COURSE EE101: INTRODUCTION TO LIGHTING CONTROL

INTRODUCTION

A good lighting design includes a good controls design. Lighting controls play a critical role in lighting systems, enabling users manually or automatically to:

- turn the lights ON and OFF using a switch; and/or
- adjust light output up and down using a dimmer.

This basic functionality can be used to generate these benefits for the lighting owner:

- flexibility to satisfy user visual needs; and/or
- automation to reduce energy costs and improve sustainability.

In recent years, lighting controls have evolved two additional capabilities:

- adjust light source color, including shade of white light; and/or
- generate data via measuring and/or monitoring.

EE101: Introduction to Lighting Control provides an overview of the basic functionality of today's lighting controls, benefits and the basic questions to ask when identifying an appropriate lighting control strategy.

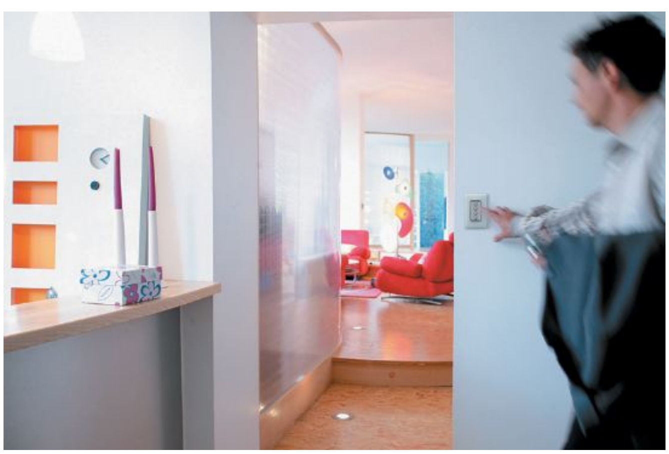

Photo courtesy of Schneider Electric.

LEARNING OBJECTIVES

By the end of this course, you will be able to:

- Explain the functionality and benefits of lighting controls.
- Recommend lighting controls to clients based on benefits appropriate for various applications.
- Identify lighting control strategies based on inputs and outputs.
- Match lighting control strategies to applications.

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LIGHTING CONTROL EFFECTS AND BENEFITS

LIGHTING CONTROL EFFECTS

Lighting controls provide the following basic functions. End-users harness these functions to support energy management and/or visual needs.

WHAT	HOW
Produce the right amount of light …	Light output (intensity) dimming
… where the light is needed …	Zoning of luminaires to controllers
… and when the light is needed.	Automatically reduce lighting when the space is unoccupied

LIGHTING CONTROL EFFECTS

Lighting controls are evolving to provide advanced functions, which vary in availability depending on system type and application need.

WHAT	HOW
Produce light at the right color or shade of white light …	Separately dimming arrays of LEDs with different colors or white-light correlated color temperatures (CCTs)
… allow remote programming and control …	Control systems with programming and lighting management capability
… and tell you how your lights are performing.	Centralized intelligent control systems with measuring and/or monitoring/alarm capability

BENEFITS: VISUAL NEEDS

By adjusting the intensity of one or more layers of lighting in a space, lighting controls can:

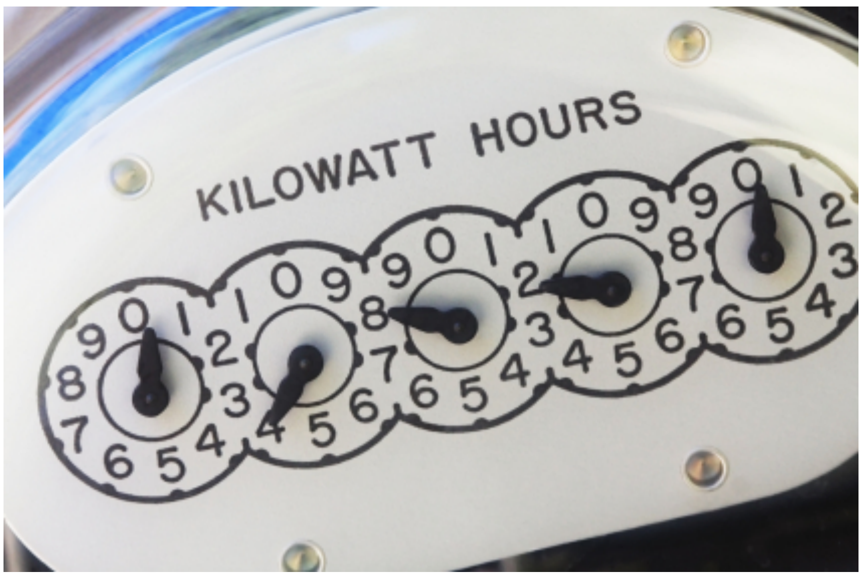
- change space appearance;
- facilitate different functions of the space;
- alter atmosphere and mood;
- reduce glare; and/or
- increase user satisfaction by providing users the ability to control their lighting.

Images courtesy of Finelite.

BENEFITS: ENERGY MANAGEMENT

By reducing lighting ON time, intensity or zoning, lighting controls reduce both demand and energy consumption. According to a Lawrence Berkeley National Laboratory (LBNL) study, popular lighting control strategies produce 24-38% average lighting energy savings, which reduces building operating costs.

Because of strong energy savings, the majority of state commercial building energy codes require a wide range of controls in new construction. In existing construction, the controllability of LED lighting results in an ideal pairing with controls, combining to minimize energy costs.



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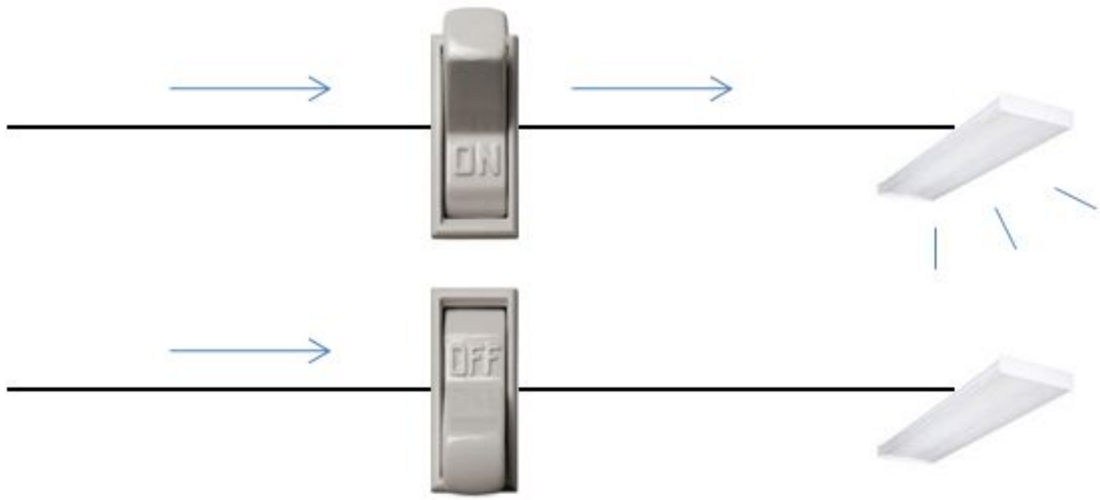
BASIC CONCEPTS

BASIC FUNCTION

Lighting controls are input/output devices and systems. The control system receives information, decides what to do with it, and then adjusts lighting power accordingly. Here we see a basic lighting circuit (switch leg). Power travels along the circuit to energize a group of lights. This lighting system supplies illumination.

