, or achieved by reconfiguring the institutional tuning level over time.

MOTORIZED SYSTEM CONTROL

ENHANCED LIGHTING PERFORMANCE
ENHANCED ENERGY MANAGEMENT
ENHANCED FACILITY PRODUCTIVITY

Control over simple motorized systems, such as window shades, projection screens, and audiovisual (A/V) equipment, provides convenience and can be provided manually, through preset controls, by sensors or scheduling.

PLUG LOAD CONTROL

CODE COMPLIANCE
ENHANCED ENERGY MANAGEMENT

The sensors or timeclocks that control luminaires can also control the outlets that supply plug loads, which can consume significant amounts of energy when in idle mode for long periods. Cost can be high (especially for smaller projects) and user annoyance and circumvention is a major risk. Plug load control can be a capability of the lighting control system, or it can be achieved with sensors located with the controlled outlets, which may be a simpler and less costly approach.

IMPLEMENTATION NOTES: Plug load controls are required by many energy codes; however, they are not required to be incorporated into the lighting system. The most basic form of plug load control is accomplished using a timeclock that is not integrated with the lighting control system. If plug load controls are integrated with the lighting system, they may utilize occupancy status or timeclock control.

DEMAND RESPONSE

ENHANCED ENERGY MANAGEMENT

Also Known As: Load Shedding and Grid Interaction

During a demand response event, a utility offers an opportunity or incentive to reduce lighting and reduce motor loads when peak electricity demand stresses the grid and the generating stations that supply it. For buildings, the primary benefit of grid interaction is improved grid reliability and resiliency. Participating in demand response utility programs can better align peak loads to available renewable energy sources and contribute to decarbonization of the grid.

IMPLEMENTATION NOTES: This capability requires installation of a server or dedicated end node that can communicate externally. Cybersecurity risks should be discussed with the appropriate members of the project team.

Demand response operational profiles may be incorporated directly into a system during programming or accessed via an Application Programming Interface (API). API queries (e.g., the workflow to be implemented to send and receive a signal or exchange data) should be thoroughly tested before deployment. Open Automated Demand Response (OpenADR) is a non-proprietary, standardized interface commonly used to communicate demand response signals.

EXTERNAL SYSTEM INTEGRATION

ENHANCED ENERGY MANAGEMENT
ENHANCED FACILITY PRODUCTIVITY

Connection to more complex systems, sharing sensors and their measurements, reporting, and monitoring dashboards can assist facility managers in optimizing building systems, such as HVAC and security, as well as streamlining operations. Setup and troubleshooting are major contributors to cost.

IMPLEMENTATION NOTES: Typically requires a gateway, server, or other device to interface with the central control system and a server to store and transmit data to third-party applications. BACnet is a commonly used ASHRAE, ANSI, ISO standardized communication protocol for building automation and controls (BAC).

ENERGY MEASUREMENT AND REPORTING

ENHANCED ENERGY MANAGEMENT
ENHANCED FACILITY PRODUCTIVITY

Energy data collected from advanced LED drivers (e.g., D4i or ANSI C137.4 compliant drivers) or dedicated measurement equipment can be used to track system performance, optimize system parameters, and secure utility incentives. Quality and format of the data will vary between systems, which can affect usefulness; utility incentive programs often mandate specific requirements.

IMPLEMENTATION NOTES: Energy reporting at the luminaire level requires two-way (digital) communication between the driver and central system processor or gateway or a dedicated measurement device.

SYSTEM DIAGNOSTICS AND MONITORING

ENHANCED ENERGY MANAGEMENT
ENHANCED FACILITY PRODUCTIVITY

Remote system diagnostics permit maintenance and service personnel to address problems rapidly and with reduced cost. Reporting that compiles data also aids in improving performance. The alternative, on-site investigation by third parties to identify and address problems in the lighting and control systems can be very costly. Systems with remote access can allow service companies or manufacturers into the lighting control system for support, updates, service, and troubleshooting.

IMPLEMENTATION NOTES: Requires two-way (digital) communication between the driver and central system processor or gateway. Diagnostic capabilities range from simple status alerts to detailed, product-specific maintenance information.

INDOOR POSITIONING

ENHANCED FACILITY PRODUCTIVITY

Also Known As: Real-time Location Services and Wayfinding

Nodes or sensors communicate with enabled personal devices, such as phones or ID badges, to provide indoor positioning. Combined with mapping applications, this capability can assist in navigating unfamiliar facilities or guiding users through retail or cultural displays. User concerns about privacy should be considered upfront.

IMPLEMENTATION NOTES: While the lighting system contains the sensors or nodes used to facilitate indoor positioning, most of the functionality stems from components outside of the lighting system. A local or cloud-based server is required to store data and communicate with other software applications.

