INSIDE THE NGLS LIVING LABS

An Observational Understanding of Connected Lighting Systems

Pacific Northwest NATIONAL LABORATORY

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Connected lighting systems provide additional control capabilities and non-lighting-related services (such as communications and data infrastructure) to reduce energy use while increasing both application efficiency and system value. But the positive or negative energy impact of implementing these systems is still largely unknown due to the variety of human factors associated with installation, maintenance, and use. These complications interfere with adoption and acceptance rates of products that have the potential to play a significant role in achieving long-term energy savings.

Next Generation Lighting Systems, or NGLS, developed and implemented an observational research methodology for connected lighting systems. The methodology was implemented at an indoor (classroom/office) Living Lab at Parsons School of Design in New York City, and an outdoor (parking lot) Living Lab at Virginia Tech Transportation Institute in Blacksburg, Virginia. Although this report focuses on the approach for indoor installations, observational research in both settings provides insights into the type, scale, and frequency of issues across available products as experienced by contractors, end users, and other stakeholders.

In 2017, NGLS began a study looking at the expanded capabilities of connected lighting systems and their incorporation into the IoT ecosystem. Such systems

NEXT GENERATION LIGHTING SYSTEMS

NGLS is organized by the U.S. Department of Energy in partnership with the Illuminating Engineering Society and the International Association of Lighting Designers, and 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.

***NGLS Observational Research** is used to understand the processes associated with installing, configuring, using, and maintaining emerging building technologies to find and resolve pressure points, with the goal to increase adoption rates and fully realize energy-savings potential.*

had exposed new complexities in specification, installation, and operation due in part to the lack of IoT-device training and familiarity among design and construction teams. Connected lighting systems could be subject to digital technology obsolescence, cybersecurity vulnerabilities, and operational inconsistencies related to control system installation and configuration, all of which have been outside the scope of a lighting designer, electrical engineer, or electrical contractor. This report documents the research methodology used in the Living Labs to evaluate connected lighting systems from 2017 to early 2020, when evaluations were paused because of the COVID-19 pandemic.

THE BASIS FOR NGLS OBSERVATIONAL RESEARCH

New and emerging building technologies often undergo significant laboratory performance testing but are rarely evaluated in real settings due to factors such as cost and timeline to market. Any field testing usually analyzes only energy savings after installation is complete and the system operational, or it takes place in a controlled environment to study specific outcomes.

NGLS conducted observational field testing of connected lighting systems when market feedback indicated that configuration complexity inhibited the adoption and performance of advanced control systems, also limiting a valuable source of energy savings. Observational research could be used to understand the processes associated with installing, configuring, using, and maintaining emerging building technologies to find and resolve pressure points, with the goal to increase adoption rates and fully realize energy savings potential.

The research described in this report covers two separate projects: interior classroom/office installations and exterior parking lot installations. The projects share common NGLS leadership, but occur in different locations, with different facility owners, installing contractors, and industry professionals. Both projects are installed in already constructed spaces with existing lighting, representing retrofit, remodel, and upgrade applications. They represent an important opportunity for energy savings that is barely served by advanced controls, such as connected lighting systems.

The interior project focuses on connected systems described by their manufacturers as “easy to install and configure,” with 14 systems installed between 2017 and 2020. Each system features wireless connectivity, occupancy sensing, and manual and daylight dimming.

The exterior project focuses on parking lot luminaires with presence detection and wireless connectivity for remote control and data collection. Six systems have been installed to date.

Planning the Observational Research Process

The NGLS research methodology includes the tasks completed by the research team to form the project, develop research objectives, and observe and document problems inherent to installing, configuring, and using an emerging building technology—in this case, connected lighting systems. The process continues through everyday operation by users and the development of feedback for manufacturers.