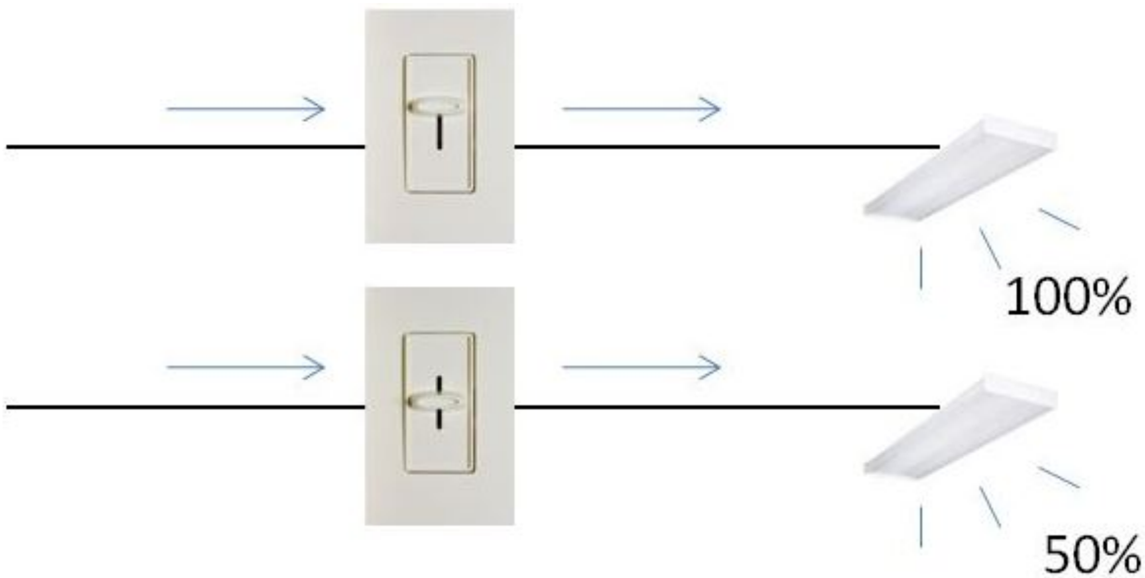
SWITCHING

One basic output is switching. Here we see a switch placed on the line between the power source and the load. When the switch closes (i.e., switch is flipped “ON”), the circuit completes, allowing power to flow to the load. When it opens, the circuit breaks (switched flipped “OFF”), which disrupts power to the load. This makes the switch a power controller.



DIMMING

Another basic output is dimming. If a dimmer-switch is used, in addition to ON/OFF, it can alter current flowing through the load during the ON state, which raises or lowers light output. Here we see a dimmer placed on the line, with the output being continuous dimming over the load's dimming range.



COLOR AND CCT CONTROL

With LED, it is relatively economical to provide users the ability to adjust lighting color and CCT.

With tunable-white LED products, separately dimming arrays of warm- and cool-white LEDs allows users to adjust light source CCT. Other colors may be added to enhance the available color spectrum and ensure good color rendering.

Two other approaches are dim-to-warm (LED products that dim to a very warm white similar to incandescent dimming) and full color tuning (separately dimmable red, green and blue LEDs plus amber or white and potentially other colors).

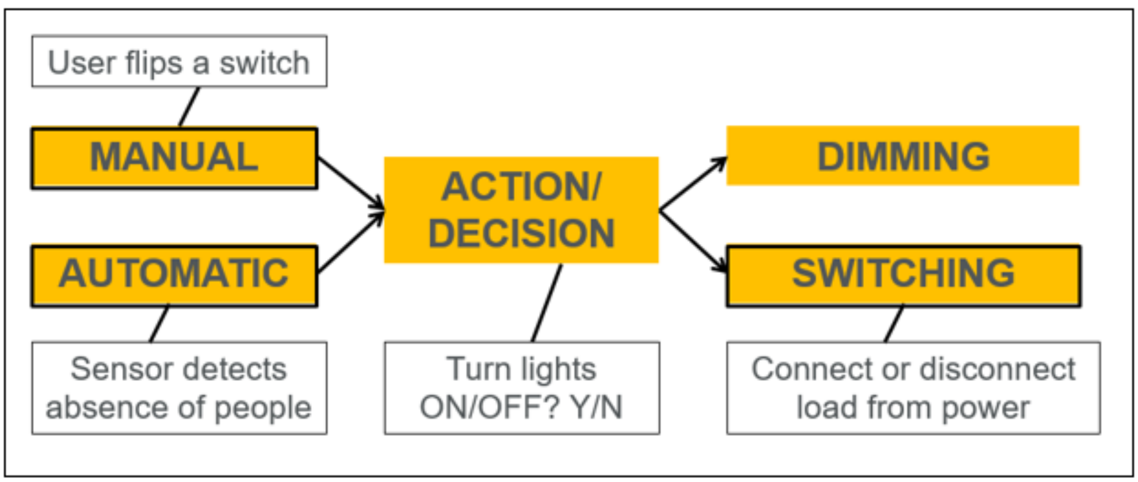
Image courtesy of USAI Lighting.

MANUAL VERSUS AUTOMATIC INPUT

The input may be manual, automatic or a combination of the two, as shown in this drawing depicting the functionality of a manual-ON wallbox occupancy sensor.

With manual control, the input is user-initiated and implemented by hand. It is ideal for applications driven by visual needs.

With automatic control, a signal from a sensor (occupancy or light sensor), computer or another building system provides the input. The input may be based on time of day, occupancy, light level or some other condition. Automatic control is ideal for energy management applications.

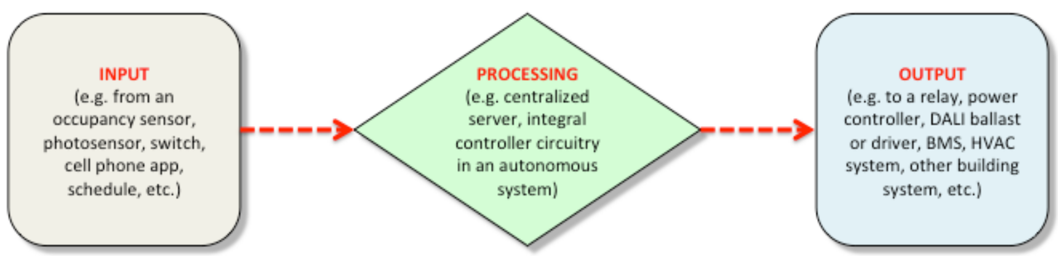


MANUAL-ON OCCUPANCY (VACANCY) SENSOR

INTELLIGENCE

With manual control, a human makes decisions about whether to adjust the lighting and by how much. With automatic control, a microprocessor or logic circuit performs this function. This microprocessor or logic circuit is called the lighting controller, which provides the control system's intelligence. The lighting controller evaluates input control signals based on its algorithm and decides whether to adjust lighting power, when to adjust it, and by how much.

The controller may be installed as a logic circuit within a standalone control device or as a separate component within a control system. If a separate component, it may reside in a central location (centralized intelligence) or reside in proximity to the load or embedded in luminaires (distributed intelligence). The more distributed the system's intelligence, the more flexible and responsive the lighting becomes.



SWITCHING VERSUS DIMMING OUTPUT

Often, both switching and dimming will be desirable in the same building.

