INSIDE THE NGLS INDOOR LIVING LABS

Characterizing Connected Lighting Systems

January 2022

K. Ruth Taylor
Mary Matteson Bryan, PE

CONTENTS

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <https://www.ntis.gov/about>
Online ordering: http://www.ntis.gov

In the context of evaluating a lighting control system, characterization refers to the identification and description of key attributes and distinctive features of that system. NGLS has to date characterized both the form and function of 14 lighting control systems installed in the Living Lab at Parsons School of Design in New York City.

Installation of the lighting systems took place between 2017 and 2019 in the Living Lab. The lighting systems had been marketed by their manufacturers as "easy to install and configure." The goal of NGLS characterizations in the Living Lab has been to achieve a broad understanding of "these types of systems" as a class, rather than a detailed description of any individual system.

NEXT GENERATION LIGHTING SYSTEMS

NGLS is organized by the Department of Energy in partnership with the Illuminating Engineering Society and the International Association of Lighting Designers, is managed by Pacific Northwest National Laboratory. NGLS uses "Living Labs" to conduct observational research in real-world settings—indoors at Parsons School of Design in New York City and outdoors at the Corporate Research Center adjacent to the Virginia Tech Transportation Institute in Blacksburg, Virginia. NGLS teams consist of a broad range of industry experts, including lighting designers, engineers, and utility professionals.

NGLS evaluators use detailed protocols to observe, document, and measure how systems are installed and configured, how well they perform, and how users operate them. NGLS seeks to learn from manufacturers' varied approaches—identifying those that work, revealing needed improvements, articulating effective principles and practices, and publishing findings for the benefit of the lighting community.

THE NGLS APPROACH TO CHARACTERIZATION

Members of the NGLS team were assigned individual system aspects to characterize; these evaluators followed a phased and multi-pronged approach:

1) Survey product literature and observation notes relevant to the system aspect being characterized.

2) Identify the features and attributes that are important and distinctive to each system, either by relying upon professional experience or drawing conclusions based on information supplied with the system by manufacturers.

3) Analyze how each manufacturer approaches a specific feature. Various manufacturers might address the aspect in the same way, or the approach might differ significantly.

4) Summarize manufacturers' approaches, and group similar approaches into sub-categories.

5) Review the characterization with NGLS team members.

6) Present the characterization in NGLS reports using a combination of narrative text and summary tables that note, for example, whether the manufacturer collaborated with another supplier for controls.

ENTRANT SYSTEMS

Lighting system characterization provides a high-level understanding of the different approaches taken by manufacturers who entered products for NGLS analysis that were identified as “easy to install and configure” lighting systems.

Entrant *(control in bold)*	Entrant Type	Luminaire	Quantity	Room Area *(sq. ft.)*	Year Installed
Lumenwerx/**Magnum**	Collaboration	Pendant	4	624	2017
Selux/**Signify**	Collaboration	Pendant	4	624	2017
Crestron/Starfire	Collaboration	Pendant	4	624	2017
Signify	Single	Pendant	4	624	2017
RAB Lighting	Single	Troffer	9	490	2017
Cree	Single	Troffer	9	490	2017
Nextek/Independence	Collaboration	Troffer	9	544	2017
Cooper Lighting	Single	Retrofit	6	342	2018
LG	Single	Retrofit	4	266	2018
Signify	Single	Retrofit	6	324	2018
Lutron/Orion	Collaboration	Retrofit	9	270	2018
Acuity	Single	Retrofit	6	252	2018
MaxLite/**Avi-on**	Collaboration	Troffer	8	544	2019
Silvair/Finelite	Collaboration	Pendant	8	480	2019

SYSTEM ARCHITECTURE

System architecture refers to the basic structure of the control system and characterizes lighting control systems at the highest level.

Lighting control systems typically comprise of a variety of physical components, which may include relays, occupancy sensors, photocells, a local area network device, and wall switches.

These components can be connected over hardwire (line voltage, low voltage, or Power over Ethernet [POE]) or wirelessly.

