

Observational Research Methods for Evaluating Emerging Technologies in the Built Environment

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ABSTRACT

For years, energy efficiency programs have focused on the installation of energy efficient technology, with anticipated savings typically determined through modeling, engineering calculations or controlled field experiments. Yet measurement and evaluation completed after the fact have frequently found that the technologies are not delivering the anticipated savings. What happens in the real-world during installation, configuration and operation that leads to this disconnect?

To find out, the DOE Next Generation Lighting System (NGLS) program has pioneered the use of observational research for evaluating energy efficient technologies in the built environment. NGLS uses non-participant, real time observational research in conjunction with technology performance evaluations and traditional surveys to discover and document challenging human and technology intersections.

This report describes one application of observational research used to evaluate connected lighting systems (CLSs) in the built environment. Although CLSs are enabled to reduce energy consumption and increase the value of the lighting system, the NGLS observational research found a variety of human factors associated with installing, maintaining, and using CLSs that are barriers to realizing the full potential of the technology. The NGLS research methodology is outlined, and key outcomes in three main areas are discussed: the installation, configuration, and performance of CLSs; long-term maintenance and operation of CLSs; and user experience and interaction with CLSs.

In addition, recommendations are included for applying observational research to other building energy-efficiency technologies. Understanding and addressing the human factors issues related to energy efficiency is critical to ensuring savings potential is realized and adoption is persistent.

Introduction

Energy efficiency program design has traditionally focused on computer modeling, engineering calculations, and controlled field experiments to determine technology efficacy, market-readiness, and potential energy savings. While these methods provide appropriate estimates of energy savings and performance from an engineering perspective, measurement and verification studies have often identified a gap between the predicted and actual performance of emerging energy efficiency technologies.

Where do issues arise? What happens in the real world when these technologies are installed, configured, and operated that leads to this disconnect? Historically, little research has been devoted to studying the implementation of the emerging technology in real world applications, where human factors come into play.

This paper presents a mixed-methods research case study, primarily driven by observational methods, for evaluating emerging energy-efficiency technologies for the built environment. The report reviews details for one case study conducted by the Next Generation Lighting System (NGLS) program; connected lighting systems (CLSs). General conclusions, recommendations, and program guidance for applying to other technologies are also provided.

Observational Research in the Context of the Built Environment

Observational research methods are typically used when the subject's behavior is directly related to answering the research questions or when determining the "why" and "how" of the research questions. For example, authors from the UK conducted a study to examine the contributing factors of a well-known occupational health hazard, lead exposure. Authors observed workers before, during, and after spending time at the jobsite. In addition, authors collected blood samples to objectively measure lead levels in workers before and after their shift.

The objective results of the blood test confirmed the hypothesis that the worker's lead levels would be higher after leaving the jobsite, however, it was only possible to identify the "why" and "how" with observational research. The authors reported that incorrect use of the decontamination unit and lack of personal hygiene habits after spending time at the jobsite posed a greater risk to workers than their time spent on the jobsite (Sen, Wolfson, and Dilworth 2002).

Similarly, there are issues and complexities related to installation and operation of energy systems in the built environment that can be better understood through observation. The process of designing, constructing, and using a building is inherently complex and necessarily involves people and their behaviors that, to date, have been left out of energy estimates because they are challenging to accurately predict, model, or simulate. Observational research methods involve the research team carefully watching and recording the behaviors that lead to an eventual outcome, thereby exposing the complexities of human interactions with people and technology that may influence the ultimate success or failure associated with a technology or building system.

Observational research methods are used to systematically observe and record behaviors, actions or interactions, or subjective evaluation of emotions in ways that do not manipulate or interfere with the natural setting. The research team may decide to immerse themselves in the setting and gain a firsthand experience by participating in the task or culture, or the team may decide not to participate and instead to observe in real time or retrospectively, through video or other documentation. In either case, the flexible nature of observational research allows the research team to determine an appropriate study duration. In the case of the built environment, watching a product from design through maintenance allows the research team to establish connections between problems that occur during installation that result later in operational issues.