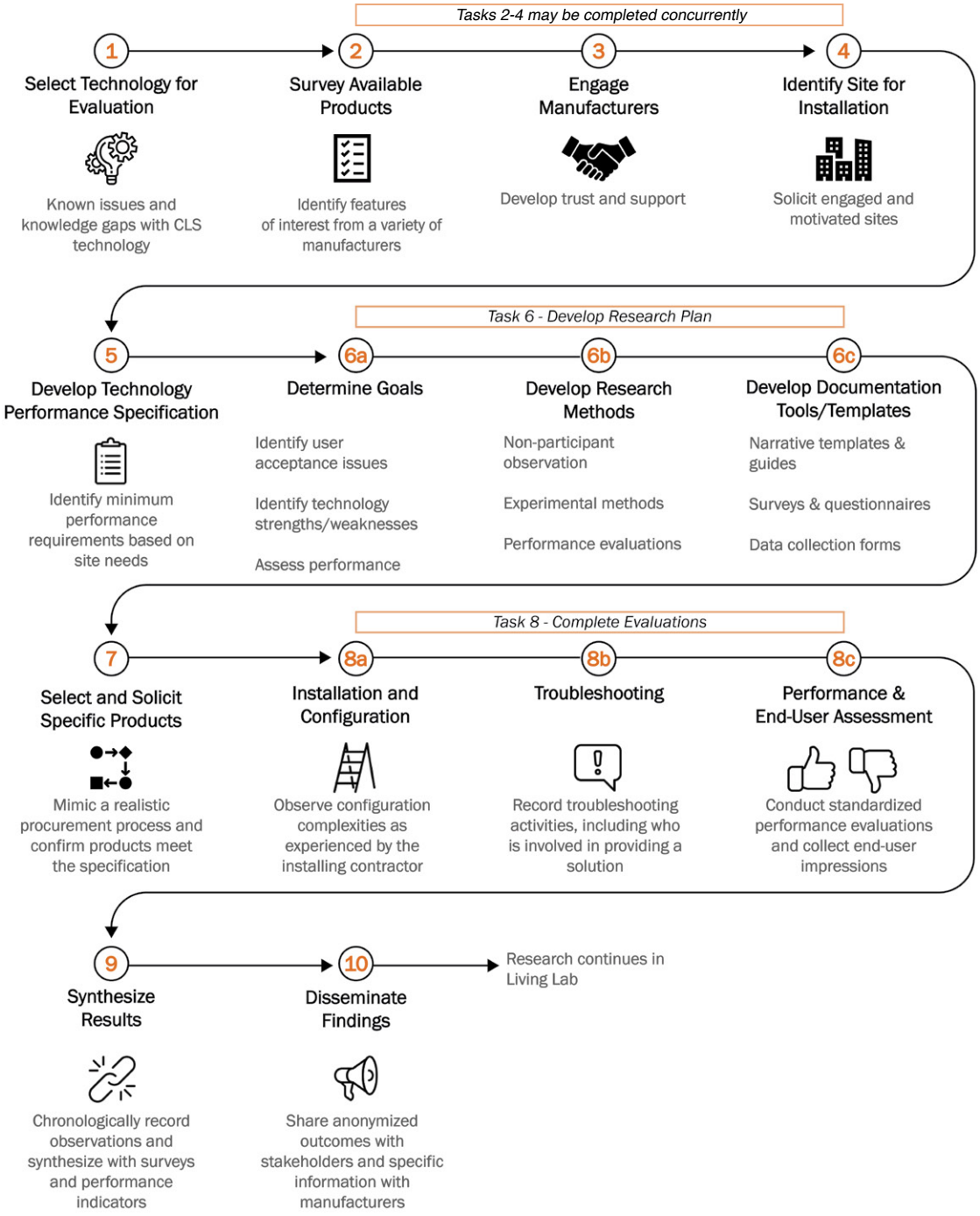


Figure 1. The NGLS Observational Research Process

Selecting Technology for Evaluation

NGLS used the known issues circulating in practice with connected lighting systems as a basis for research. In 2017, an abundance of products entered the lighting market and a wide variety of system approaches were available across manufacturers. Potential users had little awareness of the benefits and applications of connected lighting systems. Similarly, contractors were unfamiliar with the breadth of systems and lacked installation and configuration experience. This combination of unfamiliar processes, challenges with installation and user acceptance, and the abundance of products available motivated NGLS to conduct testing of connected lighting systems in the Living Labs.

Surveying Available Products

The NGLS research team reviewed connected lighting products on the market and identified features and functions of interest for evaluation—including those that might influence system performance and relied heavily on human interaction for success. For example, presence detection capabilities of integrated occupancy sensors in the outdoor environment were of interest to evaluate system performance. Studying installer interactions with manufacturer documentation was important to characterize the ease or difficulty of understanding and implementing installation instructions.

Engaging Manufacturers

Conducting observational research of connected lighting systems in a natural setting requires relationships with manufacturers, host sites, and industry stakeholders. NGLS drew on its established relationships and those of its precursor, the Next Generation Luminaires Design Competition, to begin this project. By 2017, the NGLS leadership and steering committee (comprising industry professionals) had been engaging in open dialogue with manufacturers and evaluating products for over a decade, earning NGLS a reputation as fair and trustworthy. Therefore, when NGLS leadership approached manufacturers with a proposal to undertake an extensive, real-world evaluation of connected lighting systems aimed to further develop the technology, they were able to assemble a team of experienced and knowledgeable industry evaluators and engage installers, including host-site facility staff and electrical contractors at the Living Labs.

Identifying Installation Sites

NGLS relies on the Living Labs as a platform for conducting observational research. In contrast to a typical laboratory-controlled environment, a Living Lab functions as a long-term setting with ongoing and dynamic installations, exposing pressure points from the perspective of installers, facility managers, and everyday users in the real world. The term Living Lab implies continuous activity, as the spaces are being used as normal. However, the research process can be long and intrusive, and troubleshooting can be less than ideal for host sites. Universities often make successful host partners because their facilities include a variety of classrooms, laboratory spaces, and exterior spaces for consistent evaluation and access to students and professionals interested in the topic.

The Parsons School of Design Indoor Lab in Lower Manhattan features high-traffic classrooms and offices in a high-rise setting. The Virginia Tech Transportation Institute in Blacksburg, Virginia includes surrounding parking lots in steady, year-round use.

Specifying Features to Evaluate

The NGLS research team created a detailed technology specification for the lighting and control system performance requirements for systems to be included in the study. Above all, NGLS chose to limit the required capabilities and configuration complexity of the systems. Maintaining consistency among the systems simplified on-site evaluation and facilitated accurate system comparison. By limiting the number of variables in play, researchers could draw actionable conclusions rather than merely collect descriptive observations.

