6.7.5 Wireless. Wireless technology sends modulated radio signals through the air in certain licensed or unlicensed frequency bands. Wireless-enabled devices are ubiquitous in today's computing environment. Businesses, universities, and home users alike are taking advantage of the easy deployment of wireless devices to provide network connectivity without the expense associated with wired connections. Standards for these transmissions are determined by governmental agencies such as the U.S. Federal Communications Commission (FCC) and Industry Canada, with respect to which frequencies or channels may be used. Also, multiple standards exist in regard to the addressing and channel access mechanisms, modulation, and other features that allow devices to exchange information. It is important to note that when using a wireless solution, it is prudent to be aware of other wireless systems nearby and to ensure that all devices meet the appropriate government agency's regulation, such as the FCC Title 47 CFR Part 15 for the U.S.[35] and ICES- 003 for Canada.[36] Unfortunately, the wireless medium is inherently unreliable with respect to assured delivery of data. Therefore, significant work is required to better understand the characteristics of the wireless environment, provide secure connections, and ensure delivery of data.

6.7.5.1 Wireless Control Features and Considerations. Due to the potential savings in installation time and cost they offer, wireless controls are increasingly being implemented in indoor lighting systems and in exterior areas, parking facilities, and roadway lighting, particularly as new LED lighting systems are increasingly being deployed.

Some operational features are applicable to both wired and wireless control systems, but certain features can only be realized with wireless technologies. For instance, access to data, protocol standardization, centralized or distributed processing, and IoT connectivity are features of both wired and wireless controls, but other features, such as location tracking and wireless device integration, are attributes of only wireless systems. **Table 6-1** provides a summary of features and capabilities of lighting controls as realized in wired and wireless systems. In considering which technology to use, there is not one correct answer but instead a more advantageous choice for a given application.

Table 6-1. Lighting Product Control and Networking Comparison

	Location Tracking	Integration with Other Wireless Devices	Luminaire, Device Networking – Distributed Intelligence	Standard Protocols	Data Collection	Sensing	Roadway and Site Lighting	Open Area Interior Deployment	Retrofits
Wired			x	x	x	x	x	x	x
Wireless	x	x	x	x	x	x	x	x	x

The trade-offs that should be considered when selecting a wireless communications implementation include:

- **Location tracking.** Because of the comparative ease of retrofit into existing building lighting, wireless control systems lend themselves to location-based capabilities such as fault detection and diagnostics, and personnel and asset tracking, as well as other value-added functions.
- **Integration with other wireless devices.** Integration of, for example, occupancy sensors with HVAC systems is more easily accomplished via a wireless lighting controller integrated with a gateway device for communication among building systems.
- **Luminaire and device networking.** Luminaires featuring integrated controls and networking capabilities are increasingly being implemented. From an installation standpoint, although power needs to be supplied to the luminaires via some type of wiring regardless of the controls implementation, a wired system may require additional cabling for communication, whereas a wireless system will not.
- **Standard protocols.** The use of standard networking protocols enables easier implementation for both wired and wireless control systems as well as other building systems. Selecting a wireless control system that can interface with existing wireless building infrastructure simplifies

integration of the lighting controls into the top-level building network.

- **Data collection and storage.** Whether the implementation is wired or wireless, luminaires and/or sensors might either store data locally and provide it only when queried or provide it to the network controller at a preset interval. However, because low-cost microcontrollers with smaller memory are often used, data stored at the luminaire or sensor level may be limited, and transfer will need to occur on a regular basis to avoid data loss.
- **Sensing.** Occupancy sensors, motion sensors, and daylight sensors are the most common sensing devices in lighting systems, but other types of sensors can be incorporated into luminaires.
- **Roadway and site lighting.** Roadway lighting is the most challenging to implement in terms of communication among devices. Challenges include greater distances between nodes, and attenuation due to precipitation and foliage. Wireless signal propagation is limited and is addressed through the design of the network architecture. The cost of running wires over considerable distances is a limiting factor for both roadway lighting and other types of exterior lighting such as parking lots, making a wireless system more practical.
- **Open-area interior deployment.** In open-plan offices, wireless control devices can be easily relocated to accommodate modifications to the furniture layout, without the need for running additional control or communication wiring.
- **Retrofits.** The main challenge with retrofit projects involves working with the existing lighting system and building infrastructure. Facilitating changes to the lighting design may be prohibitive due to limitations of existing lighting and lighting control equipment. For example, dimming may be precluded when existing luminaires are not 0-10V-enabled, resulting in lower total energy savings. In addition, wireless communication may be impeded by building structure, physical barriers, or interference from other existing equipment, such as other RF communications systems or devices. It is important, therefore, to fully understand the overall objectives of the retrofit design when deciding whether wired or wireless controls are better suited for the project.