The "easy to install and configure" control systems submitted to NGLS varied significantly in the number, placement, and connection of components, but their essential simplicity permitted characterization by just a few attributes.

Entrant *(control in bold)*	Sensor/Control Mounting	Wall Switch	Local Area Network Device	Connection
Lumenwerx/**Magnum**	Luminaire-Integrated	Yes		Wireless
Selux/**Signify**	Luminaire-Integrated	Yes		Wireless
Crestron/Starfire	Remote-Mounted	Yes		Wired
Signify	Luminaire-Integrated	Yes		Wireless
RAB Lighting	Remote-Mounted	Yes		Wireless
Cree	Luminaire-Integrated	Yes		Wireless
Nextek/Independence	Remote-Mounted	Yes		PoE
Cooper Lighting	Luminaire-Integrated	Yes	Yes	Wireless
LG	Luminaire-Integrated	Yes		Wireless
Signify	Luminaire-Integrated	Yes		Wireless
Lutron/Orion	Luminaire-Integrated	Yes	Yes	Wireless
Acuity	Luminaire-Integrated	Yes		Wireless
MaxLite/**Avi-on**	Luminaire-Integrated	Yes		Wireless
Silvair/Finelite	Luminaire-Integrated	Yes		Wireless

Prevalence of Characterization Feature	Arrangement	Number	%
Sensor Mounting	Luminaire	11	79%
	Remote	3	21%
Connection	Wireless	12	86%
	Wired	1	7%
	PoE	1	7%

CHARACTERIZATION BY COMPLEXITY OF INSTALLATION

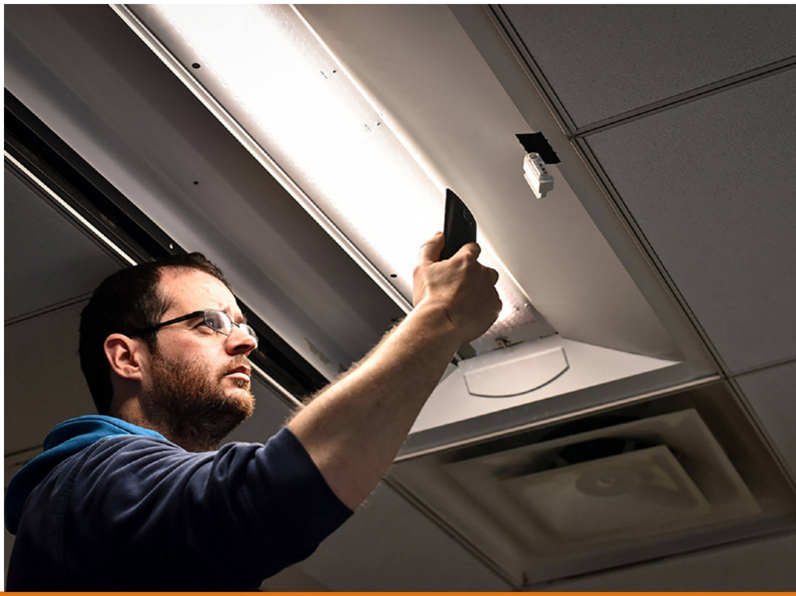
After analysis, the individual systems can be placed in three groups characterized by the degree of installation complexity and using two basic features: components and connection.

System Characterization by Installation Complexity			
	Least Complex	**Moderately Complex**	**Most Complex**
Components	Luminaire-integrated sensors Wall switch	Luminaire-integrated sensors Wall switch Local Area Network Device	Remote-mounted sensors Wall switch
Connection	Wireless	Wireless	Wireless Wired PoE
Systems	**Acuity** MaxLite/**Avi-on** **Cree** **LG** Lumenwerx/**Magnum** **Signify** (3) **Silvair**/Finelite	**Cooper Lighting** **Lutron**/Orion	**Crestron**/Starfire **Nextek**/Independence **RAB Lighting**
Prevalence of Installation Complexity Level	64%	15%	21%

Not surprisingly, systems with a less complex physical architecture proved easiest to install. Occupancy and daylight sensors were factory-integrated, so no additional field installation was required, and the wireless wall switches were typically installed easily.