In developing the specification, the research team worked with facility managers for each site, as these spaces and lighting systems would continue to be used regularly post-evaluation.

Developing the Research Plan

The research planning phase began by identifying the goals that would guide its design and subsequent research methodology. The NGLS research team's primary goals were associated with processes, people, and behaviors. Real-time observation proved to be an appropriate research method. Other project goals, related to technology performance, specific capabilities, and user functionality, led the team to incorporate more formal research methods, such as surveys and technology performance evaluations.

These goals and accompanying research methods guided development of specific documentation tools and a template to standardize data collection in the field. For example, in each Living Lab, the NGLS research team used nonparticipant observational research methods during installation of the connected lighting systems—meaning the evaluators did not actively participate, but installers were aware of their presence. Observers recorded the start and stop times throughout installation and configuration of the first system, which provided the data necessary to answer key research questions. A free-form narrative document was used by evaluators to capture actions and events, serving as a guide for subsequent systems. Each evaluation followed the same procedures in the same order. See Appendix A for example templates used in the NGLS evaluations.

The NGLS research team developed more than a dozen original tools and templates, each tied to a specific research methodology and evaluation, capturing a combination of qualitative and quantitative data points using subjective and objective metrics and measures. The research team also developed an initial plan for analyzing and synthesizing the various data types collected.

Consistent documentation lays a foundation for equitable data analysis across technologies or evaluators and helps ensure unbiased results. For the interior Living Lab especially, creating thorough documentation, including evaluator instructions, at the start proved to be a critical step. The 12 classrooms included in the original indoor evaluation were spread across the Parsons School of Design campus in different buildings and on multiple floors, preventing the NGLS research team from participating in concurrent evaluations.

Selecting and Soliciting Specific Products for Evaluation

At this point in the process, NGLS identified indoor and outdoor host sites and developed an appropriate technology specification for the characteristics of each site. The invited manufacturers entered 20 systems (14 indoor and six outdoor) and were asked to design an applicable system for their assigned installation site with performance specifications. The NGLS research team collaborated with manufacturers in modifying the submitted designs to make sure, at least on paper, the proposals would meet team specifications.

In one important departure from real-world conditions, NGLS arranged procurement directly with participating manufacturers rather than following typical industry sales processes and supply chains. This arrangement saved time with finalizing configuration designs, and the resulting communications provided useful information related to the specification process, notably the misunderstandings that can arise. Although this does not completely reflect a typical specification and procurement process, the lessons learned can inform current practice and provide general recommendations to the manufacturing community.

Completing the Evaluations

During the research planning process, the NGLS team identified several unique evaluations requiring a phased approach—in other words, early evaluations must be successfully completed before subsequent ones could begin (e.g., evaluating installation and configuration of the system before its performance could be tested). The phased approach also allowed for a realistic troubleshooting period that could be observed and documented for analysis as the research team identified recurring issues across systems, system-specific issues, and user/operator issues. The length of time and specific research teams varied over the multiple systems.

In both Living Labs, the first evaluation phase focused on the installation and configuration process; the second phase focused on troubleshooting; and the third phase (ongoing) focuses on performance evaluations and end-user assessments. Each phase has taken place on-site over multiple days with a team of knowledgeable industry professionals and the research team performing the evaluations.

Synthesizing Results

Observational research provides data collected in various formats, most of which are typically associated with a specific point in time or a defined period. The NGLS team organized the collected data chronologically for each individual connected lighting system. With the initial timeline of events established, similarities and differences between systems emerged and high-level metrics or performance indicators could be extracted, such as the number of times an installation issue was experienced, or the number of systems that experienced hardware issues during the troubleshooting phase.

The NGLS team noted several unconventional metrics during the outdoor data syntheses, like the length of time spent on the phone and the number of bucket truck trips needed to reach a streetlight during troubleshooting. As the number of bucket truck trips increased, the amount of time and resources wasted increased—both serving as quantifiable measures that influenced practice along with rates of potential adoption or acceptance. See troubleshooting tables on page 11.

Disseminating Findings

With the rapid growth and transformation of the market, NGLS understands the importance of promptly sharing results and practical feedback with manufacturers and stakeholders. Results are presented to each manufacturer for consideration and rapid product improvement. Anonymized information is shared with designers, specifiers, installers, and facility managers to improve market-wide design, installation, and operation. Research conducted in NGLS Living Labs will continue to provide feedback post-pandemic as users take control of each space and facility managers address maintenance issues.

NGLS EVALUATIONS

NGLS indoor evaluations of connected lighting systems in classrooms at Parsons School of Design began in 2017, and outdoor evaluations of systems in parking lots near the Virginia Tech Transportation Institute began in 2019. To date, NGLS has completed the installation and configuration evaluations, system troubleshooting, and performance evaluations at both locations. Other end-user assessments and hand offs of the systems to facility maintenance staff have been delayed because of the COVID-19 pandemic.