Some other considerations when evaluating whether to use wired or wireless control systems include:

- **Total project costs.** These include product and installation cost, commissioning cost, and cost of ongoing product support. In the past, wireless controls were considered an option of last resort in situations where running wires was not possible, but as the cost of wireless products has decreased, wireless controls are no longer necessarily more expensive overall. Commissioning for wireless systems is generally more complex and therefore costlier, as the commissioning process may be complicated by requirements for device identification and establishment of communications. Evolution in networking technology is alleviating the challenges of commissioning wireless control systems, with a resultant decrease in overall project cost.
- **System configuration flexibility.** “Wireless” does not always translate to “no wires”; the term *wireless* refers to the means of communication. Unless they are battery-operated, luminaires still require connection to the power distribution of the building. Wireless networks, however, do allow for flexibility in relocating luminaires, as controls are either located in the luminaire housing itself or can be easily co-located. Wireless controls are especially effective for retrofit projects, as power is usually already being supplied in close proximity to the desired luminaire location. Wireless controls generally provide communication to a local hub, which makes them attractive for both new projects and retrofit outdoor lighting where the luminaires are in fixed locations (poles) for which a means of communication needs to be established.
- **Electromagnetic compatibility (EMC).** Wireless systems have a greater susceptibility to other signals in the environment, including coupled and radiated electrical signals, RF interference, and physical barriers.
- **Troubleshooting and problem resolution in the field.** Wireless controls can be more challenging to troubleshoot, as the exact cause of a failure can be difficult to determine. For example, as discussed above, signals may be blocked by noise or physical obstacles, disrupting propagation.

Wireless troubleshooting relies on appropriate instrumentation that can mimic system operation, detect and analyze signal strength, and log communications, and on personnel trained to use these tools to locate and resolve failures.

6.7.5.2 Wireless Devices. One of the most common interior wireless lighting control devices is the occupancy sensor, used to detect the presence or absence of occupants in an interior space. In exterior environments, the motion sensor, used in parking lots or to detect the presence of moving vehicles, is one of the most commonly used devices. Daylight sensors, also commonly used in both interior and exterior environments, are devices that detect the amount of daylight and/or ambient light. Daylight sensors installed in an interior space are typically referred to as *daylight-harvesting sensors*, and those installed in an exterior environment are typically referred to as *photocells*.

While it was more common in the past for wireless controls to be standalone devices, as interest in controls implementation has increased they are increasingly being integrated directly into luminaires. User interfaces with graphical displays have also migrated to personalized configuration and control capabilities (e.g., from a smartphone) in addition to the system-level interface.

Wireless devices may be powered using batteries, photovoltaics, energy-harvesting devices, or mains power. Batteries are advantageous in terms of minimal wiring requirements, but since all batteries will eventually lose their charge, labor costs for battery replacement should be taken into account. In addition, not all battery-powered devices provide an easily detectable indication of end of life. Although status is typically provided as part of the communication protocol, it is not always monitored by building maintenance personnel. Harvesting electromechanical energy (vibration) or ambient light energy eliminates the need for batteries but has a functional capability limited by the small amount of power generated.

6.7.5.3 Data and Communication Considerations. When implemented properly, wireless controls offer improved visibility into system operations, as compared with non-communicating systems, providing information such as device status and configuration, user inputs, energy usage, and network health. Using the data provided via wireless systems requires an understanding of device sampling rates, how and where data is stored, and the tools needed to perform analytics.

- **Data sampling rate.** The sampling rate can be important for communication and for energy management; each has its own considerations.
  - *Communication sampling rate*. Sampling rates can vary widely among devices, particularly on wireless networks, due to the influence of a number of variables that are discussed below. While the device itself may sample sensors many times a second for internal functions, it may send updates to the network at a much lower frequency or intermittently. Two factors generally limit wireless network communication rates and, therefore, the data update rate available from each device:
    - Battery-powered devices may limit transmission intervals to conserve power. For wireless networks such as Wi-Fi and Zigbee, the power required for transmission can be an order of magnitude greater than the power required for the device to operate. To maximize battery life, devices may transmit data only when critical values change, referred to as change of value (COV) operation, or may transmit on fixed intervals of up to several minutes. COV operation can provide longer battery life, depending on the number of times data is transmitted. It is therefore difficult to predict what battery life will ultimately be for this circumstance, compared to that for data transmission at a fixed interval. Interval-based transmissions have a more predictable battery life across a range of different applications and environments.
    - Network traffic may also limit transmission rates, though this is often less of a concern than battery life. Usually, network traffic limitations will affect the number of devices a system can manage and is more of a design decision for the manufacturer than a concern of the installer or end user.