Applying Observational Research: A Case Study

NGLS Program Overview

NGLS is organized by DOE in partnership with the Illuminating Engineering Society and the International Association of Lighting Designers and is managed by Pacific Northwest National Laboratory (PNNL). It is part of a broad DOE/PNNL effort to advance the effectiveness

of connected lighting systems. NGLS evaluations primarily focus on the configuration complexity challenges faced by connected lighting projects in the field.

Observing the specification, installation, configuration, operation, and maintenance of CLSs allowed the research team to identify and address complexities plaguing adoption and provide feedback directly to manufacturers. Completing this work in a “living lab” environment allowed for ongoing and dynamic engagement with the technology and the people interacting with the system.

The following sections outline the research framework implemented by the NGLS research team in a living lab located in 14 university classrooms at Parsons School of Design, The New School located in New York City. The research process is summarized below in Figure 1, and a detailed description of the methodology can be found in a related publication (Collier, Taylor, and Matteson Bryan 2021).

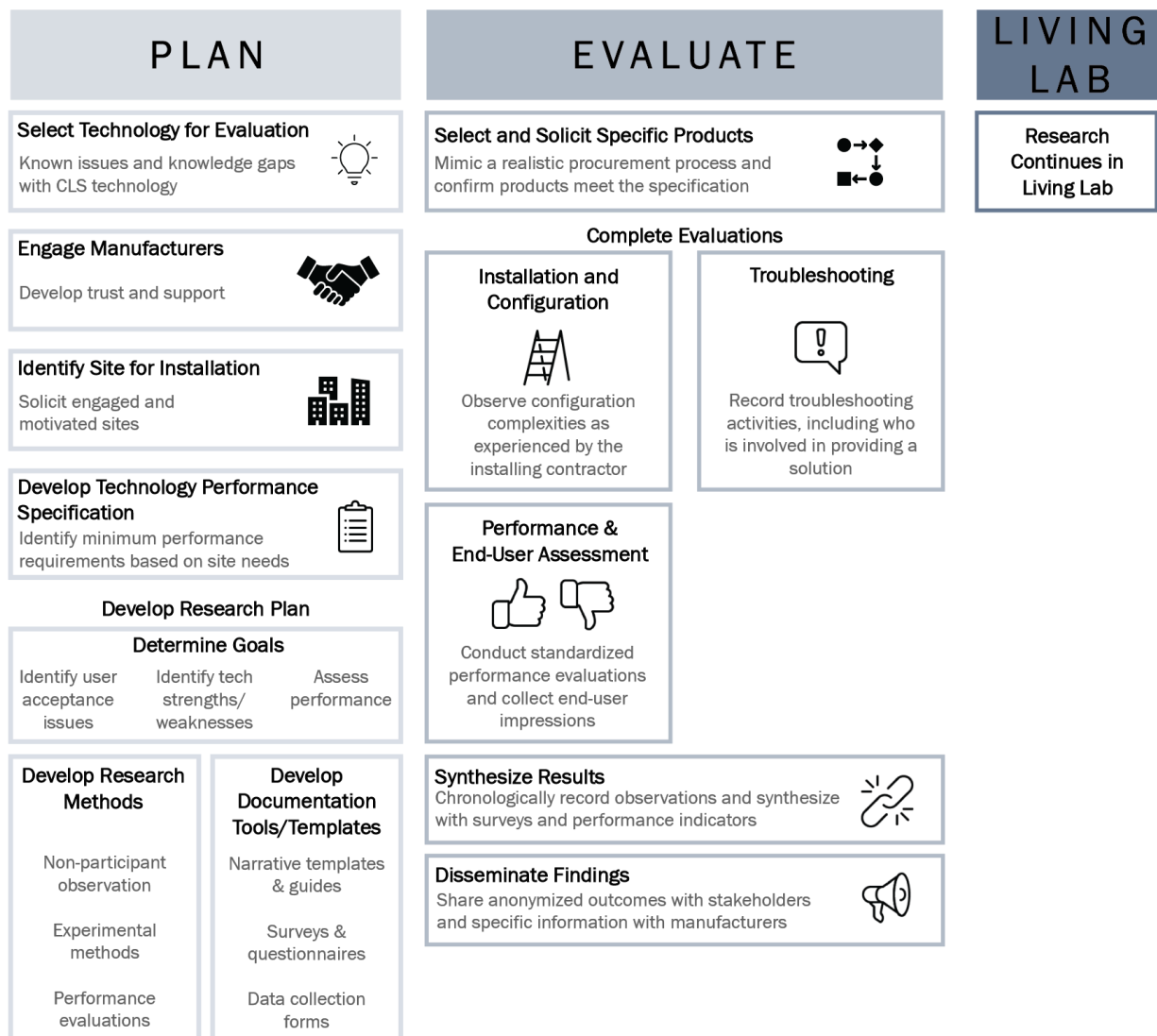


Figure 1. A summary of the NGLS research planning and execution process.

Project Planning

In addition to the known challenges and knowledge gaps described above, the number of new, unique lighting systems entering the market supported the decision to focus on connected lighting systems, more specifically, lighting systems that were being marketed as “easy to install and configure”. The research team reviewed available products to determine the number of on-the-market systems that belong to this category and to determine the functionality and capabilities that would be required to participate in the study.

Prior to completing any further technology specifications, the team discussed appropriate applications to install and evaluate the technology at hand. Ultimately, a university site offered several elements key to the project’s success: an engaged facility team, faculty and students with interest and experience in lighting, and a number of similar classroom spaces that provided an equitable baseline for the system comparison. In collaboration with the Parsons facility staff, the research team identified classrooms in three existing buildings for the retrofit installations and technology evaluations. All three midrise buildings are in a dense urban setting and host a variety of university administrative spaces, classrooms, studios, and workspaces. The classrooms all have access to daylight and vary between 266 and 715 sq. ft.