Switching is simple but limited in flexibility and can be disruptive in spaces occupied by more than one user. As a result, it's particularly effective for energy management applications such as automatic shutoff or reduction in vacant spaces, as well as manual control in spaces where user(s) have a unified expectation when the lights will be switched.

Dimming changes intensity with smooth transitions between light levels, resulting in a high level of flexibility that can satisfy user visual needs. The majority of LED luminaires feature dimmable drivers as a standard or standard option, reducing the cost of dimming. Dimming is particularly suited to visual needs applications and for enacting energy management strategies, such as daylight-responsive or task tuning control, in occupied spaces.

Image (right) courtesy of Schneider Electric.

CONTROL ZONING

Control zoning is an important aspect of lighting control system design, as zoning is the mechanism through which lighting controls are assigned to lighting loads. A control zone is defined as one or more light sources controlled simultaneously by a single control output. Zones may be organized in accordance with energy codes, desired energy savings and flexibility, common lighting equipment (e.g., fluorescent vs. LED), space characteristics (e.g., furnishing and finishes), tasks, daylight availability and lighting schedules.

Smaller control zones (higher granularity of zones in a space or building) introduce greater flexibility and typically higher energy savings. For this reason, a majority of energy codes regulate control zoning by imposing limits on area.

Traditionally, control zoning and future rezoning was limited by lighting circuit wiring. Advances in communications enable relatively economical zoning as granular as individual luminaires or ballasts/drivers, and zoning and rezoning using software instead of hardwiring.

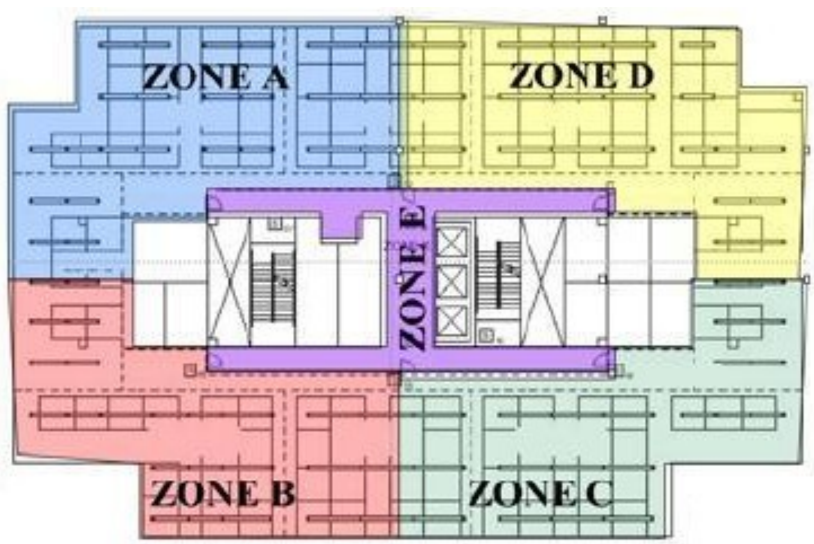


Image courtesy of Wattstopper.

CONTROLS NARRATIVE

Another important aspect of lighting control system design is definition of the sequence of operations for the system. The sequence of operation is a description of system outputs in response to various inputs for each control point. It is expressed as the controls narrative, a written document produced during the project conceptual design phase. This document serves as a project roadmap for the intended lighting control system.

Specifically, it can be used to:

- support contract document and specification preparation;
- provide clear direction during bidding to contractors and manufacturers;
- identify criteria for testing and accepting the control system; and
- serve as a general reference for the owner detailing how the control system operates.

INTEROPERABILITY

For a control system to provide proper operation, the ballast/driver and light source must be compatible; the ballast/driver must be compatible with the control strategy and control devices; and the control devices must be able to communicate if needed.

Largely, interoperability depends on control method or protocol. A protocol is a set of rules that define the behavior of components in a system. In a network, this includes communication. Examples include the Digital Addressable Lighting Interface (DALI) and ZigBee. All controls must be designed to the same protocol to provide reliable interoperability, though different-protocol systems, including lighting and building automation, may integrate using a gateway, which may be a device or software function. The protocol may be:

- open, or standardized and available to all manufacturers, which provides multivendor choice;
- closed, or manufacturer-specific, which provides a solution optimized by the manufacturer but ties the owner to that manufacturer for future service, changes or expansion; or
- a mix of the two, such as an open protocol adapted to become manufacturer-specific, or a manufacturer-specific protocol that is made available to other manufacturers through licensing.

Note that 0-10V dimming is a method, not a protocol. Controls and ballasts/drivers designed for 0-10V dimming therefore may be interoperable but produce somewhat different dimming performance. This is because they dim the same way but otherwise do not perform in accordance with the same uniform specifications. To ensure consistent dimming, it is recommended to avoid mixing ballast/driver types from different manufacturers in the same dimming system.

SOFTWARE

Various apps and software support implementation of lighting control systems. The most robust software is available for centralized intelligent networked lighting control systems. Residing on a server or in the Cloud, the software may provide many functions, such as:

1) discover control points (devices, etc.)
2) assign control points to zones
3) program sequences of operation for zones
4) calibrate sensors
5) monitor control points and issue service alerts/alarms
6) record and display energy use and other recorded data
7) back up data and event logs and create users/access levels

Image courtesy of Lutron Electronics.

WIRED SYSTEMS

Control devices may communicate using:

- **Line-voltage wiring**, also called powerline communication or phase-control dimming. When used for control, line-voltage wiring provides a path for both power and control signals. While simple, it is not flexible, limiting control options.
- **Low-voltage wiring.** When used for control, low-voltage wiring provides a dedicated pathway for control signals, which manifest as variations in voltage. Because this type of wiring is not limited to conduit, it is flexible. However, each shared function requires its own wire, resulting in the potential for a large number of low-voltage wires with associated risks of miswiring.
- **Digital low-voltage wiring.** This type of low-voltage wiring transmits control signals comprised of digital binary messages instead of variations in voltage. A pair of wires forms a bus, or transmission path for control signals connecting multiple luminaires and control devices that communicate. Control zones are created using software instead of hardwiring. The operator may program and calibrate the control devices remotely. The wiring potentially is bi-way, allowing collection of data from sensors.

Low-voltage control wiring is typically transported in bulk and cut in the field. Structured wiring options are available, such as factory-installed terminations with RJ45, RJ11 or other connectors, which can simplify installation though they require predetermined wire lengths.

WIRELESS SYSTEMS

Wireless controls communicate using radio waves or some other wireless approach, eliminating control wiring. This is particularly attractive for implementing sophisticated controls in existing buildings. Control input devices may be powered by an internal battery or by harvesting energy from ambient light, temperature differential or mechanical energy produced by flipping a switch. They communicate control signals from a wireless transmitter to a wireless receiver in a lighting controller, which is installed at the luminaire, a junction box or at a panel.