ASSET TRACKING

ENHANCED FACILITY PRODUCTIVITY

Also Known As: Real-time Location Services

A variety of technologies – sensors, RF tags, and beacons – can identify and locate valuable equipment and therefore minimize idle, misplaced, or stolen assets. Data capture and display are key to effective utilization of this capability and add to system cost.

IMPLEMENTATION NOTES: Similar to indoor positioning, advanced sensors embedded in the lighting system can facilitate the communication required to locate assets; however, most of the functionality occurs outside of the lighting system in third-party software applications. A local or cloud-based server is required to store data and communicate with other software applications.

OCCUPANT COUNTING

ENHANCED FACILITY PRODUCTIVITY

Special sensors that determine the number of occupants in a space provide granular data that can improve long-term facility planning, emergency intervention, and real-time space allocation. Data capture and display are key to effective utilization of this capability and add to overall system cost.

IMPLEMENTATION NOTES: Advanced sensors (and cameras) capable of counting individual occupants (as opposed to detecting occupancy) are required. A local or cloud-based server is required to store data and communicate with other software applications.

GATEWAYS

Also Known As: Hubs, Bridges, and Central Processors

A gateway is a physical device that acts as a translator between networks with different protocols. Gateways may also include an access point that establishes the network and routing functionality to connect to a server or external building system. Gateways that are not connected to the internet can facilitate capabilities such as scheduling and energy monitoring across the installation; however, an internet connection is necessary for more advanced capabilities. The location of the gateway(s) in wireless systems should be considered to ensure adequate signal strength to communicate with other devices.

LOAD CONTROLLERS

Also Known As: Power Packs, Dimming Modules, and Relays

A controller is a device that sends and/or receives a command to execute a change. Load controllers may be separate physical devices or integral to a luminaire driver (common for digital systems) or other control device such as a user interface or sensor.

LUMINAIRE DRIVER

Although luminaire drivers are typically included in luminaire specifications, it is critical to document the compatibility between the luminaires, drivers, and the controls system, as some controls manufacturers only interface with specific drivers (and luminaires).

It is the driver manufacturers responsibility to identify the correct protocol for its driver; the specifiers role is to specify appropriate luminaires and a controls system that use the same protocol.

NODE

A node is a communication device that sends and/or receives control signals in both wired and wireless systems. Nodes may be standalone devices but are typically packaged with sensors, controllers, or user interfaces. Nodes in a mesh network pass information node-to-node, while centrally controlled nodes will typically communicate via a gateway. Some systems limit the number of nodes that can be connected to each gateway.

SENSORS

Simple sensors may be employed to detect occupancy, light, or other environmental conditions. More advanced sensors may be employed to track assets or personnel, count occupants, or assist with wayfinding capabilities.

Sensors may be integral to the luminaire or wall switch or they may be mounted in the ceiling. For simple sensor capabilities, this decision will most likely be driven by the form factor of each luminaire, as not all luminaires (e.g., downlights) accommodate integral sensors. If more complex sensor capabilities, such as asset or personnel tracking, are desired, sensors integrated into some or all luminaires can provide a more granular sensor network and adequate coverage for better performance. Luminaire-integrated sensors can provide granular coverage and reduce installation cost; however, luminaire location determines the sensor locations, which may not be ideal.

SERVERS

Lighting-control servers may include BACnet servers, specifically dedicated for building system management, or locally or cloud-hosted servers that facilitate remote management, connect to utility programs for demand response incentives, or store data for other purposes such as space utilization or asset tracking. Servers can store and share data captured by sensors or other building systems.

In some systems, the function and intelligence of the server is integrated into the gateway itself, eliminating the need for a server unless there is a requirement for storing and sharing data or remote monitoring.

USER INTERFACE

User interfaces can include wall switches, remote control devices, scene controllers, touchscreens, central computer-based systems, or software-based control. They send commands to load controllers and some can display system information.

Additional Resources

For more information regarding the specification and documentation of a lighting control system, see the following:

- ANSI/IES LP-6-20 “Lighting Control Systems – Properties, Selection, and Specification”
- ANSI/IES LP-16-22 “Documenting Control Intent Narratives and Sequences of Operations”
- Pacific Northwest National Laboratory “Understanding the Potential of Connected Lighting Systems”
- Pacific Northwest National Laboratory “Strategies for Success with Connected Lighting Systems”
- Integrated Lighting Campaign “Integrated Lighting Resources”

    https://integratedlightingcampaign.energy.gov/resources
- Lighting Controls Association Web Resources

    https://lightingcontrolsassociation.org/resources/

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