The research team worked with the site facility staff to develop a realistic specification and narrow the research scope to the features and capabilities that supported site use cases and the universities organizational goals. The program was announced as an industry competition and interested manufacturers were instructed to submit a product proposal for eligibility review by an NGLS industry committee. Products that were described as “easy to install and configure” and that met the minimum performance requirements were assigned a specific classroom and each manufacturer prepared a retrofit design proposal for their assigned space.

The specification language was written to meet the controls requirements in ANSI/ASHRAE/IES STANDARD 90.1-2016 (ANSI/ASHRAE/IES 2016) and to provide a luminous environment consistent with recommended practice (e.g., illuminance levels and contrast ratios) for classroom lighting in the 10th Edition of the IES Lighting Handbook (IES 2011). Minimum control requirements included: occupancy or vacancy sensing, local on/off/dimming, daylight harvesting, high-end trim, and the ability to control multiple zones. The form factor or type of luminaire, optics and light distribution were selected by the manufacturer and reviewed by the NGLS industry committee.

Evaluations

Fourteen systems were selected for inclusion in the study. The host site was responsible for identifying contractors and electricians they would typically hire to perform the installations. The installers were licensed electrical contractors who had limited exposure to advanced lighting systems. Installers were permitted to call manufacturer support, consult product documentation, or view manufacturer web materials during the installation. Manufacturer representatives were invited to watch the installation but were not allowed to intervene in any way.

In addition to the installers and the manufacturer representatives, two NGLS evaluators were assigned to each installation. The evaluators were primarily responsible for observing and documenting the installation and configuration activities, however, they also ensured proper procedures and protocols were followed throughout the process. It was important that the evaluation team was familiar with lighting systems and associated terminology so that they could succinctly and accurately describe what they were observing. While the evaluators were not

allowed to answer questions posed by the installers, they were able to ask the installers questions about their process, actions, or reactions in the moment to provide an accurate record.