  - Because battery-powered wireless devices are at higher risk for data loss, it is important to confirm how often data is transferred to the server, to avoid data gaps.
- ▪ *Sampling rate for energy management*. The data from luminaires and sensors, such as daylight levels, occupancy, dimming levels, and energy consumption of individual luminaires or by lighting zone or area, may be important for overall building management. In addition, various utility rebate programs may use data collected by a lighting system for measurement and verification of energy savings. Therefore, sampling rates should be coordinated with both end user energy managers and utility rebate program technical evaluators.

- **Data storage.** Data from devices is often stored on a server or network manager, either in the end-user facility or in a cloud service. Understanding where data is stored, how the data will be accessed, and what may affect data availability are all important in selecting a control system. While storage is typically not a major cost, the amount of data storage and length of time that stored data needs to be retrievable should be considered. Cloud services may at times become unavailable or may become inaccessible when network access credentials expire. It is always best to coordinate access with facility IT staff before committing to a technology where cloud access is an important part of the project. At times it may be necessary to provide a separate outside connection though a dedicated internet service or cellular modem.
- **Big data and analytics.** Various analytical tools are available to process big data and provide useful information to building managers and owners. Big data can identify long-term cycles and trends, as well as operation that is outside normal ranges. Coordination with analytics of other building systems, such as air conditioning, can provide energy managers with a comprehensive view of building performance and insight into interactions among various building systems.

Firmware updates: Data transfer for firmware updates can be time consuming because the amount of data needing to be transferred is usually significantly larger than the typical data transfer bandwidth requirements. The lighting system designer should investigate the potential impact to overall system operation of periodic firmware updates, in an effort to make the process as transparent as possible. For example, one way to mitigate the impact to the overall system operation is by scheduling firmware updates for times during which the network is not as active; e.g., evenings or weekends.

Gateways: A gateway is a device that translates commands and responses between incompatible control systems. Gateways are frequently required for wireless networks to either connect the wireless network to the building network or internet, or to act as a bridge to other building management systems. Gateway placement and connections are often critical to the proper operation of a wireless network. Improperly placed gateways may have difficulty communicating with all wireless devices, or may not have all the connections to other networks needed for full operation. Coordination among network equipment manufacturers and building systems suppliers is essential to ensure proper overall functionality.

6.7.5.4 Wireless Communication Protocols. Open protocols and proprietary protocols are defined in **Sections 2.6.1** and **2.6.2**, respectively.

Currently, Zigbee and Bluetooth are most widely used in wireless controls implementations.

Some communication protocols that have traditionally transported information via a wired communication system can also do so wirelessly.

As the idea of an “internet of things” (IoT) has grown, existing wireless network limitations have led to development of new wireless communication techniques. Examples include Low-Power Wide-Area Network (LoRa) and Narrow Band, both of which provide the potential for low-power, long-range control communications. Wi-Fi, while widely available, is not ideal for low-power lighting control, especially as spectrum crowding becomes more of an issue, because it is meant to transport high-speed data and because of its range limitations. Both LoRa and Narrow Band offer much greater range at low power, with speed sufficient for commercial lighting applications.

Wireless communication is not limited to the radio frequencies used by Wi-Fi. A newer technology to deliver data by modulating the light output of a luminaire, referred to as *Li-Fi*, has generated interest in the lighting industry. The main limitation to Li-Fi is the challenge of bidirectional communication. Data can be delivered to individual devices in a space via Li-Fi, but receiving data from individual devices in that space is more problematic due to interference. Because RF communications may penetrate walls and Li-Fi communications typically will not, Li-Fi may provide a more secure means of communication.

6.7.5.5 Design Considerations. When designing wireless lighting control systems, it is important to determine the expectations of the end user. A homeowner may have very different needs than the facility manager of a large shopping mall. The homeowner may want a simple system for turning on or off all of the home's lighting with a smartphone, but may be hesitant to install complex user interfaces. A facility manager may want feedback from each individual luminaire, making it easier to troubleshoot the system and schedule preventive maintenance.