Evaluation Phase - Installation and Configuration (Step 8a)		Observation	Traditional	Performance	Objective	Subjective	Quantitative	Qualitative
Research Goal: Understand installation and configuration complexity for connected lighting systems.	Data Collection Tools:							
	- Installation complexity survey		X			X		
	- Video interview with installing contractor	X						X
	- Metric summary	X			X		X	
	- Time-stamped narrative	X			X		X	X
	- Verification of installation to specification				X			
	- Video documentation of installation	X					X	X
Evaluation Phase 2 - System Troubleshooting (Step 8b)								
Research Goal: Record the types of troubleshooting activities taking place and the path to resolution.	Data Collection Tools:							
	- Free-form narrative	X			X			X
	- High-level objective metrics	X			X		X	
Evaluation Phase 3 - System Performance (Step 8c)								
Research Goal: Verify lighting performance meets specification and evaluate sensor performance.	Data Collection Tools:							
	- Daylight harvesting functionality verification			X	X			
	- Occupancy/vacancy functionality verification			X	X			
	- Lighting performance (pass/fail)			X	X			
	- Lighting quality survey		X			X		
	- Group deliberation	X			X			X
Evaluation Phase 3 - End-User Assessment (Step 8c)								
Research Goal: Evaluate hand-off effectiveness and end-user assessment.	Data Collection Tools:							
	- User assessment narrative	X				X		X
	- Facility feedback to NGLS (user complaints)	X				X		
	- Hands-on system training (ongoing)	X						

Figure 2. Data collection tools used during NGLS indoor evaluations.

Data collection methods included time-stamped narratives, video documentation, original surveys, performance assessments, verification procedures, and group deliberation sessions. Each method was developed or selected in response to the specific goal of each evaluation. Ultimately, the combination of observational and experimental research methods, performance methods, and resulting subjective, objective, qualitative, or quantitative data produced a rich dataset that was shared with stakeholders to improve the performance, acceptance, adoption rates, and functionality of connected lighting systems. The data collection methods used by NGLS are summarized in Figure 2.

Installation and Configuration Evaluation

To evaluate installation and configuration, the NGLS team sought to describe and assess the ease or difficulty installing luminaire and retrofit kits and the installation and the startup of lighting controls, including initial adjustments (configuration). In this phase, the NGLS team worked on-site in the Parsons classrooms, observing and documenting these processes.

The Installation Teams

The indoor Living Lab installing contractors were teams of licensed electricians (a lead and one or more helpers) contracted by the host site (Parsons). NGLS involved different teams of contractors during this process—all of whom were novices with connected lighting systems—to reduce the potential learning curve from system to system and provide an accurate gauge of each system's ease of installation. The contractors were responsible for installing the luminaires and controls along with the initial configuration and adjustment of the control system. They were allowed to reference provided manufacturer documentation, use the internet, and call the manufacturer's customer support phone line for assistance. The installing contractors were aware they were being observed, but NGLS evaluators did not intervene with any installations or give guidance on the process. As described below, the contractors provided feedback on their experience via an installation complexity survey and participated in video interviews in which they assessed manufacturer documentation and the installation and configuration process for

each system. NGLS evaluators with diverse lighting industry experience also provided observational feedback.

Observations

During each installation, NGLS evaluators observed the contractors in real-time, documenting specific predetermined metrics, detailing a timeline, and logging feedback on the perceived ease or frustration associated with installing and configuring the connected lighting systems. The evaluators were also required to verify that the systems were installed correctly before the installers started configuration. To help document the installation experience, students from Parsons video recorded the installations when possible for review at a later date.

Evaluating in real-time allowed evaluators to ask installers to clarify what was happening at specific points in the installation without sharing industry expertise that might affect the result. For example, one contractor observed that the installation instructions illustrated the luminaire from a viewpoint different than that of a typical installer on a ladder, causing confusion. This comment might not have been captured in surveys or video observation.

The evaluators' time-stamped narratives were free-form—they did not follow predetermined checklists or surveys. They documented the issues and strengths, regardless of magnitude, and the behaviors and reactions of installing contractors as they occurred—often yielding unusually granular information, such as a problem's circumstances and resolution. In addition, the length of time to install the first luminaire could be easily calculated from the narrative, providing a more accurate estimate of typical total installation time.

The industry experience of NGLS evaluators allowed rapid, succinct, and accurate lighting and control system descriptions as part of the observations.

When an installation had been completed, NGLS evaluators video interviewed the installation teams to ask specific questions about challenges and for feedback to improve the installation and configuration process or the connected lighting system itself.

Participant Surveys

Installing contractors and NGLS evaluators for each product completed post-installation surveys consisting of multiple-choice questions, rating scales, and open-ended comment fields for personal explanations and observations. These multiple perspectives aimed to reduce any single bias from distorting the overall picture.

System Troubleshooting

In some research settings, the study may officially begin after the technology is installed and fully functional to reduce the risk of failure during experimental periods. NGLS has found that observing and recording realistic troubleshooting activities after installation is a critical part of improving a technology and increasing the likelihood it will be used again.