Observation began during the design and review phase. The NGLS research team tracked items such as the number of design document revisions required and manufacturer responsiveness. The research then moved to onsite observation of installation and configuration. Prior to the start of the onsite evaluations, the team developed the necessary protocols and data collection forms that ensured a rigorous and equitable evaluation process. For example, several evaluation-specific free-form narrative templates were developed in a way that allowed flexibility when capturing observed actions and behaviors (digitally or on paper) but also operated as a step-by-step guide, ensuring evaluators captured key metrics and timestamps along the way. An example is shown below in Figure 2.

PHASE 2 - CONTROL SYSTEM INSTALLATION AND STARTUP
Start with blinds closed. Allow lighting levels to stabilize (5 minutes).

Function	Verification Steps	Start/End Time	Observations
Grouped into zones	Visually verify two zones using manual dimming controller.		
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.		
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.____		
Occupancy Control: turns OFF	1. Ensure no movement within range of sensors and record time to off (NGLS Spec = 5 minute timeout period). 2. If multiple sensors, record timeout period for each.		
Vacancy control: Manual ON	Operate manual switch to turn on lights in each zone.		

Figure 2. Example of a narrative template created for NGLS evaluators.

The four formal onsite evaluation procedures are described below.

Installation and configuration. The goals of the installation and configuration evaluation were to describe and assess the relative ease or difficulty of the installation of the luminaires or retrofit kits and installation and startup of the lighting controls, including the initial adjustment and programming of control settings (configuration). In this phase, the NGLS evaluators observed

and systematically documented the process in each classroom in real time. The installations took place in multiple phases between 2017 and 2019; the first phase included rooms with full luminaire replacement installations and the second phase included rooms with retrofit kit installations. The observations took place over several days in each phase.

For the installation and configuration evaluation, the NGLS evaluators instructed the electrical contractors to install the luminaires and confirm that they were electrically powered. Next, contractors were instructed to install the control system and start the system. Finally, the contractors were asked to adjust the control settings as necessary to meet the NGLS specification. Evaluators were instructed to verify each task was completed before allowing installers to move on to the next step. Each evaluator individually completed a time-stamped narrative and was directed to freely and thoroughly document the actions and behaviors exhibited by the installing contractors during each task. Video documentation of each installation was also collected for future reference.

In addition to observation, the team developed surveys that were completed by the installing contractors and the evaluators immediately following the installation and initial configuration. The surveys focused on assessing the perceived difficulty or complexity associated with installing and configuring the lighting system and consisted of multiple-choice questions, rating scales, and open-ended comment prompts. At the conclusion of each installation, the evaluators conducted recorded interviews with the installers to ask specific questions and gather detailed feedback related to challenges the installers faced, strengths of the products, as well as any suggested improvements to the installation process.

System troubleshooting. In most field evaluations, the study period typically begins after the technology is installed and fully functional. Conversely, the NGLS research process continued observation through the troubleshooting phase to record the variety of issues and the eventual path to resolution. At the conclusions of the installation and configuration phase, five of the 14 systems were operating according to the specification. In some cases, the last task of configuring the lighting controls in accordance with the specification was never completed, largely due to software or hardware issues that appeared during the installation process and halted the process.

While the facility staff on site were primarily responsible for coordinating troubleshooting activities, the research team remotely monitored email correspondence with manufacturers and captured pertinent metrics like the number of unresolved issues, length of time to resolution, or the number of people involved in resolving each issue. This information was captured chronologically in a free-form narrative template. After four months of troubleshooting, seven systems were fully functional and two were still awaiting resolution. Five systems ultimately did not meet the initial specification; several systems are currently being upgraded, modified, or replaced. The research team will continue to observe these systems as they are modified.