Different systems can vary greatly in their product offerings and can range from very simple to very complex. Simpler systems are often limited in scale, addressing a single room or a small home or store. They will have fewer devices and capabilities but a lower upfront cost. High-end lighting control systems are often scalable, with capabilities to not only control lighting but also interface with mechanical shades, audiovisual systems, and even building management systems (BMS). They will often offer an array of devices to meet a wide variety of customer needs. Higher-end lighting control systems will be more costly up front but, depending on the requirements of the end user, could have a very short payback in energy savings, rebates, and luminaire maintenance costs. For example, if a system is used to reduce a facility's light levels at night during non-occupied hours, the potential for a very short payback is high.

Energy codes also continue to drive the operating requirements of lighting control systems. In addition, high-performance "green" buildings require more sophisticated controls, such as daylight-responsive lighting, occupancy sensing, astronomical scheduling, high-end trim, and personal control. It is critical to understand what the requirements of the applicable codes and other standards are, in order to properly design a lighting control system. Requirements for many states are becoming more stringent, and it is often more difficult and expensive to meet those requirements through lighting control using traditional methods such as time switches, contactors, individually wired occupancy sensors, and individually wired switches. In these cases, networked lighting control systems can be a less expensive solution for meeting code requirements.

An important final design consideration is the commissioning of the system, and this is especially true for wireless control systems. Commissioning is critical to ensure that the system functions properly and meets the design intent and standard operating procedures set forth. Part of the commissioning process is training the end user on the use of the system, with information usually captured in an owner's manual. Integrating a wireless lighting control system into other systems, such as a BMS for large-scale installations, or a residential network, may be also part of the commissioning process. There are advantages and disadvantages to integration with other building systems. On one hand, building energy performance can be significantly improved, but on the other, there could be potential challenges with system interoperability. In addition, any security risks from one system will carry to other systems with which it communicates.

ANSI/IES LP-8-20, Lighting Practice: The Commissioning Process Applied to Lighting and Control Systems provides a more detailed discussion of the lighting and controls commissioning process.[3]

6.7.5.6 Environmental Factors Important in Determining Distances between Devices. Wireless networks function by sending information at radio frequencies, which can potentially be bent, reflected, or outright blocked, depending on physical environmental factors. Therefore, for a network to function properly, a clear line of sight or a reflected line from one device to another is essential.

The materials used in a building's construction can also cause RF signal absorption, making them an important consideration when determining the spacing of devices on the network. For example, concrete walls can inhibit wireless transmissions to a greater extent than sheetrock. Steel doors will block transmissions, while wood or glass doors offer less of an obstruction. Other factors such as occupancy level, humidity, and existing RF infrastructure can also affect the performance of the lighting control system.

It should be noted that building materials can also act as reflectors for transmissions; for example, while direct line of sight between two devices may be blocked by a steel door, the signal could nonetheless rebound off the concrete walls surrounding the doorframe.

A common method of alleviating transmission obstacles is to implement a system that utilizes a mesh network. This type of network allows the signal to "hop" from node to node and will in many cases continue to operate even when one or more nodes fail.

6.7.5.7 Antenna Placement. While antenna placement in a central location or in individual quadrants within a space is simple and straightforward, it may not be optimal in terms of cost, performance, or security. Modeling tools that identify antenna placement locations based on considerations such as location of users, building material characteristics, and throughput needs can often provide better results. In addition, replacing the typical circular-pattern antennas with directional ones may improve overall results while minimizing the number of antennas required.

6.7.5.8 Device Power. Many wireless devices require local wired power to operate and provide communication. These devices may source their power for control and communication from the equipment they are servicing, such as a luminaire. When device power is wired, the design should take into consideration the amount of power the device consumes in both full operation and standby mode, to ensure that the needed power is available and not inefficient or excessively burdensome to the design. Sensors and controls may use batteries, though some use energy-harvesting methods such as solar cells, piezoelectric generators, micro-turbines, thermoelectric devices, and other low-power-generation technologies. In some cases, energy harvesting is combined with battery power.

Loss of power to a device could have significant impact on wireless network communications. Gateways and repeaters should always be designed with sufficient standby power to ensure an orderly network shutdown if normal power is lost. Endpoint devices should be capable of independent local operation in the case of power loss in other parts of the network or gateways.