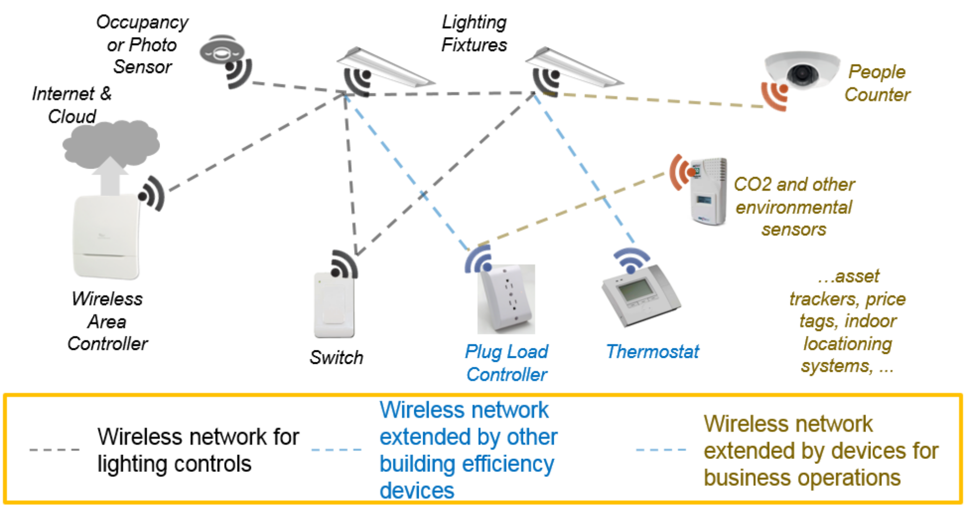
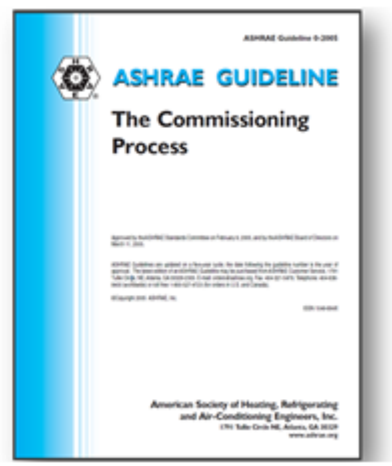


Image courtesy of Daintree.

COMMISSIONING

Commissioning is a recommended quality assurance process that ensures that installed lighting control systems operate in accordance with manufacturer recommendations and construction documents. The Commissioning Process is defined by ASHRAE Guideline 0 (and summarized in IES-DG-29) and requires a number of steps, including Owner Project Requirements, Basis of Design, functional testing, systems manual and operator training. Some commissioning activities are required by the latest commercial building energy codes. To support commissioning, manufacturers offer devices that are either self-calibrating or are easier to calibrate.



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LIGHTING CONTROL STRATEGIES

CONTROL STRATEGIES

Combining various inputs and outputs results in several unique lighting control strategies available that can address visual needs, energy management needs, or both. In turn, control strategies can be combined in the same space via layering to maximize value.

- Manual control
- Occupancy sensing
- Time scheduling
- Daylight response
- Institutional task tuning
- Color tuning
- Data generation
- Demand response

MANUAL CONTROL

Manual control is a simple strategy providing users the capability of choosing light levels either in steps (switching) or over a wide range with smooth transitions between levels (dimming). Visual needs drive manual control, though it may save energy as a byproduct. Typical applications include private and open offices, meeting and education spaces, houses of worship, entertainment venues and other spaces. According to LBNL, this strategy can result in 31% average lighting energy savings.

Switching may be ON/OFF or multilevel via separate ON/OFF control of separate ballasts/drivers or luminaires. Dimming may be continuous, providing smooth transition across a dimming range, or stepped, providing either an abrupt or a smooth transition between two or more fixed outputs.

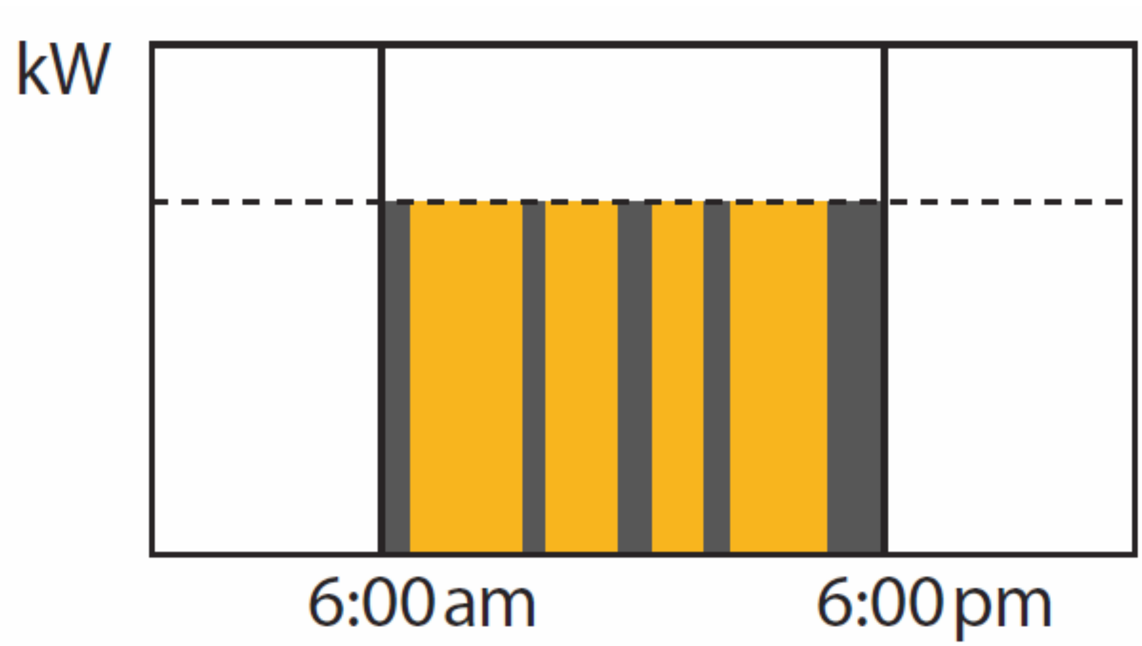
Image courtesy of Lutron Electronics.

OCCUPANCY SENSING

Occupancy sensors are devices that automatically turn the lights ON and OFF based on whether the space is occupied. By ensuring the lights are ON only while the space is occupied, occupancy-based strategies realize 24% average lighting energy savings, according to LBNL.

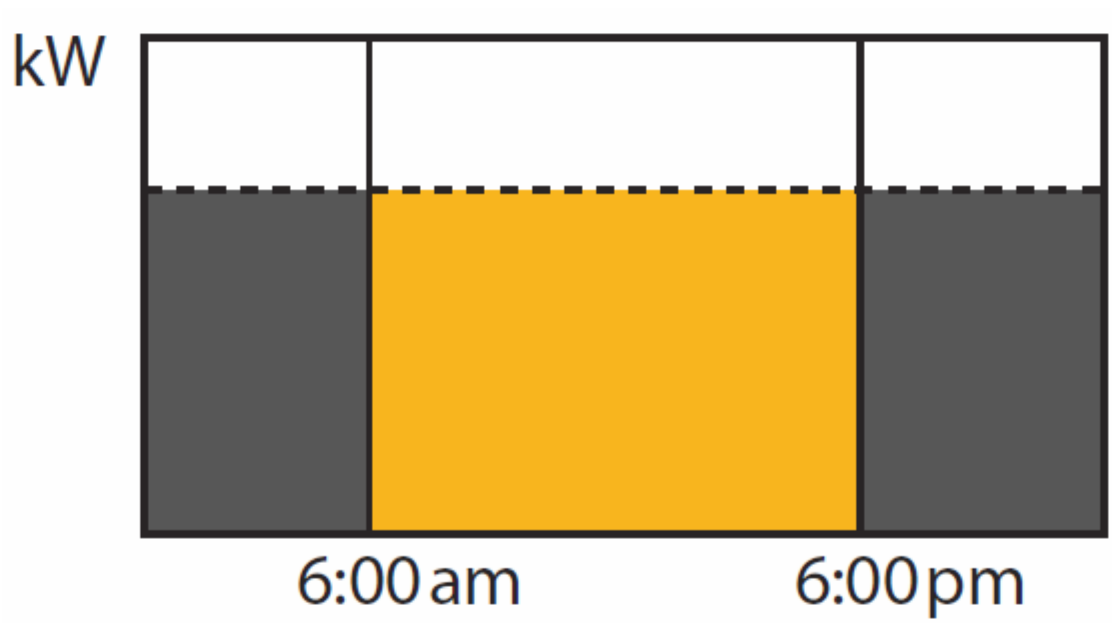
Occupancy sensors are highly suited to smaller, enclosed spaces that are intermittently occupied, such as private offices, classrooms, conference rooms, copy and break rooms, restrooms and other spaces. They may be networked for larger spaces.