Performance evaluation. After the troubleshooting activities were complete, the research team began evaluating lighting system performance. This phase was designed to verify that the lighting systems met the performance requirements and provided an appropriate and pleasant lighting quality, and to evaluate the performance of the additional system features, such as occupancy or vacancy sensing and daylight harvesting. The team verified objective metrics presented in the specification, collected subjective responses through interviews and surveys, and developed testing protocols to evaluate the operation of additional features. The evaluations were

completed on site over several days by knowledgeable lighting professionals and the NGLS research team.

To ensure that the lighting systems were operating within the bounds of the specified lighting quality metrics, the NGLS research team measured several key aspects according to standard industry practices and procedures. The measurements were taken at full power and at multiple dimmed levels and included average, maximum, and minimum illuminance, correlated color temperature (CCT), color rendering index (CRI), and luminaire luminance. Each system was rated on a “pass/fail” basis for each metric.

For the subjective evaluations, lighting practitioners were invited to tour each classroom, use the wall controls, and visually assess both the aesthetic quality of the illuminated environment and of the luminaires themselves. At the start of each evaluation, practitioners were given the specification sheets, objective metric results, and a survey that included multiple-choice questions and open-ended prompts. The practitioners were instructed to complete their surveys individually, but the research team did not discourage active conversation amongst the group during their assessment. The NGLS research team was present for the evaluations to observe and listen to their conversation but did not interact with the practitioners.

The two remaining evaluations, occupancy/vacancy sensing and daylight harvesting, required the research team to develop testing protocols in the absence of standardized procedures or verification metrics. Step-by-step protocols were developed so that the procedures would be followed in a repeatable manner by all evaluation teams. Knowledgeable evaluators were responsible for performing the tests and recording the results from an observational perspective, as well as on a “pass/fail” basis. Notes regarding irregularities, successes, and contributing factors were collected in a freeform narrative. In this evaluation, four aspects of occupancy (i.e., vacancy, minor motion, micro motion, and coverage) and five aspects of daylight response performance (i.e., appropriate illuminance, stability, appropriate zoning, dimming smoothness, and speed of response) were evaluated on a “pass/fail” basis according to the performance guidance outlined in the specification.

Subjective end-user assessment. Narrative feedback was collected through observation of both experienced (NGLS evaluators) and naïve users (students and faculty) to understand user interaction with each lighting system, particularly the lighting control interface. User feedback was initially collected during the performance evaluation on site and continued remotely once classes returned to the upgraded rooms.

To assess ease of use, participants were asked to simply interact with the control interface and provide verbal feedback on whether the system was doing what they expected based on their action. More experienced users were able to comment on the quality and perception of dimming or if there was an unacceptable delay between their manually activating the control and a resulting effect, while naïve 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. The reported issues included both functional failures and user confusion about system operation. Additional onsite evaluations focused on facility staff were paused due to the pandemic.

Synthesis and Reporting

At the conclusion of the onsite performance evaluations, the invited practitioners, evaluation teams, and the NGLS research team gathered to discuss the lighting systems as a group. This discussion focused on identifying the common problems and achievements across the lighting systems and across the multiple perspectives present in the study. As the evaluations effectively ranked the systems, this open discussion introduced a 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 collected throughout the multiple evaluation phases.

Combining research methods such as narrative observation and a standardized performance evaluations provided the research team with a well-rounded assessment, however, without careful documentation and synthesis, observational research risks accumulating a mass of essentially anecdotal information. Synthesizing the data into a consistent account enables the research to progress beyond description and characterization to produce reportable and actionable conclusions.

The NGLS research team began by developing a “system story” for each lighting system, which organized data chronologically. The team captured specific strengths and weaknesses, troubleshooting procedures, functionality verification results, and calculated time-based metrics from the data collected in narrative form. This information was supplemented by targeted survey questions and objective performance metrics that were consistently captured across all systems.