6.7.5.9 Interoperability, APIs, and Compatibility Verification. Due to the large number of both standard-based and proprietary communication protocols, proof-of-concept as well as thorough commissioning and testing at implementation should be performed to ensure true interoperability and suitable performance. Application programming interfaces (APIs) can be an effective way to collect specific data from systems. Design documentation should address specific criteria for how independent components or systems are to interoperate, what control and information will be exchanged, and which parties are responsible for ensuring the interoperability performance. Any APIs critical to overall system function or user experience should be tested before the system is deployed.

6.7.5.10 Battery-Powered Devices. Because battery life can vary due to device usage, a maintenance schedule for battery replacement will ensure that battery-powered devices are operational. Used batteries should be disposed of properly; the method of disposal will depend on the battery type.

6.7.5.11 Expertise in Information Technology (IT). Because building managers and maintenance staff are not usually trained in managing wireless systems, wireless network design should have either self-correcting capabilities or rigorous diagnostics available. Training on system troubleshooting should be included with commissioning.

6.7.5.12 Network Security. Security is a concern for any network, but wireless control systems are potentially more vulnerable than wired systems because physical contact is not required to intercept or inject signals. Because of this, coordination with other disciplines—

e.g., IT—is needed to ensure that the lighting control network fits into the overall network architecture at the appropriate level and with appropriate security.

The ANSI/IEC 62443 family of security standards provides guidance on specifying security solutions and evaluating implementations. *ANSI/IEC 62443-4-2, Security for Industrial Automation and Control Systems – Part 4-2: Technical security requirements for IACS components* provides specific requirements for wireless components.[37]

UL 2900-1:2017, Standard for Software Cybersecurity for Network-Connectable Products, Part 1: General requirements may be used to evaluate network-connectable products for vulnerabilities, software weaknesses, and malware.[38] In addition, industry-specific companion standards are available for specific types of facilities, such as industrial facilities, and for security and life safety signaling systems, such as fire alarm control.

6.7.5.13 Open or Standardized Systems vs. Proprietary Systems.

Compatibility and interoperability. Currently, wireless control systems are based on both open and proprietary communications protocols. Proprietary control solutions are developed by a single manufacturer for use with its own products and in most cases are not compatible with control solutions from other manufacturers. Early development of proprietary wired protocols was often due to the lack of existing standard control solutions, leading to a lack of interoperability.

Trends toward open protocols in related industries. As lighting control requirements have grown more complex, there has been a correspondingly greater reliance on standardization. In lighting, this was first implemented in theatrical systems, where large-scale complex control has been required for many years. Wireless networks help drive the need for standardization in lighting controls, as it is increasingly impractical for manufacturers to develop proprietary wireless hardware.

6.7.5.14 Emergency Lighting and Controls. Documentation for a wireless lighting control system should clearly identify how emergency lighting should be implemented to comply with the life safety and emergency lighting control requirements. (For more information on Emergency Lighting Control, see **Section 4.12**.)

6.7.5.15 Occupant and Building Security. There are two considerations here: integration with building security systems and live sensor mapping.

- **Integration with building security systems.** Many wireless lighting controls can be integrated with building security systems for added safety, energy efficiency, and crime prevention. The security system can signal lighting to turn on when people are present, or to operate in an alarm-trip condition to deter criminal activity and provide illumination during security personnel response. The security system can help save energy by turning the lighting off upon confirmation that the space is unoccupied or when the alarm system is armed.

  Connection to a security system can be accomplished via wireless communication protocols that are compatible with the security and lighting control systems. Commands to be sent and received, and their intended actions, should be explicitly detailed in the building specification documents. Compatibility between systems should be confirmed in advance of live operational demonstrations, ensuring that each desired command is exchanged between the systems successfully. During the project construction and commissioning process, it is critical that adherence to the specified functions be fully verified.
- **Live sensor mapping.** The consistent spacing of lighting throughout a building provides an excellent platform for luminaire-level lighting controls to sense and collect localized building use and operational information. Such information can include occupancy levels, foot traffic flow, temperature, light levels, and other analytical building data. This data can be shared with other building systems to optimize building performance and provide metrics to help property owners assess building occupancy rates and use patterns to optimize space utilization. Wireless controls can make the deployment of luminaire lighting control systems easier by reducing the amount of wiring necessary between luminaires. Depending

on the type of wireless luminaire-level lighting controls, the system may also have features for direct connection to localized user control devices such as handheld controllers, or may even control communication to tablets and smartphones. These can be used for system setup and for end-user individual control of lighting in the workspace.