If the sensor provides automatic shutoff but requires manual-ON, it is commonly called a vacancy sensor. Alternately, the sensor may automatically turn the load on to 50%, with manual operation via a switch needed to turn the lights ON to full. These sensors are commonly called partial-ON occupancy sensors.



TIME SCHEDULING

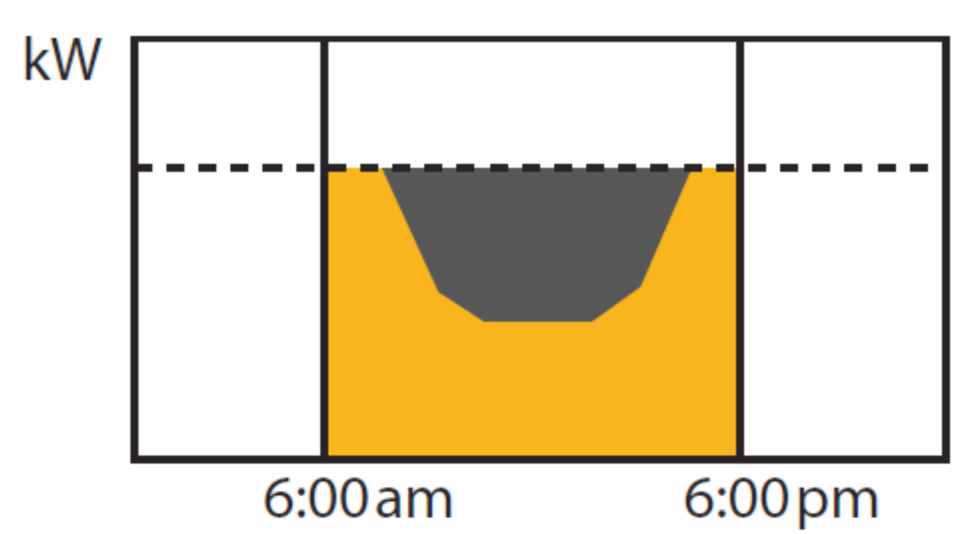
Scheduling adjusts the output of the lighting system based on a time event implemented using a time-clock, which may be implemented using a microprocessor built into the control system. At certain times, controlled lights will turn ON, OFF or dim to either save energy or support changing space functions. Scheduling is highly suitable for larger, open spaces that are regularly occupied as well as spaces that are intermittently occupied but where the lights must remain ON all day for safety or security reasons. Local override (time extension) wall controls are often used to allow for irregular use of the space. Occupancy-based strategies (lumping together time scheduling with occupancy sensing) can realize 24% average lighting energy savings, according to LBNL.



DAYLIGHT RESPONSE

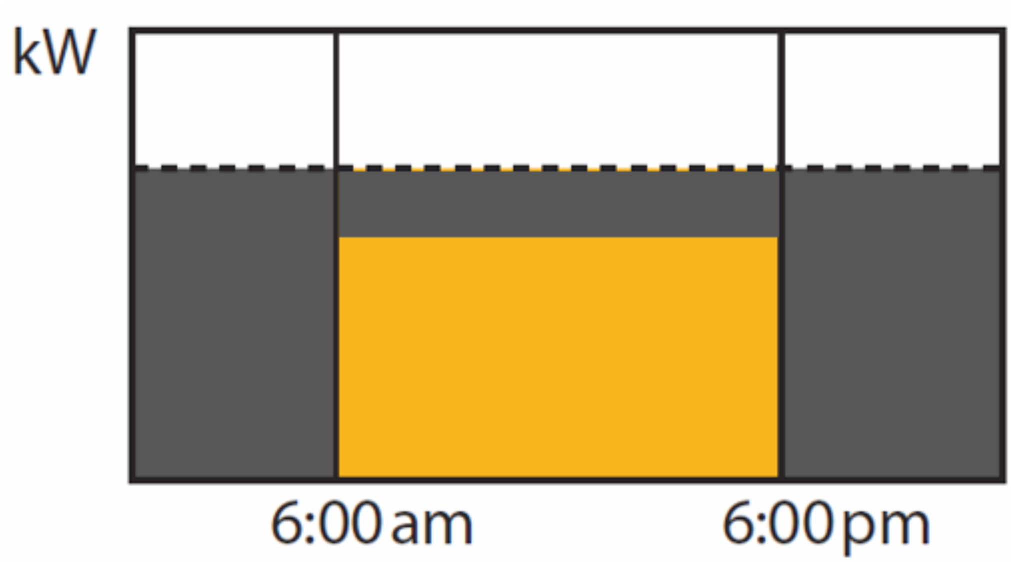
Daylight-responsive control (also called daylight harvesting) uses a light sensor (also called a photosensor or photocell) with a power controller to switch or dim lighting in response to available daylight. As light levels rise above a target threshold due to daylight contribution, the photosensor signals the controller to reduce light output, thereby saving energy. According to LBNL, daylight-responsive control can generate 28% average lighting energy savings.

This strategy is highly suitable for lighting zones adjacent to windows and clerestories and under skylights and roof monitors—anywhere daylight is consistent and plentiful.



TASK TUNING

Also called “institutional tuning” and “high-end trim,” task tuning involves reducing lighting in a space based on IES-recommended maintained task light level requirements or user preference for individual spaces rather than the originally designed maintained light levels, which may be higher than needed. According to LBNL, task tuning generates 36% average lighting energy savings.



COLOR TUNING

By separately dimming red, green, blue and potentially other color LEDs, virtually any color can be produced. This is called color tuning. Color tuning is suitable for entertainment, signage and similar applications. By separately dimming arrays of warm- and cool-CCT white LEDs, luminaire CCT can be adjusted across a range, which is called tunable-white lighting. Below are several examples of opportunities for tunable-white general lighting:

- Automatically shift to a very warm CCT during dimming to imitate incandescent dimming.
- Dynamically calibrate CCT across installed luminaires and maintain the designated CCT over time.
- Adjust CCT after initial installation to fine-tune the appearance of spaces and objects such as art.
- Adjust CCT to accommodate changing space use, displays, interior finishes and user preference.
- Automatically adjust CCT to produce an idealized daylight cycle or optimally blend with actual daylight.
- Imitate the color appearance of popular traditional light sources and customize new light sources.
- Play a potential role in circadian lighting, as light rich in blue wavelengths acts as a circadian stimulus.