The somewhat more complex systems also tended to be easy and quick to install, similarly benefiting from the luminaire-integrated sensors and controls and the wireless wall switch. Complexity in this category resulted from additional wireless area network devices that required additional installation time mainly related to providing electrical power to the device.

The systems with the most complex architecture required the longest period of time to install control components. Contractors had to identify and understand the remote occupancy sensors and other components, which required consultation and comprehension of the manufacturers' printed instructions. The devices then had to be mounted and connected correctly using a variety of methods. Moreover, during the evaluation, these systems failed to operate to the NGLS specification in one or more areas.



WALL CONTROLS

The NGLS team characterized wall controls based on their evaluation of the 14 systems in the Parsons Living Lab, fully described in the report *The Impact of Wall Control Performance on Connected Lighting Systems*. The summary below is derived from the results of that report.

The 14 wall controls can be broadly classified across six attributes: user interface type, configuration, quantity used, power source, communication to luminaires/sensors, and labels for functionality. The systems evaluated demonstrated considerable diversity among the designs used by different control system manufacturers. Scrutiny of the rows in the table below shows that no single overall wall control design was preferred by manufacturers.

User Interface Type

Rocker (paddle-style) devices are the most common user interface in this evaluation.

Configuration

Pre-configured wall controls were generally easier to set up but did not permit users to modify device functionality. Field-configurable types offered more flexibility for modifications but required more time to set up. Note that all wall devices needed to be incorporated into the system network.

Quantity Used

The number of wall controls required to operate the system per the NGLS specification was determined by the entrant. Most systems employed two user interface devices, one for each zone. Only three systems used a single, multi-button device and two others used three devices. Based on user experience, a separate device for each zone proved more intuitive and easier to operate than additional (or fewer) devices.

Classification of Entries

		UI		Configuration		Quantity Used			Power Source			Communication to Luminaires/Sensors						Labels	
Entrant	Control Systems	Rocker	Button	Pre-Configured	Field-Configured	1 Device	2 Devices	3 Devices	Wired	Kinetic	Battery	Zigbee or IEEE802.15.4	Bluetooth	Other	Mesh Network	Point-to-Point	Unidentified	Labels	No Labels
Lutron/Orion	Vive		●	●			●				●			●		●		●	
Acuity	nLight AIR		●	●		●					●		●				●	●	
Cree	SmartCast	●		●			●		●			●					●		●
Lumenwerx/ **Magnum**	Magnum	●		●			●			●				●	●				●
Selux/**Signify**	EasySense	●		●			●			●		●			●				●
Signify	SpaceWise	●		●			●			●		●			●				●
Signify	SpaceWise	●		●			●			●		●			●				●
Silvair/Finelite	Silvair	●			●		●			●			●		●				●
MaxLite/**Avi-on**	Avi-on Pro	●			●		●				●		●		●			●	
Cooper Lighting	WaveLinx		●		●	●			●			●					●	●	
Crestron/Starfire	Zūm		●		●		●				●			●	●			●	
Nextek/ Independence	SKY-controls	●		●				●			●			●		●		●	
RAB Lighting	Lightcloud	●			●			●	●			●					●		●
LG	Sensor Connect		●	●		●					●	●					●	●	
	14 Entries	9	5	9	5	3	9	2	3	5	6	7	3	4	7	2	5	7	7

Power Source

All approaches to powering the wall controls appeared to have issues. Installation of the three AC-powered devices was sometimes confusing to contractors and generally required more time than installation of kinetic- or battery-powered devices. Devices using kinetic power, generated by pressing the rocker panel, challenged some users because more pressure is required than with other rocker devices. Finally, battery life and maintenance were identified as concerns for battery-powered devices.