6.7.5.16 Third-Party Evaluations. The DesignLights Consortium® (DLC)'s Networked Lighting Control (NLC) initiative provides technical requirements for inclusion in a Qualified Products List for both interior and exterior lighting controls, which utilities can use as rebate or incentive eligibility requirements. In addition, a number of utilities are considering using actual energy data as a basis for lowered demand rates and/or energy efficiency incentives or rebates.

Wireless control systems are particularly suited to facilitating the data collection capabilities needed to monitor and provide reporting on energy usage in real time at the luminaire, building, or even enterprise level, providing building owners with the potential to realize the full benefit of utility rebates and incentives. This is especially the case for lighting retrofit projects in which wireless controls eliminate the need for installation of new wiring.

Coordination at project initiation with the local utility to determine rebate or incentive eligibility and details of potential rate reductions is recommended.

6.7.5.17 Recommissioning. Given the complexity of many lighting control solutions, the changes that are likely to occur over time, and the added dynamics of wireless control systems, it is recommended that users consider recommissioning within 10 months following lighting control system acceptance testing. During the recommissioning process, maintenance personnel, the commissioning agent, or even the manufacturer should inspect all lighting controls for proper operation, address any remaining actions items identified during final acceptance testing, and make any additional modifications resulting from occupant interaction with the control system and an increased awareness by end users of how they would like the system to operate.

A second recommissioning is recommended near the end of the control system warranty period, in order to address systemic issues and make modifications to the system operation. This second recommissioning is also a good time to consider incorporation of firmware, software, or even hardware updates.

ANSI/IES LP-8-20[3] is a helpful guide for commissioning and includes a discussion of ongoing commissioning with recommendations for the end user for ongoing training, periodic system tests, and regular updates to control system manuals. In addition, the Lighting Controls Association provides an Education Express course on commissioning, which includes the consideration for additional testing post-occupancy.

6.7.5.18 Industry Consortia and Alliances. In response to the need for protocol standardization, a number of wireless technology consortia and alliances have been created. The goal of these organizations is to simplify installation and commissioning of wireless lighting controls through the use of a common protocol. A few examples are described in the subsections that follow. (*Note:* In addition to lighting-specific organizations, there are numerous alliances focused on general connectivity and networking, of which lighting controls are increasingly a part.)

- **The EnOcean Alliance** is based on an energy-harvesting wireless standard geared to sensors and networks with very low power draw. These devices typically draw their power from motion, light, or temperature variations, allowing the devices to function without an external power supply.
- **The Zigbee Alliance** was founded in 2002 and focuses on open standards for the Zigbee communication specification that is used by a wide range of lower-power, low-bandwidth wireless devices. Zigbee standards support a vocabulary of messages for a wide range of devices for lighting and other building management functions. Zigbee also runs a certification program that includes more than 3,000 devices.
- **Wi-Fi Alliance®** is the worldwide network of companies that provides Wi-Fi certification through authorized independent test laboratories for products indicating that they have met industry-agreed standards for interoperability, security, and a range of application specific protocols.

- **Digital Illumination Interface Alliance (DiiA)** is an industry organization composed of numerous manufacturers that develops guidance documents pertaining to the Digital Addressable Lighting Interface (DALI) protocol. Many of these standards are subsequently published by the IEC as industry standards. Standards published to date cover drivers as well as auxiliary devices such as switches and sensors. The DiiA also manages a certification program to ensure interoperability of devices under the DALI-2 standard.

7.0 Lighting Control Equipment

A wide variety of control equipment is available to enact lighting control strategies, ranging from simple switches to computer-based systems that automate all lighting in one or more buildings. All control systems include a controller, which affects the load, and may include other devices such as sensors and computers to provide automatic inputs. The controller may be able to accept multiple inputs, enabling it to enact multiple control strategies in the same space.

7.1 User Interfaces

The most basic application of lighting control is the use of a single zone switch or dimmer installed in an electrical switch box. This arrangement provides manual control and can be used to meet some codes and standards.

7.1.1 Switches. Multiple styles of switches are available, with the most common being the traditional toggle switch and decorator paddle switch. They can be single-pole, controlling the lighting from one location, or three- or four-way, connected together to control lighting from two or more locations. Due to the growing requirements for energy conservation and aesthetic control, switches are becoming less common in many areas of commercial applications.

Key-activated switches are wall switches that turn lighting on and off using a key. They are installed to prevent unauthorized or accidental use of certain lighting circuits. Key selection is a design consideration for owners, affecting access to essential equipment.

The functionality of a switch may be automated based on occupancy and time.