In conducting a troubleshooting evaluation of connected lighting systems, the NGLS team recorded the types of issues that occurred after

Troubleshooting Installation, Configuration, and Operation *(Indoor Living Lab)*

		Installation and Configuration Punch List Statistics				Additional Operational Issues AFTER Startup				Additional Operational Issues AFTER System Upgrade			
			Type of Punch LIst Item		Assistance Required to Resolve		Type of Operational Issue		Assistance Required to Resolve		Type of Operational Issue		Assistance Required to Resolve
System	Operational Months	# of Punch List Items	Hardware Issue	Software Issue	Phone/ On-Site	# of Issues	Hardware Issue	Programming Issue	Phone/ On-Site	# of Issues	Hardware Issue	Programming Issue	Phone/ On-Site
1	28	0				2		●	Phone	N/A			
2	28	1	●		Phone	1	●		Phone	N/A			
3	28	1	●	●	Phone/ On-Site	2	●	●	On-Site	0			
4	28	0				1	●		Phone	N/A			
5	28	3	●	●	Phone/ On-Site	1		●	Phone	3	●	●	Phone/ On-Site
6	28	0				1	●		Phone	0			
7	22	4	●	●	Phone/ On-Site	3	●	●	Phone/ On-Site	N/A			
8	24	0				0				N/A			
9	24	1	●		Phone	0				2		●	Phone
10	24	0				1		●	Phone	1		●	Phone/ On-Site
11	24	0				0				0			
12	24	1		●	Phone	0				0			
13	6	1	●	●	Phone	1	●		Phone	N/A			
14	6	1		●	Phone	0				N/A			

Troubleshooting After Installation/Configuration *(Outdoor Living Lab)*

System	Number of Luminaires	Number of Occupancy Sensors	Call Backs	Bucket Truck Lifts	Lift/Luminaire	Estimated Troubleshooting Hours by Owner	Number of Days from Installation to Function
1	6	6	2	9	1.5	3	3
2	8	8	4	19	2.4	20	40
3	5	3	5	8	1.6	16	50
4	11	14	2	3	0.3	30	15
5	11	11	6	50	4.5	32	Unknown
6	8	4	3	12	1.5	16	60

completion of the installation evaluation and their path to resolution. This evaluation took place over several months, with the team documenting the troubleshooting process for each system as a free-form narrative and collecting items, such as email correspondence with manufacturers and high-level objective metrics (e.g., hardware- or software-related issues, number of unresolved issues).

System Performance and End-User Assessments

System performance of the connected lighting systems is evaluated both with objective measurements and subjectively by evaluators' experience with lighting quality. The goals are to verify systems meet performance requirements and user expectations and to evaluate the performance of the additional occupancy and daylight harvesting sensors required for each system. Final evaluations will cover both facility hand off and user interaction once the NGLS team returns on-site after the pandemic. While such evaluations are typically not practical in experimental research, they will provide important information, particularly with respect to how the systems are actually used (or misused) and maintained, which significantly affects energy savings and the use of additional connected lighting system capabilities.

Performance Evaluations

NGLS created specific performance verification procedures for the connected lighting systems in both Living Labs. The procedures reflect different specifications and performance expectations of classrooms and parking lots, including lighting performance, daylight harvesting functionality, and occupancy sensor functionality for the interior systems. In addition, the procedures capture lighting performance, presence detection, and wireless control for the exterior systems.

Most aspects of system performance, such as illuminance, dimming, occupancy sensing, and system settings, could be measured and verified on a pass/fail basis despite variations among systems and site conditions. Other aspects, most notably

CONTROL SETTING VERIFICATION STEPS FORM

General Information			
Entrant #		System Name	
Installer Name			
Room Number		Date of Installation	
Evaluator Name			

CONTROL SYSTEM INSTALLATION AND STARTUP
Start with blinds closed. Allow lighting levels to stabilize (5 minutes).

Function	Verification Steps	Comments
Grouped into zones	Visually verify **two** zones using manual dimming controller	☐ Complete
Manual dimming	Test each zone independently 1. Adjust manual dimming control to maximum setting. 2. Measure light level at specified locations. 3. Adjust manual dimming control to lowest setting. (NGLS Spec = min dim setting of **10%** lumen output) 4. Measure light level at specified locations. 5. Adjust manual dimming control back to maximum setting.	☐ Complete
Daylight harvesting: lights in daylight zone change in response to daylight	1. Measure light level at specified locations. 2. Open blinds and allow light levels to stabilize (5 minutes) 3. Measure light level at specified locations.	☐ Complete
Task tuning	No verification needed this Phase.	☐ Complete
Occupancy control: turns OFF	1. Ensure no movement within range of sensors and record time to off (NGLS Spec = **5** min timeout) 2. If multiple sensors, record timeout period for each.	☐ Complete
Vacancy control: manual ON	Operate manual switch to turn on lights in each zone	☐ Complete

daylight harvesting and exterior presence detection, lacked established verification metrics. Here, the NGLS team developed its own approaches.

Knowledgeable NGLS evaluators performed the system verification because they were familiar with required light meters and standard measurement procedures. And they could provide more detailed feedback in terminology familiar to the lighting industry. As with typical experimental research, the evaluators completed detailed step-by-step forms to document the results and provide for replicability.