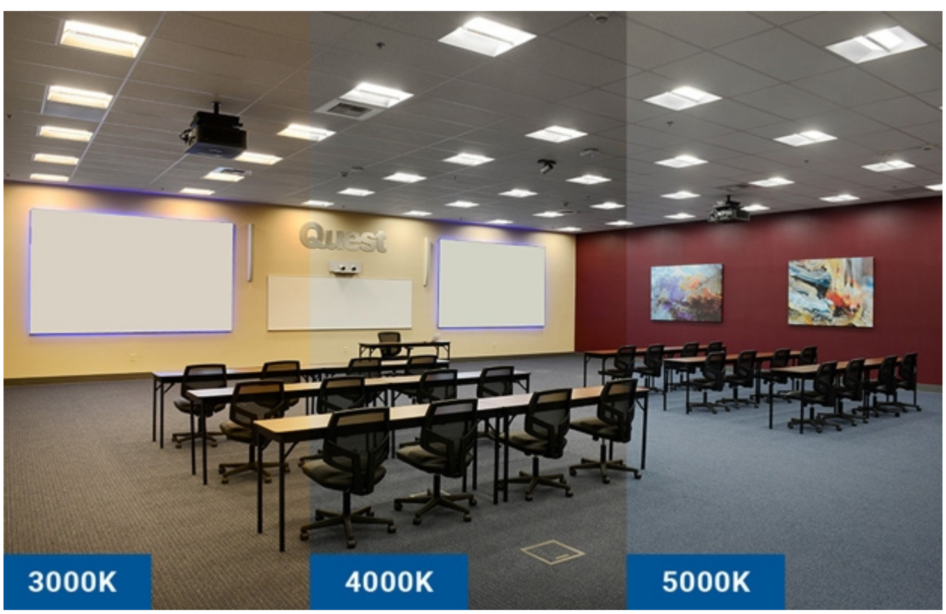


Image courtesy of Cree, Inc.

DATA GENERATION

Some lighting control systems allow data collection from control points connected via a digital network. The system may directly measure or estimate energy consumption and/or monitor operating parameters. Additional sensors may collect data such as occupancy and temperature. In some outdoor lighting control systems, other sensors may be added that collect data on everything from carbon monoxide to snowfall.

Data feeds to a server or the Cloud for retrieval and use via software. Energy consumption data may be analyzed and shared for a variety of purposes. Monitored conditions may prompt alarms for maintenance response, such as the example shown here.

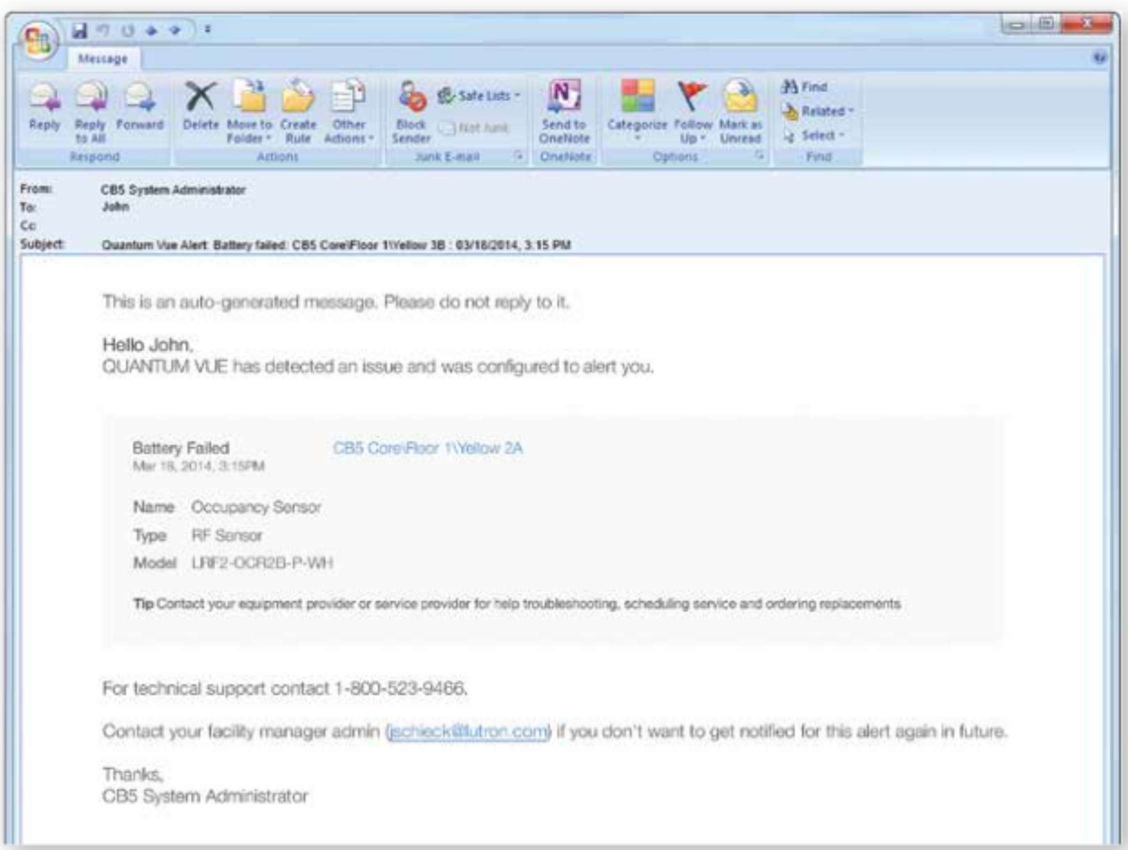


Image courtesy of Lutron Electronics.

DEMAND RESPONSE

Demand response (DR) involves reducing lighting power either upon request from the power supplier during an emergency event (emergency DR), or based on time of day to minimize demand costs (economic DR). As a significant portion of the typical building's lighting load can't be turned OFF during operating hours, this typically entails dimming.

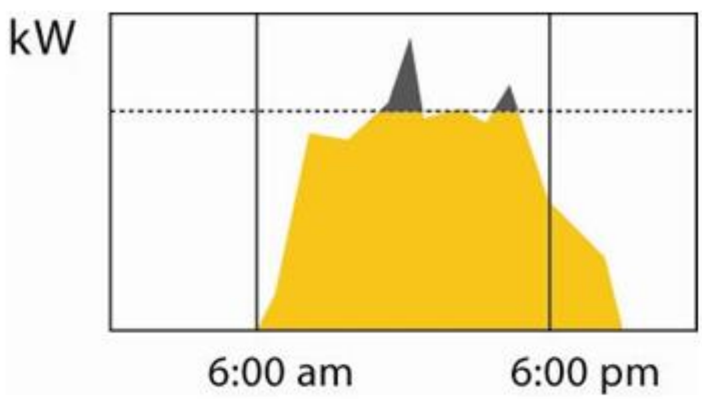


Image courtesy of OSRAM Encelium.

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GENERAL TYPES OF CONTROL SYSTEMS

GENERAL TYPES OF LIGHTING CONTROLS

Lighting controls may be categorized as:

- Standalone devices
- Room-based control systems
- Centralized building control systems

STANDALONE CONTROLS

Standalone controls are control devices designed to provide autonomous operation of a lighting load, which may be a luminaire or luminaires installed on a switch leg. They typically install on the AC power line and directly control the load.

Examples include toggle switches, occupancy sensors, timer switches, dimmers, light sensors and hotel keycard switches.

The advantages are they are relatively simple to install, are familiar to installers, and do not require connection to a lighting controller. The disadvantages are adjustable standalone controls require individual calibration, and layering multiple control strategies on the same load can result in complex wiring.

Image courtesy of Wattstopper.