Historically, most wall switches have been line-voltage devices, which open and close the phase wire (hot wire) that supplies power and voltage to the luminaires. When this basic lighting control approach is applied at a single location, a single-pole switch is used. If lighting is be controlled from two different locations, three-way line-voltage switches can be used at both locations. Three-way switches are technically referred to as single-pole, double-throw switches. If switching is required at three or more locations, the first and last switch in the series are three-way switches, and any intermediate switches are four-way switches which connect incoming and outgoing pairs of travel wires by alternating which incoming wire is connected to each outgoing wire as the switch position changes.

7.1.2 Dimmers. Dimming control is a more flexible alternative to simple switching of lighting equipment, with a variety of equipment available to provide this function. The dimmer should be easy to use and have intuitive elements enabling switching and dimming. It is important to note that switches can control any type of light source, but dimmers need to be matched to, and NRTL-listed for, the controlled light source and load. **Figure 7-1** provides some examples of wall-box dimmers.

Figure 7-1. Examples of wall dimmers. These devices are available in a variety of different styles and operational configurations. (Images 1, 2 and 5 from left © Lutron Electronics; image 3 © Crestron; image 4 © Wattstopper)

7.2 Multi-zone Systems: Relay Switching and Programmable Dimming Systems

Spaces such as meeting rooms, restaurants, and lecture halls need independent systems that can control multiple zones of lighting, typically four to 12 zones.

Local control is required, but a large bank of switches and dimmers could easily prove to be confusing, while also marring space aesthetics. A multi-zone control system consists of wall stations (see **Figure 7-2**), operated by the user and connected to remote switching relays and/or dimmers (analog) or processor hubs (digital).

Figure 7-2. An example of a wall control station. (Image courtesy of Lutron Electronics)

The local wall station features switches, buttons, and other control elements that are either mechanical or incorporated into a touchscreen display. The functions are designed to be intuitive to the user to provide simple lighting control. The lighting is generally configured within multiple scenes—set lighting conditions that are appropriate for particular moods or uses of the space. These scenes are preprogrammed using permanent manual programming panels, computers connected during setup, or handheld wireless devices such as smartphones or tablets. The wall station controls are connected to the relays, dimmers, or process hubs via low-voltage cabling providing communication using digital protocols.

In addition to user controls, energy-saving strategies are often incorporated into these systems. Occupancy sensors, time switches, and photosensors provide code-required automatic inputs. The programming panels can provide an interface to audiovisual systems.

7.2.1 Low-Voltage Relays. The primary device used for switching is typically a low-voltage relay with a low-voltage input for accepting control signals from sensors and manual controls, and a line-voltage output for controlling the load (not to be confused with low-voltage lighting). These power switching devices are often rated to handle the 16-amp load of a lighting circuit, and may be electromechanical or solid-state in design. Various techniques are used to ensure that the relays provide a long service life. Relays should latch or stay in their currently selected status after a power interruption. Some products that are available use digital controls to operate switching circuit breakers grouped in panelboards. These systems omit relays and offer control via computer systems, including access via networks and mobile devices.

Relay-based control systems may be centralized or distributed. Traditionally, the relays are housed in central panels with switches connected to the relays via low-voltage wiring, and with the entire enclosure typically installed in the electrical room, near the lighting panel. The disadvantage of this centralized approach is that every input to the controller, as well as every line voltage switch leg, requires its own homerun wiring between the local control and the central controller. Distributed control entails the use of small panels with two to four relays, which are installed close to the loads they control. By reducing the amount of homerun wiring, installation costs can be reduced, although the facility operator will need to maintain accurate records of mini-panel locations and have these panels be conveniently located, for cost-effective maintenance (see **Figure 7-3**).

For digital addressable control systems, processor hubs are mounted in centrally located electrical rooms or locally within the space being controlled.

7.2.2 Scene Controllers. Scene controllers are wall station units that permit different combinations of lighting zone switch and dimmer settings to be recalled with the push of a button (see **Figure 7-4**). In some cases, these devices contain dimmer modules within the junction box, while in others they signal remote hardware to perform the control function. Master units generally have controls that permit the user to set the zone operating conditions for each of the scenes.