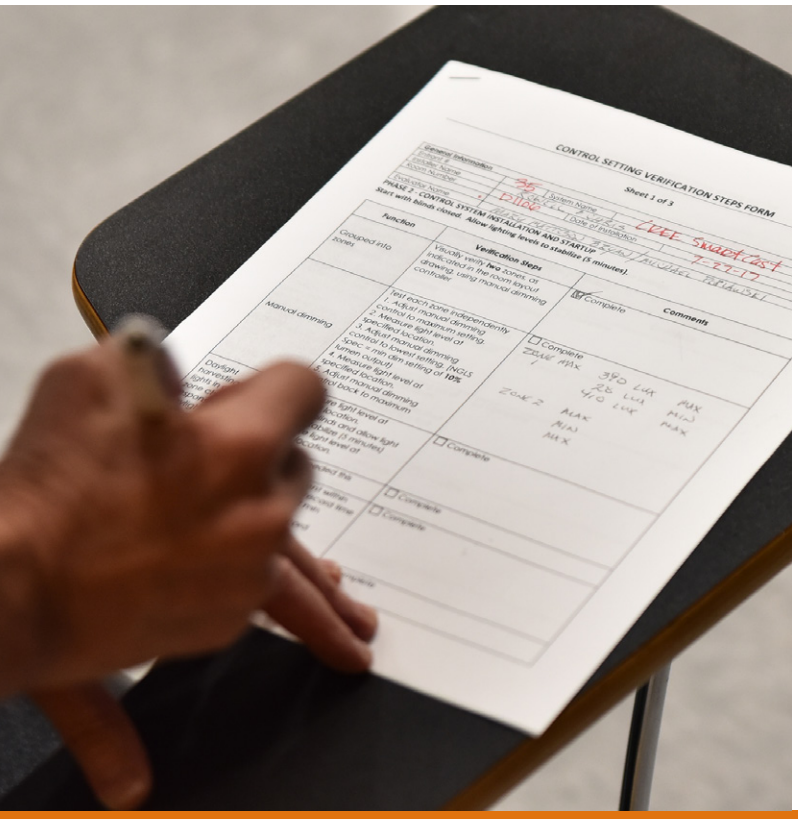
For the indoor subjective evaluation of system functionality, NGLS team members and a group of lighting students at Parsons who had been assisting the team operated the lighting controls and observed the quality of light in the space. Their results and reactions were collected through surveys with multiple-choice questions and open-ended comments. This subjective evaluation was not focused on user acceptance or interaction with the control interface; rather, it looked at the resulting lighting quality for the specific application.

Once all system performance evaluations were completed, the NGLS team reviewed the findings as a group to share objective results and individual perceptions. As the evaluations effectively ranked the systems, the open discussions introduced team-wide perspective and helped to minimize the impact of individual bias or experience. These reviews also began the process of synthesizing the large and diverse quantity of data.

User Experience

Narrative feedback and video documentation of both experienced (NGLS team) and inexperienced users (students and faculty) were reviewed to understand user interaction with each connected lighting system. Feedback on the usability of the wall controls began during system performance evaluation with more long-term user acceptance data collection planned for after the pandemic.

The NGLS system specification called for basic manual functionality: on/off and dimming control for two lighting control zones in the room. Each system used a unique interface for this functionality, distinguished by the number and type of buttons that activated each function. The specification did not require labels for the interface, although some systems provided them. Despite the objective of simplicity, many interface devices did not prove intuitive to users most familiar with an on/off toggle switch.



To assess ease of use, users interacted with the control interface and provided verbal feedback on whether the system did what they expected. Experienced NGLS users commented on the quality and perception of dimming, and on any unacceptable delays between their manual activation of the control and the resulting effect. Inexperienced users provided feedback on labeling strategy, visual complexity of the control station, and overall willingness to spend time controlling the lighting to create an appropriate environment.

Following the formal evaluations, NGLS continued to receive feedback collected through the facility maintenance department as end users requested assistance with the control systems. Reported issues included both functional failures and user confusion about system operation.

Facility Handoff/System Maintenance

The handoff for the interior sites began with a formal status report to Parsons' Facilities Management department, which detailed each system's operating status, outstanding issues, and NGLS recommendations for further actions. The COVID-19 pandemic prevented the next step, a training session with members of the maintenance team responsible for handling ongoing issues in each classroom.

Because new lighting systems have new components and features, as well as unique digital commissioning procedures unfamiliar to most maintenance staff, direct training after the reopening of Parsons should help limit frustration and prevent problems when they arise.

This phase will involve classroom delivery of a PowerPoint presentation to maintenance staff that includes an overview of basic characteristics of the control systems, and information about differences between each system, manufacturer, and communication protocol.