Some systems offered a choice in power source, providing options for the user (see the Classification of Entries table for the installed condition). A benefit of self-powered devices using a battery or kinetic energy is that they can be located without the cost and limitations of new or existing electrical wiring.

Communication to Luminaires/Sensors

Information about the wireless communication used by each wall control was not observable. The NGLS team relied on review of manufacturer documentation accompanying each device and conversations with manufacturers to characterize the methods of communication.

In terms of radio protocol, most systems used Zigbee or one complying with IEEE 802.15.4. The systems installed most recently in the Living Lab (2019) use Bluetooth. Of the four systems with communication listed as "Other," two were confirmed as fully proprietary at that time. Similarly, half of the systems featured a mesh network, two relied on point-to-point communication, and five did not specify.

Labels for Functionality

All of the multi-button devices used labels to communicate functionality—usually engraved words or icons. Only one of the rocker-type systems was labeled by the manufacturer, and this labeling was added after installation.

Because rockers are a familiar style of wall control, it is likely that manufacturers assume rocker operation is sufficiently familiar to users with no identification needed. Unfortunately, this did not prove to be the case during the NGLS evaluations. Users found the kinetic rockers unfamiliar to operate because of the hard press required. The use of three rockers for two zones was also found to be confusing.

As users stood at the wall control, labels that were clear and easy to read definitely improved ease-of-use, absent other factors. However, lack of consistent and intuitive descriptions for zones, scenes, and actions presented a major challenge. In one case, simple and straightforward icons, including engraved up/down arrows, were not enough to explain operation, as one longtime room occupant was unaware that the system could dim.

CHARACTERIZING PRESENCE DETECTION

The NGLS characterization study of installed presence detection in the Living Lab reveals some consistency and considerable variation among the 14 systems. The table on page 9 summarizes the characterization.

Entrants

The 14 systems split evenly between those using controls branded by the luminaire manufacturer (single entries) and those using controls and luminaires from different manufacturers (collaborative entries). The sensors for each system may have been manufactured by an independent third party in either single or collaborative entries.

Three entrants used the same type of control system; the others appeared to use sensors from different manufacturers. A total of 11 unique systems have been installed so far.

Sensor Technology

All systems currently in place use passive infrared (PIR) sensors. All but two of the sensors combine presence detection and light measurement (for daylight harvesting) in the same device.

The small size and relatively low cost of PIR sensors serve as important considerations for the 11 systems that integrate sensors into luminaires.

An array of sensor-equipped luminaires reduces the risk of "false off" PIR failures.

Sensor Location

Eleven systems integrated sensors in the luminaire. Nine of these included a sensor in each luminaire; two used a "master satellite" arrangement with a sensor in one luminaire controlling two luminaires via wireless communication. The area to be covered by each sensor, based on the area of the room and the number of luminaires or sensors, varied from 30 to 179 square feet.

Ceiling-mounted sensors were placed near the middle of the room, as specified by their manufacturers in design submittals. Room area per sensor varied from 490 to 715 square feet.

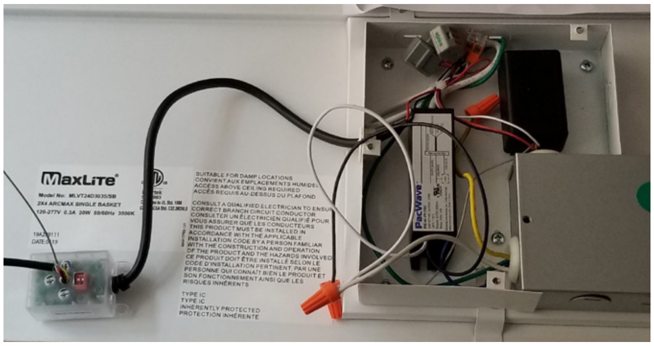
The use of multiple luminaire-mounted PIR sensors reduced the risk of false-off triggers due to body shadowing. Single ceiling-mounted sensors, on the other hand, lost sight of motion by a seated occupant whose back was to the sensor.