STANDALONE EMBEDDED SENSORS

Standalone occupancy and light sensors may be mounted in or attached to luminaires for autonomous luminaire control. Typically, sensors are specified via the luminaire manufacturer and installed at the factory. However, they may be specified from a control manufacturer for relatively simple field attachment. The controls may offer options such as dimming or switching to a lower light level during vacancy instead of turning OFF. If the luminaires dim instead of shut OFF, additional scheduling control may be needed to provide energy code-compliant shutoff.

The advantage of this approach is individual luminaire control, which maximizes energy savings and responsiveness, but without additional wiring. A concern is that autonomous individual luminaire control may produce a mix of ON, dimmed and OFF states on the ceiling, which may present an aesthetic tradeoff.

Images courtesy of Leviton.

ROOM-BASED CONTROL SYSTEMS

Room-based control systems include a package of lighting controllers and input devices designed to offer plug-and-play installation, out-of-the-box energy code compliance, and autonomous room-based operation.

The majority of room lighting controllers feature manual switch, occupancy and light sensor inputs; 2-3 relays for switching; and 2-3 dimming outputs for dimming. Typically, Ethernet cabling connects switches and sensors to the controller. Line-voltage wiring connects the lighting controllers and the luminaires. For dimming, the controller transmits signals via line- or low-voltage wiring. The controllers install near the luminaires.

These systems often feature preconfigured sequences of operation for easy energy code compliance. Some systems enable the controllers to connect with each other and to a central server for scalable centralized networked lighting control. The advantage of this approach is simplicity.

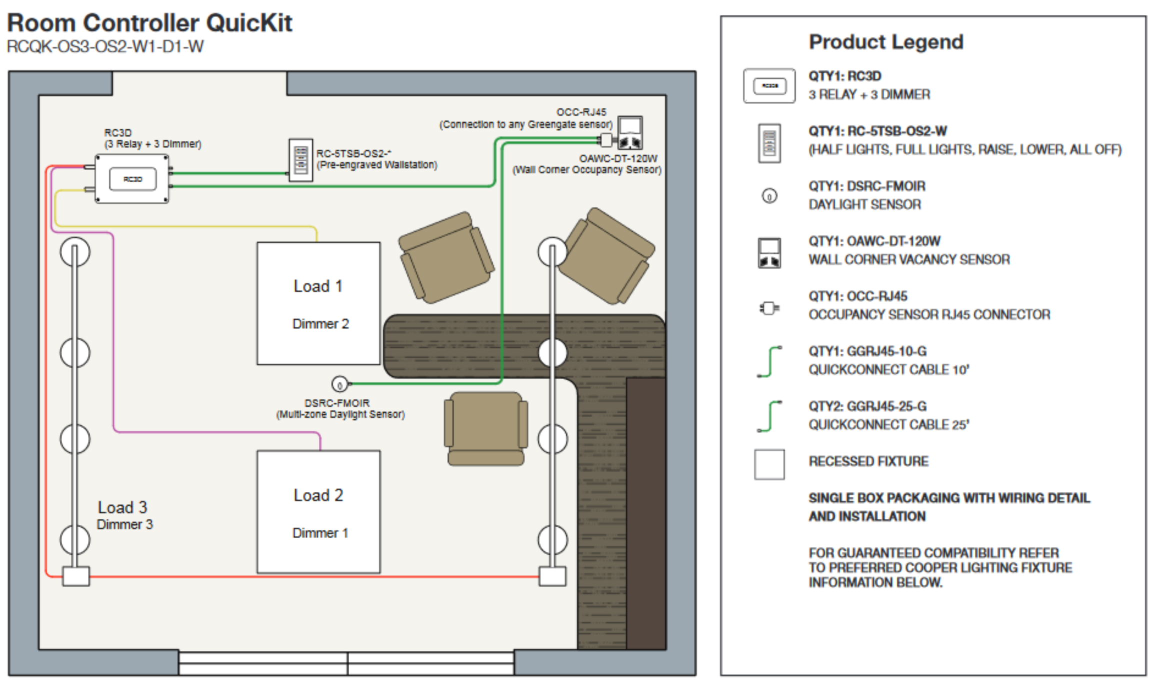

Image courtesy of Eaton.

LUMINAIRE-BASED NETWORKED SYSTEMS

In this type of approach, LED luminaires feature factory-installed embedded sensors and lighting controller. The lighting controllers have unique addresses within the lighting network, enabling them to be grouped and programmed. Many solutions feature preconfigured sequences of operation to simplify setup and provide energy code compliance. Controllers are connected using low-voltage wiring or wirelessly using radio waves. Some systems offer the capability to assign luminaires to groups and program them using a handheld IR remote. Control zoning is not limited to switch legs. Some systems permit interfacing with building management systems, a central server or other networks.

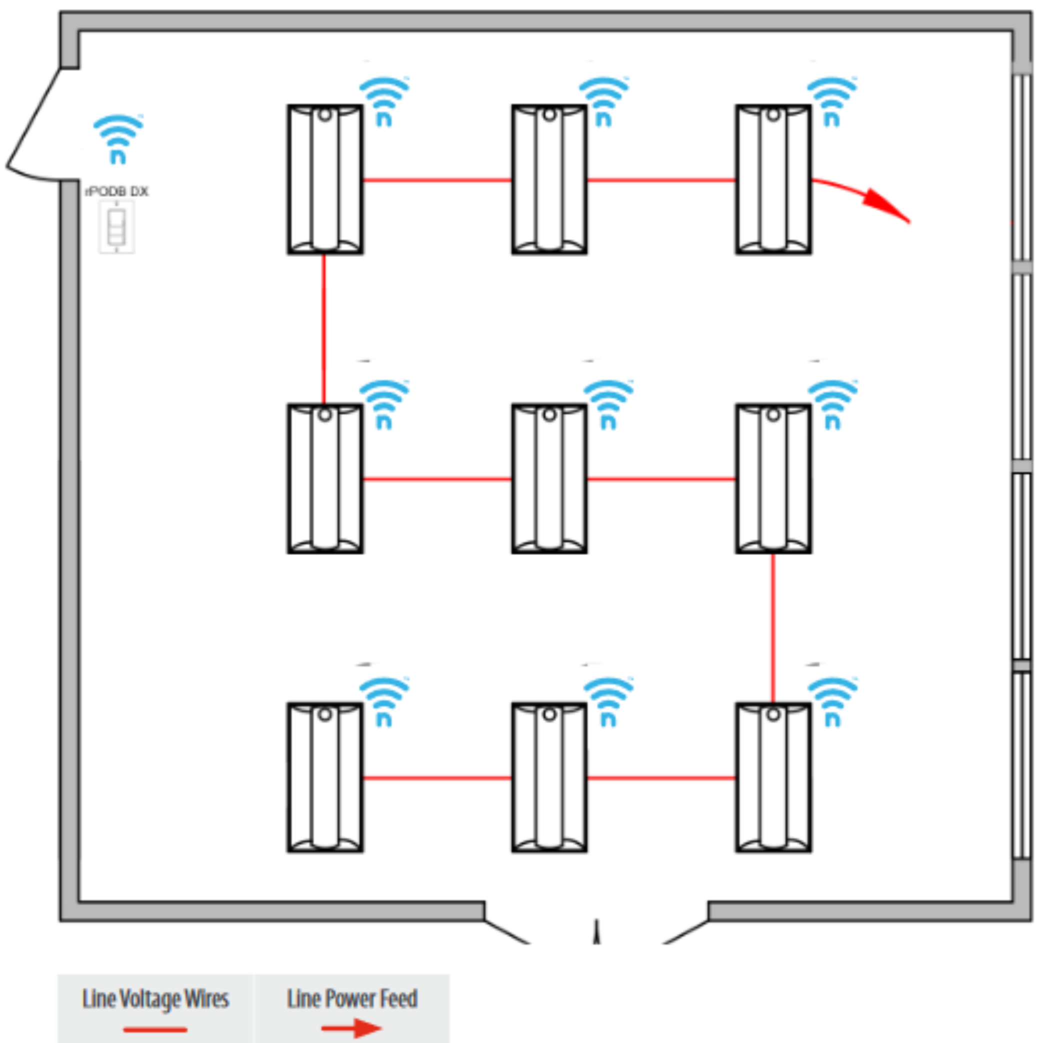

Image courtesy of Acuity Brands.