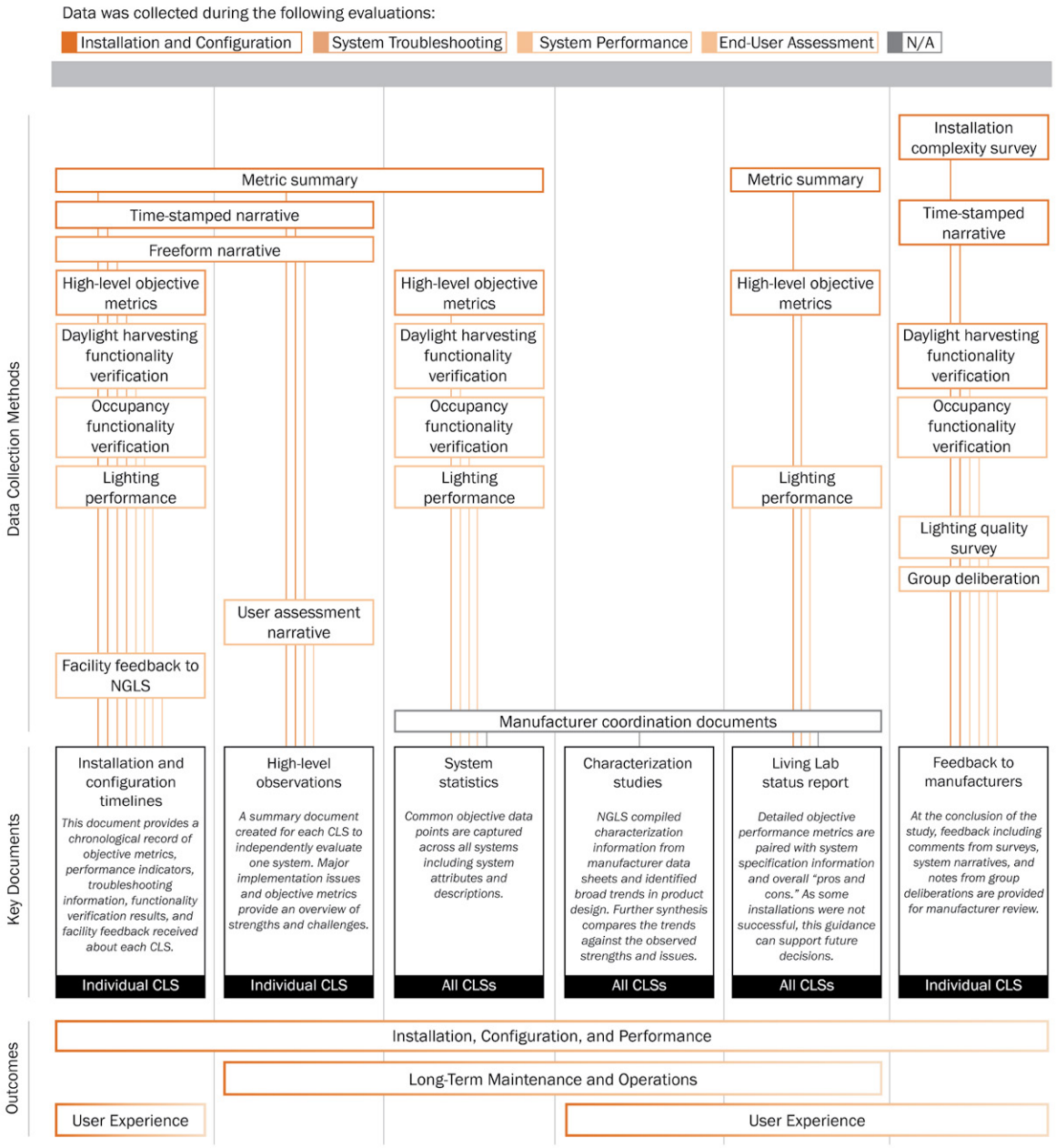


Figure 3. NGLS indoor synthesis

The NGLS research team also plans to brief maintenance staff on the commissioning process observed during the configuration and installation evaluation, sharing information gathered from observation. Then, facility staff will perform the commissioning process themselves and provide narrative feedback during the experience.

DATA SYNTHESIS

To date, NGLS research has generated volumes of observations, comments, recordings, and measurements. Synthesizing these data into a consistent, comprehensive account of the entire investigation enables observational research to progress beyond description and characterization, ultimately producing reportable and actionable conclusions.

System	External Controls Partnership?	Communication	Wall Control Type	Wall Control Power	Communication Protocol	Luminaire
1	Yes	Wireless	Rocker	Kinetic	Proprietary	Pendant
2	Yes	Wireless	Rocker	Kinetic	Zigbee	Pendant
3	Yes	Wired	Multi button	Battery	Proprietary	Pendant
4	No	Wireless	Rocker	Kinetic	Zigbee	Pendant
5	No	Wireless	Rocker	Line	Zigbee	Recessed
6	No	Wireless	Rocker	Line	IEEE 80215.4 based	Recessed
7	Yes	No	Rocker	Battery	6LoWPAN	Recessed
8	No	Wireless	Multi button	Line	IEEE 80215.4 based	Retrofit kit
9	No	Wireless	Multi button	Line	Zigbee	Retrofit kit
10	No	Wireless	Rocker	Kinetic	Zigbee	Retrofit kit
11	No	Wireless	Multi button	Battery	Proprietary	Retrofit kit
12	No	Wireless	Multi button	Battery	Bluetooth	Retrofit kit
13	Yes	Wireless	Multi button	Battery	Bluetooth	Recessed
14	Yes	Wireless	Rocker	Kinetic	Bluetooth	Pendant

The synthesizing process occurs both during and after evaluations and may prompt researchers to ask additional questions or more closely record specific actions or behaviors in the later phases of an evaluation. Without careful documentation and synthesis, observational research risks accumulating a mass of essentially anecdotal information.

For the connected lighting system indoor evaluation, the NGLS research team produced five key documents synthesizing data from the individual collection methods. Figure 3 depicts how each data collection method contributed to these five documents, and how those documents began to inform the key outcomes of the project.

Each data collection method (e.g., time-stamped narrative and lighting performance) was synthesized into one or more key documents (e.g., high-level system observations and Living Lab status report) that facilitated meaningful discoveries for the project outcomes (e.g., long-term maintenance and operations and user experience). Some documents focused on an individual connected lighting system, and others compiled similar information across all connected lighting systems.