System	Sensor Location	Luminaire		Sf/Snr[2]	Grouping[3]
Lumenwerx/**Magnum**	Luminaire	Pendant	4	156	2 groups
Selux/**Signify**	Luminaire	Pendant	4	156	2 groups
Crestron/Starfire	Remote Mounted	Pendant	4	624	1 group
Signify	Luminaire	Pendant	4	156	2 groups
RAB Lighting	Remote Mounted	Troffer	9	490	1 group
Cree	Luminaire	Troffer	9	54	1 group
Nextek/Independence	Remote Mounted	Troffer	9	544	1 group
Cooper Lighting	Luminaire	Retrofit	6	57	1 group
LG	Luminaire[1]	Retrofit	4	133	2 groups
Signify	Luminaire	Retrofit	6	54	2 groups
Lutron/Orion	Luminaire	Retrofit	9	30	2 groups
Acuity	Luminaire[1]	Retrofit	6	84	1 group
MaxLite/**Avi-on**	Luminaire	Troffer	8	70	1 group
Silvair/Finelite	Luminaire	Pendant	8	60	1 group

Notes: 1) Sensor in one luminaire linked wirelessly to the other luminaire in the group. 2) Number of sensors divided by room area. 3) Each group turns off independently. (All rooms have two zones for manual control.)

Connectivity

Luminaire-mounted sensors connect directly to the LED driver in the luminaire. Photosensors and wireless nodes packaged with the sensors communicate to wall controls and configuration apps and tools. Ceiling-mounted sensors incorporate wireless nodes to communicate with luminaires. Systems used a wide variety of wireless protocols, mostly proprietary to some degree. Although several manufacturers offered their controls to luminaire manufacturers, none of the systems proved interoperable.

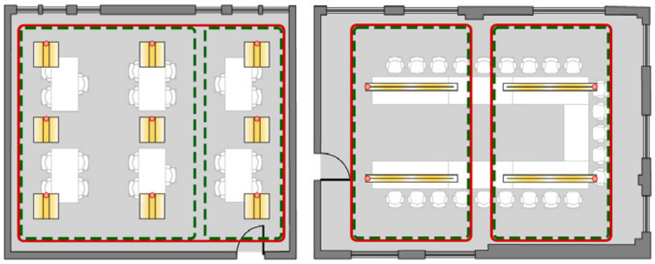


Coverage

As reflected in entrant data sheets, some sensors offered estimated ranges for both major motion (walking) and minor motion; others provided a single number. For all but one of the sensor types, the coverage pattern was circular, with radii from 6 to 16 feet. The other type offers rectangular coverage.

Grouping

Luminaire-mounted sensors in the Living Lab can be grouped into one or more zones for presence detection. With sensors grouped into a single zone, presence detected by any sensor keeps all lights on; lights turn off only after all sensors no longer detect presence. Thus, a single occupant keeps all lights on (with appropriate coverage and sensitivity).



Control for presence detection (entire room)

Manual control for use (2 zones to allow for presentation mode)

Manual control (2 zones) matches presence detection (2 groups)

Daylight Harvesting Operational Configuration						
Control System	Closed/Open Loop	Default (out-of-the-box) Operations	Calibration	Luminaire Response	Minimal Dimming Override	User-Configurable Settings
Signify	Closed	Enabled	Auto	Individual	Yes	• Enable/Disable
Cree	Closed	Enabled	Auto	Individual	Yes	• Specify minimum daylighting dim level (%)
Cooper Lighting	Closed	Disabled	Auto	Individual	Yes	• Enable/Disable • Set daylighting target (footcandle - fc)
Lutron	Closed	Enabled	Auto	Individual	Yes	• Enable/Disable • Set daylighting target (fc) using +/- slider
Acuity	Closed	Enabled	Auto or User	Individual or Zone	Yes	• Enable/Disable • Individual or zone response • Set daylighting target (fc)
Silvair	Closed	Disabled	User	Individual or Zone	Yes	• Enable/Disable • Individual or zone response • Set daylighting target (fc)