Remote stations are employed to select scenes from locations other than the master unit and communicate a user's selection to the master controller. Some systems include the option for a wireless hand-held remote, which can be operated from a podium or conference table. Scene controllers can also be linked to audiovisual

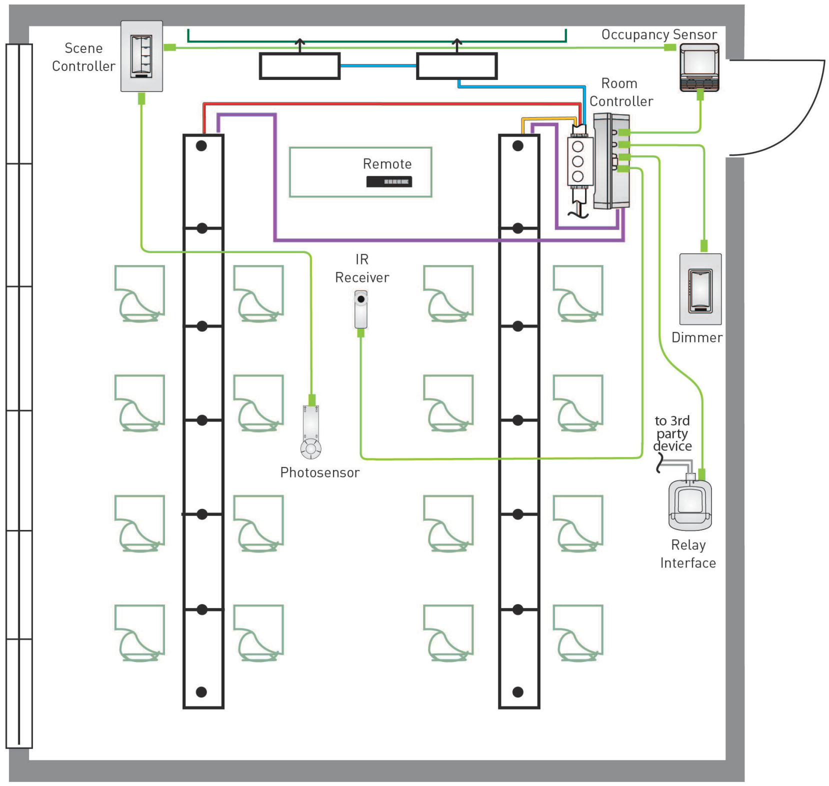

Figure 7-3. In this sample classroom with distributed control system, multiple strategies are enacted: automatic shutoff for code compliance, daylight harvesting control in the daylight zone adjacent to the windows, and scene control and dimming executed using wall-mounted and handheld controls. (Image courtesy of WattStopper)

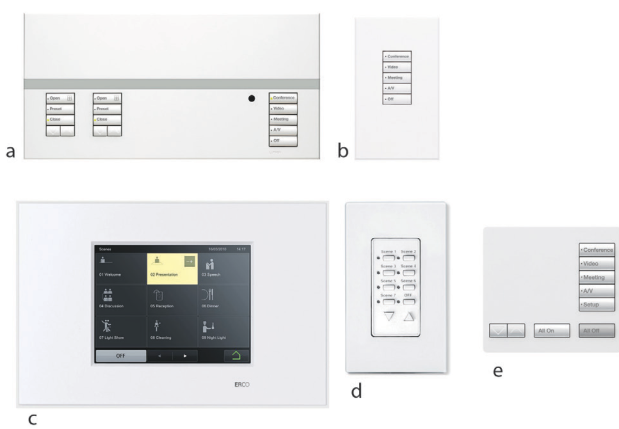

Figure 7-4. Examples of scene controllers. Preset lighting scenes are recalled at the touch of a button. Device *a* is a master controller with a remote wall station, *b*. These devices can be wired, digital, or wireless. Device *c* is an example of a liquid crystal touch display. Device *d* is a DALI scene controller. Device *e* is a handheld control that includes operation of window shading devices. (Images *a*, *b*, and *e* courtesy of Lutron Electronics Co., Inc.; image *c* © ERCO, Inc.; image *d* © Leviton, Inc.)

equipment to lower projection screens and activate projection equipment, as well as to operate shading systems to darken a room.

7.3 Central Computer-Based and Software-Based Systems

Lighting controls for large, complex areas within a building, entire buildings, or corporate campuses may be optimally configured as an integrated, centrally controlled system. Standalone systems can be effective, but they do not provide the capability of central monitoring, reporting, and managing the lighting that is required for intelligent buildings. A central computer-based lighting control system—which may be a distributed system presenting to the user as a centrally operated system—provides these capabilities.

This approach provides facility operators with the ability to track lighting system operation, manage and optimize energy consumption, and easily adjust the lighting as