Installation and Configuration Timelines

The NGLS research team consolidated and organized all metrics and performance indicators, troubleshooting items, key narrative information, functionality verification results, and user operational issues collected from Parsons facilities staff into a single chronological document for each installed system.

The timeline document is ongoing and allows the team to synthesize all information created and collected for each connected lighting system during the multiple phases of evaluation and beyond. Detailed information regarding troubleshooting and maintenance issues encountered during and after installation provides a way to assess the operational impact of system design and configuration complexities and a way to record solutions to specific issues encountered throughout the process.

High-Level Observations

The NGLS team also summarized high-level observations for each connected lighting system. Major implementation issues, narrative information, and an objective metrics summary (e.g., are the luminaires installed according to the specification?) are provided to quickly identify common strengths and challenges. These notes are recorded as close to the observed activities as possible so that recollections of context can inform the evaluators' judgments.

System	Control Node	Mapping	Occupancy Sensor	Occupancy Sensor Type	Cellular Connection	Gateway Mounting	Front-End Software
1	7-Pin	Physical	Luminaire Integrated	PIR	Owner	Building	PC
2	Luminaire Integrated	Physical	Luminaire Integrated	PIR	Owner	Building	Cloud
3	7-Pin	GPS	Pole Mounted	PIR	Owner	Building	Cloud
4	Luminaire Integrated	Physical	Luminaire Integrated	PIR	Manufacturer	Building	Cloud
5	7-Pin	GPS	Luminaire Integrated	PIR	Manufacturer	Pole	Cloud
6	7-Pin	GPS	Pole Mounted	Radar	Manufacturer	Pole	Cloud

System Statistics

A system statistics spreadsheet was created to compare the connected lighting systems across categories using objective data points captured for each system from the installation and configuration process, notably system attributes and descriptions.

Characterization Studies

Characterizing different aspects of the systems being studied helped to simplify discussion and identify and compare broad trends in product design. The NGLS team relied on manufacturer documentation for the basic information and then analyzed the data to produce distinguishing categories within such attributes as wall control devices, sensor configuration, and configuration tools (e.g., dedicated equipment, phone apps, and web-based apps).

Living Lab Status Report

The NGLS team provided the Parsons facility team with a summary of system successes and failures and each system's current operating status to help inform future decisions. This report was paired with objective performance metrics and specification information as a resource for reordering parts and communicating with manufacturers. It is an ongoing document, updated by the NGLS team in communication with facilities staff. It provides a continuing record of systems in the Living Lab.

Manufacturer Feedback

NGLS provides each manufacturer with a wide range of information collected about its system throughout the process, including open-ended comments and group discussions, survey results, detailed time-stamped narratives, and objective performance evaluation results.

NGLS project objectives seek to improve the performance of energy-saving control systems. This goal is being met. Manufacturers find the confidential feedback particularly useful and report they have used it to modify their products and, importantly, their documentation and installation tools for installers.

Conclusions and Observational Outcomes

In addition to the synthesis described above, NGLS pushed to identify relevant conclusions aimed to drive actions within the lighting and end-user communities to improve system performance in the market. While individual manufacturers could respond to the specific feedback provided, the primary conclusions tend to be general and continually inform the next steps for the Living Labs. Some of the key outcomes include:

- Currently available connected lighting systems are diverse in terms of features, device design, and configuration tools.
- The many unique approaches taken by manufacturers in developing their systems have thus far inhibited specifiers, installers, and end users from learning multiple systems.

- The “easy to configure” connected lighting systems that were studied required installer and user training and on-site assistance, in some cases, to make sure proper operation and full functionality. Real-time tech support—with rapid response—was critical to avoid potentially costly installation or construction delays. Of the 20 systems studied so far, 15 were unable to perform without factory intervention.
- The quality of manufacturer installation instructions varied significantly—some were far too detailed and long, others lacked specifics. Illustrations and videos proved most useful to installers.
- Information typically shared during the preconstruction design collaboration was not clearly communicated to the people installing and configuring the systems.
- Configuration software can change rapidly, adding to installer confusion. Changes to the initial configuration and system commissioning often proved to be just as difficult as the initial, time-consuming setup.
- Terminology is inconsistent, sometimes bafflingly so.
- Troubleshooting connected lighting systems is essentially an information technology exercise, and therefore is not in the skill set of most installers and electrical contractors.
- Parts are typically not as replaceable as they have been in traditional lighting systems. As a result, systems can be out of commission for several days waiting for replacement parts. Time is spent communicating with manufacturers, and dealing with complicated part numbers, nomenclatures, and system architectures—not to mention irritated users.
- NGLS performance evaluations revealed that the sensor technologies used were often not fully operational; thus, automated energy savings from occupancy sensing or daylight harvesting may not be realized.
- Verification methods are not standardized, notably for daylight harvesting, which limits the ability of construction teams and end users to make sure the installations provide the specified or intended performance.
- Constantly evolving technology makes it difficult to stay current and informed on best practices, and systems can fail because of firmware or software updates and connectivity issues—all of which are unprecedented problems for the people responsible for installing and maintaining these systems.

Pacific Northwest
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Next Generation
LIGHTING SYSTEMS

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