When grouped into multiple zones (two as specified for manual control in the Living Lab), lights in each zone turn off after the sensors in that zone no longer detect presence, potentially saving energy when the space is partially occupied. However, lights may stay on in an unoccupied zone (a “false on”) if sensors controlling that zone detect presence in an adjacent zone, an example of excessive coverage. Nine systems, including the three with ceiling-mounted sensors, grouped sensors into one zone for presence detection, while providing two zones for manual control.

Five entrants grouped sensors into two zones. In practice, lights turned off in one zone with occupancy only in the other zone—not a system failure per se, although occupants found this situation uncomfortable in the small rooms of the Lab. In larger spaces, this occurrence might not be a problem. Only one of the four systems could be reconfigured into the preferred single zone.

DAYLIGHT HARVESTING

The physical arrangement of photosensors is characterized as part of system architecture: 11 systems featured luminaire-integrated sensors, while three used ceiling-mounted sensors. Two systems using luminaire-mounted sensors were configured for master/satellite control, with a sensor in one luminaire controlling the other luminaire in the pair. Nine out of the 11 systems with luminaire-integrated controls had sensors installed at the end of the luminaire.

Only eight of the systems, representing six different daylight harvesting operational configurations, operated effectively—these systems received detailed consideration for the operational characterization across six key features.

Closed-Loop/Open-Loop

Closed-loop systems predominated (including all of those characterized in detail and assessed in 2020), with the luminaire-integrated sensor focused on available light directly under the sensor.

Default Operation

Daylight harvesting operation was enabled by default upon initial startup for most systems. Two systems required the user to complete additional configuration steps. For these systems, daylighting was disabled until luminaires were assigned to an area/zone/scenario that included daylighting control.

Calibration

Most systems, including all those assessed in 2020, implemented an automatic calibration procedure upon initial startup. One system allowed the user to either manually enter an illuminance (footcandle) set point for calibration or to choose automatic calibration. For another system, automatic calibration was not provided; the user was required to input the desktop illuminance target and then initiate the calibration routine during configuration.

Grouping

For most systems, luminaires responded individually to the daylight harvesting command from the integrated sensor. In this situation, some luminaires in a space, such as those closer to windows, gave the appearance they were dimmer than others, as each reacted to the amount of daylight available nearby. Two systems allowed the user to zone luminaires together such that all luminaires in the group operated the same in response to daylight harvesting commands, regardless of available daylight directly below them. For these systems, the user selected a leading sensor that controlled the entire group for daylight harvesting.

Manual Dimming Override

All systems allowed installers to manually override daylight harvesting control through operation of dimming wall controls. However, for several systems, the installing contractor could only manually dim lower, not higher, than the daylight harvesting setpoint. For all systems, automatic daylight control resumed after the luminaires were turned off manually or through occupancy control.

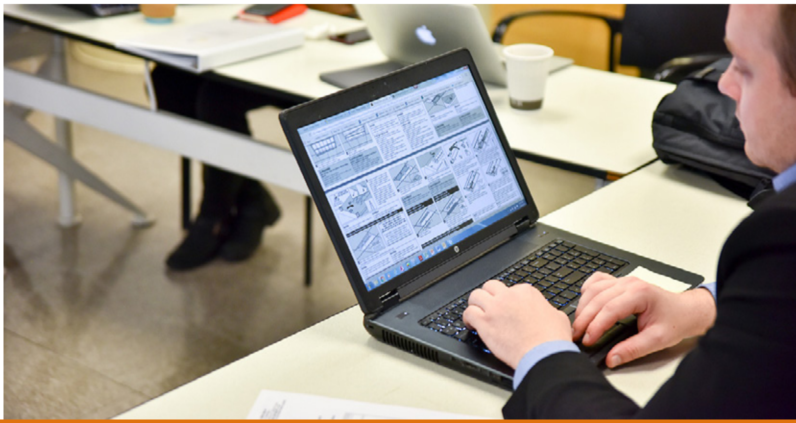
User-Configurable Settings

The systems varied in terms of the configurable daylight harvesting settings available. All but one system allowed installers to disable daylight harvesting operation. In addition, all but one of the systems allowed the setting of either a daylighting target (footcandle) or a minimum dim level for daylight operation. Two systems allowed the selection of individual or zoned luminaire response.