Each system story was then compared to one another and, along with key insights from the group deliberation, the research team formed high-level observations and outcomes regarding the technology. The synthesis documents also directed the team to produce reports regarding outcomes related to the various system architectures, presence detection performance, and wall controls perceptions, as these themes consistently emerged across the lighting systems included in the study (Taylor, Blitzer, and Matteson Bryan 2021; Taylor and Blitzer 2021; Taylor, Blitzer, and Beeson 2022; Taylor and Matteson Bryan, 2022).

At the conclusion of the data synthesis and analysis phase, a summary including key outcomes, survey comments, and objective performance measures was created for each lighting system and was shared with the manufacturers. In addition, a “system status report” was produced and included original product documentation, part numbers, outstanding troubleshooting activities, objective performance results, and a high-level subjective summary to aid the facility staff in future lighting decisions and installations, including upgrading and maintaining the systems that were installed for the study.

Case Study Outcomes

Although advanced lighting systems promise the ability to reduce energy consumption and increase the value of the lighting system, the NGLS team found a variety of human factors associated with installing, maintaining, and using the systems that are ultimately barriers to realizing the full energy efficiency and operational potential of the technology. Specific feedback provided to individual manufacturers can inform product improvements. More importantly, the primary conclusions are broadly applicable to the technology and to the processes associated with the people installing and using it. The following conclusions also informed future research questions, activities, and approaches to be explored further in the living lab environments.

Product diversity, rapid changes, and proprietary systems cause confusion and introduce unnecessary complexity. The initial market review and technology analysis made it abundantly clear that lighting systems are endlessly diverse in terms of features, device design and system architecture, and configuration tools. In the field, system diversity inhibits specifiers, installers, facility staff, and end users from learning the multiple systems they are bound to experience. During the initial configurations, installation teams used more than eight unique configuration procedures that leveraged web tools, phone apps, and handheld devices. Further, due to the IoT nature of these systems, time consuming but necessary software and firmware updates often needed to be completed before configuration could begin. In many cases, these updates resulted in connectivity issues and device incompatibly errors, which are largely unprecedented problems for the people responsible for installing and maintaining these types of systems. Lastly, the proprietary nature of lighting systems means that parts and components are not as replaceable as they were for traditional lighting systems. Instead of taking a trip to the local supply store, installers spent valuable time communicating with manufacturers, discussing complicated part numbers and nomenclatures, and then spent several days waiting for the shipment to arrive.

Accessible system support is critical. It is a known problem in the construction industry that design documents and product documentation are rarely shared with the installers before they arrive on site. The result is that installers arrive on site unprepared and rely on manufacturer documentation and support during the installation. The results of the study suggest that manufacturer installation and product documentation are of inconsistent quality – some include far too much detail while others are too superficial. Interviews with the installers revealed that illustrations and videos were the most helpful resources, however, the quality of these vary as well. Although the systems were marketed as “easy to configure”, 75% of the systems in the study did not perform properly without assistance or factory intervention. Real time tech support – with rapid response – is critical to avoid potentially costly installation or construction delays.

Lack of verification methods and reliance on automation result in underperforming systems. As more connected, IoT, and machine-learning oriented building control devices and services enter the market, more owners and users expect to experience appropriate, automated operation of building systems like lighting, heating, or cooling. The results from this study suggest that some of the sensor technologies as deployed were not fully operational after initial configuration, which resulted in lackluster performance. Performance shortcomings, such as the lights turning off when the room is occupied or staying on when the room is not occupied, led to dissatisfied users, complaints to the facility staff, and did not produce the anticipated energy savings. Additionally, the lack of standardized verification procedures limits the ability to assure that the installation was successful, and that the automated platform is operating correctly and will continue to do so over time.

Observational Research Outcomes and Lessons Learned

Since the completion of the CLS classroom study, the observational research methodology presented here has been repeated in an outdoor parking lot setting and in an office setting. Repeating the methodology in other applications has revealed the following outcomes and lessons learned to consider when conducting observational research on human factors in real-world settings.