ROOM-BASED NETWORKED SYSTEMS

This approach embeds a lighting controller in each luminaire, but the sensors install outside the luminaire. Luminaires and input devices are connected typically using Ethernet or other low-voltage wiring, forming a network of individually addressable/controllable luminaires. This allows luminaires to be zoned and rezoned individually or in groups and with multiple control strategies. Programmable features may include scheduling, target light levels and time delays. Some systems permit interfacing with building management systems, a central server or other networks.

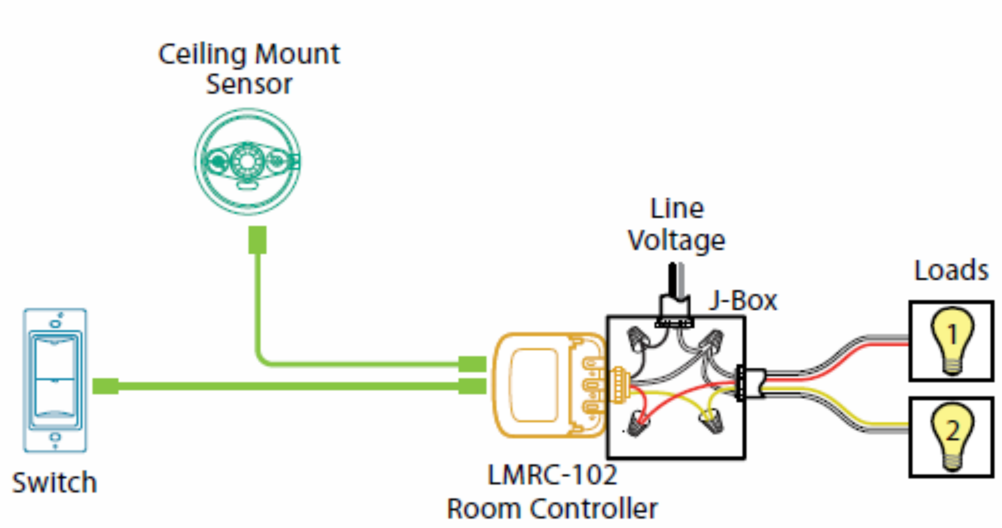

Image courtesy of Wattstopper.

TRADITIONAL BUILDING-LEVEL CONTROL

Traditionally, lighting automation at the building level was implemented using control panels, typically housed in a central location such as an electrical room. These panels are metal enclosures housing relays, contactors, remotely operated circuit breakers or dimmer modules. A typical low-voltage panel has low-voltage inputs for control signals and line-voltage outputs for controlling the loads. Intelligent panels feature an integral lighting controller for assigning input devices to loads plus scheduling of control functions. Connecting local switches to the panel allows local override of scheduled shutoff so users aren't left in the dark afterhours.

This approach centralizes lighting control and can be integrated with building management systems but offers limited flexibility in control zoning. Each zone requires low-voltage wiring run back to the panel.

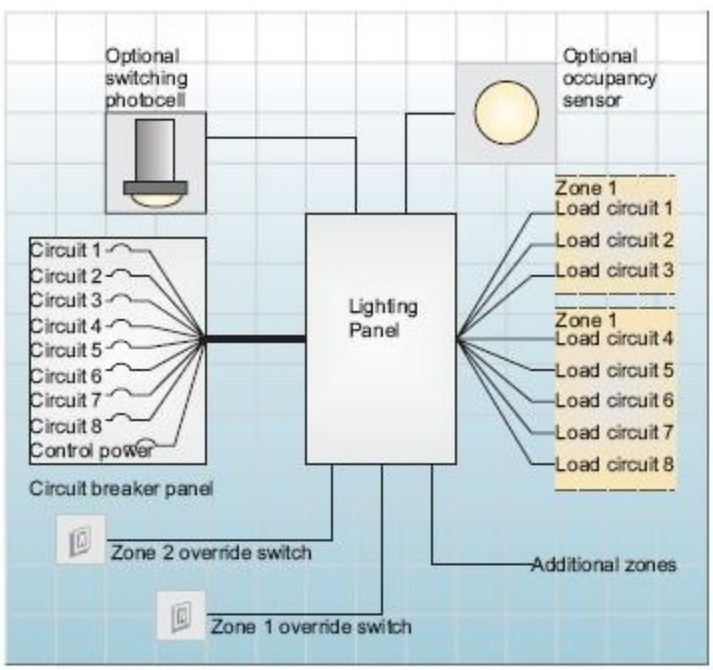

Image courtesy of New Buildings Institute.

CENTRALIZED INTELLIGENT NETWORKED CONTROL SYSTEMS

Centralized intelligent networked control systems provide programmable lighting control for entire floors, buildings or campuses. They may be an extended-feature option of a room-based control solution or packaged as a comprehensive system. Operating software and data reside on a central server or in the Cloud.

Luminaires are individually addressable within a network, enabling zoning and rezoning using software, maximizing flexibility. Luminaires accept control input signals from a wide variety of control devices, enabling a full range of control strategies including complex sequences of operation. A major advantage of this type of system is energy consumption, occupancy, luminaire/zone status and potentially other data can be recorded, stored and displayed for energy analysis and maintenance purposes.

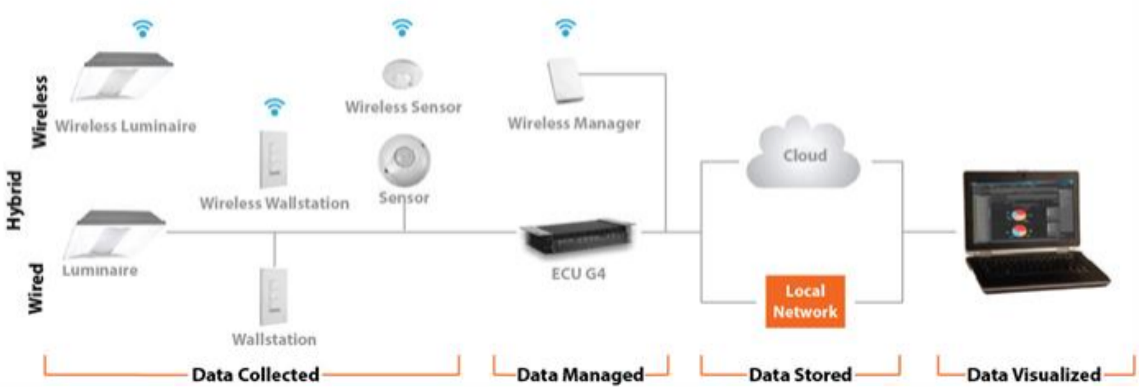

Image courtesy of OSRAM Encelium.

YOU'RE FINISHED

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