Daylight Harvesting Control Algorithms

For proprietary reasons, some specifications for the daylight harvesting control algorithms were not available for systems installed in the Living Lab. As a result, evaluators did not characterize the algorithms in detail in the table on page 12. However, some high-level information was available:

- All systems incorporated a default daylight harvesting curve.
- Systems featuring an automatic calibration process typically used a routine determined by the amount of electric light versus daylight that adjusted the default daylight dimming curve accordingly.
- Sensors measured the reflected light level from the surface below, including electric light and any daylight that fell within the sensor's view. As daylight contribution increased, the sensor dimmed the electric light, typically to maintain an illuminance setpoint.
- Often, daylight response was dampened to avoid frequent and rapid changes in luminaire dim level that was a response to intermittent changes in daylight due to passing clouds.



CONFIGURATION TOOL APPROACHES

Classification of Entries

NGLS entrants used one of three different approaches to system configuration: a dedicated handheld tool, a phone app, or computer software.

- **Handheld Tool**
  One manufacturer provided a system-specific handheld tool to configure control settings. Installers found the handheld tool to be similar to a TV remote and simple and straightforward to use. The tool generally offered fewer control function adjustments compared to the other configuration tool approaches. In addition, installers and facility managers raised concerns about the potential for misplacing a handheld tool.

- **Phone App**
  Out of the 14 systems installed, nine provided configuration through a phone app. Phone apps are typically readily accessible and familiar to users, and well-designed apps can offer intuitive control setting adjustments.

  Phone app design varied greatly, with each manufacturer taking a different and unique approach. Some apps used a visual graphic, similar to a reflected ceiling plan, to identify luminaires and devices; others used a simple list. Some apps included integral help features like embedded links to outside resources. These included user guides or video tutorials, which installers particularly appreciated. In some cases, installers found apps confusing and not intuitive.

  All of the phone apps were widely compatible with Apple and Android phones except for one that only worked on a subset of Android phones. This limitation caused delay and frustration for the installers of the system. After the NGLS evaluations, the manufacturer developed an add-on device to provide configuration capability beyond the original short list of compatible phones.

- **Computer Software**
  Three manufacturers provided configuration using software downloadable to a laptop or desktop computer. The software typically had a robust user interface and a large suite of control settings—which also made it the most complicated to use as it required access to a computer and sometimes an additional device, such as a communications dongle.

Entrant	Configuration Type			Features				
	Handheld Tool	Phone App	Computer Software	Integral Help	Visual Device View	List Device View	Apple Compatible	Android Compatible
Lumenwerx/**Magnum**			●			●		
Selux/**Signify**		●				●		●
Crestron/Starfire		●				●	●	●
Signify		●				●		●
RAB Lighting			●	●		●		
Cree	●					●		
Nextek/Independence			●			●		
Cooper Lighting		●				●	●	●
LG		●				●	●	●
Signify		●				●		●
Lutron/Orion		●		●		●	●	●
Acuity		●		●	●		●	●
MaxLite/**Avi-on**		●				●	●	●
Silvair/Finelite		●		●	●			●

Pacific Northwest NATIONAL LABORATORY

Next Generation LIGHTING SYSTEMS

Contact:

Ruth Taylor
ruth.taylor@pnnl.gov
503.417.7570

https://www.energy.gov/eere/ssl/next-generation-lighting-systems

U.S. DEPARTMENT OF ENERGY

PNNL-PNNL-SA-170842 | Updated January 25, 2022