Human Factors are Underappreciated

Reliance only on engineering calculations and controlled field experiments can lead to overestimating energy savings, in particular the persistence of energy savings. Unanticipated human factor issues during installation, commissioning and operation can upend the most detailed engineering estimates of performance. Observational research can identify the pressure points in installation and operation of energy efficiency technologies and allow these to be addressed in program design.

Emerging technologies are unlikely to deliver promised energy savings without support to address the critical but often overlooked element of all sophisticated technology: the people who install, configure, and use the systems. In particular, utilities that promote emerging technologies could play a significant role supporting the people involved in implementation of these systems.

Observational Research Uncovers the “Why”

Traditional research and data collection quantifies information and provides the “what”: e.g., the measured time for installation of the luminaire was excessive. Observational research allows for association and understanding of the “why”: e.g., the research team observed that the contractor struggled with poor installation instructions that illustrated the luminaire from a perspective different than the installing contractor’s perspective, causing confusion.

One of the key features of observational research that allows the “why” to be identified is its inherent flexibility and adaptability during the data collection period. At the beginning of a project, it is often the case that a comprehensive list of data to capture is difficult to develop; you don’t know what you don’t know. Observational research narrative and free-form observational tools allow for continuous data collection and can capture information that was potentially not considered ahead of time in other more structured tools, like surveys.

A Qualified Evaluation Team is Important

It is important to assemble a team of experienced and knowledgeable industry evaluators that are familiar with the technology under evaluation. Familiarity with the technology allows evaluators to describe in familiar terms rapidly, succinctly, and accurately what they are observing. However, evaluators also should have the ability to set aside possible preconceptions based on their experience and look at the technology with fresh eyes. Including evaluators with diverse backgrounds (design, engineering, utility, lab) is also important; multiple perspectives serve to reduce any single bias from distorting the overall assessment. Finally, it is important that evaluators are consensus-focused and work well in a team environment.

Observational Research Provides Unique Data and Unconventional Metrics

Observational research provides the opportunity to learn new information that can be missed with other research methods. The data collected through observational research is largely qualitative, which can be particularly important if the goal is to accelerate adoption and long-term energy savings performance of emerging technologies.

Often, observational research finds that perception is different than outcomes suggested by quantitative data – the numbers may show no performance issues, but if people perceive

difficulties, discomfort or dissatisfaction, there is a problem. For example, NGLS identified an issue with manual dimming due to unintuitive design of wall controls. Figure 3 provides an example of the feedback collected during the study. When naïve users were asked to operate wall controls to dim lights, they were observed to struggle and often fail because there was a delay in the visual response of the lighting (dimming) when pressing the switch. Improved wall control design that provides immediate feedback when pressed to dim, or markings on the wall control, such as arrows or a strip of LED lights indicating dimming level could address these difficulties.

Wall Controls Ease-of-Use Exercise						
Evaluators (knowledgeable users) and students (naïve users) operated wall controls to complete a specific control sequence (on/off, dimming, AV zone).						
System	Knowledgeable Users			Naïve Users		
	On/Off	Dimming 2 Zones	AV Zone	On/Off	Dimming 2 Zones	AV Zone
1	Yes	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes, but delay to dim caused confusion	Yes	Yes	No, delay to dim led to failure	Yes
3	No	Yes	No	No	No	No
4	Yes	Yes, but delay to dim caused confusion	Yes	Yes	No, delay to dim led to failure	Yes
5	Yes	Yes	Yes	Yes	No	Yes
6	Yes	Yes	Yes	Yes	Yes	Yes
7	Yes	No	Yes	Yes	No	Yes
8	Yes	Yes, but delay to dim caused confusion	Yes, but label not intuitive	Yes	Yes, but delay to dim caused confusion	Yes, but label not intuitive
9	Yes	No	Yes	No	No	Yes
10	Yes	Yes, but delay to dim caused confusion	Yes	Yes	No, delay to dim led to failure	Yes
11	Yes	Yes	Yes	Yes	No	Yes
12	Yes	Yes	Yes	Yes	Yes	Yes

Note: Due to COVID-19 restrictions, the wall controls ease-of-use exercise has not been completed for the two newest systems.

Figure 3. Results of the Ease-of-Use exercise completed by knowledgeable users and naïve users. Participants were asked to perform three tasks: turn the lights on and off, dim the lighting, and can they enable the AV lighting scene.

As previously stated, flexibility is a key benefit of observational research that can lead to the identification of unique and important metrics. For instance, during the syntheses of data collected during observational research of outdoor connected lighting systems, the NGLS team noted an important metric: number of bucket truck trips needed for each parking lot light during installation and configuration. A high number of bucket truck trips reflects a system with higher installation and configuration costs. Addressing this issue by developing a more efficient installation and configuration process could potentially improve adoption and acceptance rates.

In addition, NGLS found a disconnect between data from traditional written surveys and reality. Surveys completed by installers often indicated a positive, trouble-free installation, while NGLS observers witnessed and reported differently.

Early Observational Research Can Influence Product Design

Observational research conducted in collaboration with manufacturers of emerging technologies can provide valuable findings that can influence early product design. Observational research can quickly and directly identify problems with the processes involved with installing, commissioning, and using emerging energy efficiency technologies. These findings, when shared with manufacturers, can inform technology development and current practice.

Start Problem Solving Early

As soon as a specific technology or process has been identified, engage working groups, committees, and industry partners to learn about current experience and discuss potential solutions. Doing so will further inform the research goals and will allow for faster communication of outcomes and recommendations after the study is complete.

Guidance for Applying Observational Research Methods to Other Emerging Technologies

With the valuable insights gained by observing CLSs in the NGLS living labs, the question of whether this approach could be used to discover similar deployment barriers in other technologies should be considered. The observational process itself is not dependent on the technology or people observed, so what makes this approach appropriate for one technology over another?

Not all projects will be suitable for observational research; establish the project's research goals prior to deciding appropriate research methods. For example, NGLS established research goals that were best suited to a realistic environment with uncontrolled variables and real end users that were part of the investigation. As a result, a true experimental research design was not a suitable choice because of the uncontrolled environmental variables, lack of participant randomization, and focus on procedures rather than a specific intervention and outcome.

Observational research can reveal how a technology is used, why it is used in a certain way, and what influenced the success or failure of the installation. Understanding and addressing the human factors issues related to energy efficiency is critical to ensuring savings potential is realized and adoption is persistent.

When to Use Observational Research

Based on the outcomes of the NGLS evaluations, emerging building technologies that are new to the IoT ecosystem, are rapidly evolving, or rely on human factors for successful implementation, maintenance, and system use would be appropriate technologies to observe in a research setting. Additionally, building technologies that require interoperability with other systems or that interact with grid infrastructure would benefit from observational research. Here, the troubleshooting and resolution process could be an initial way to integrate observational research into an emerging technology demonstration project.

Understanding the pressure points and variation between systems or technology approaches can provide guidance on best practices and raise awareness of potential problems. Observational research allows for market wide and system specific feedback to be provided,

where experimental, building code based, or performance/savings-based research methods may unintentionally focus on very specific hypotheses, constrained variables, or tend to highlight positive and numeric outcomes.

Planning for Observational Research

There are several key factors and strategies to note that greatly contributed to the success of an observational research project and therefore, the success of the technology. Developing trusting relationships with technology manufacturers and installation sites will ensure support and interest for the duration of the project. These relationships can facilitate access to installation sites for observation and allows valuable lessons learned to be shared with industry partners who can implement technology innovations to improve product acceptance and widespread deployment.

If a living lab is deployed to facilitate observations, remember that this implies continuous activity at the host site, the research process can be long and intrusive. Since the spaces marked for research are potentially still being used, the troubleshooting process can be less than ideal for host sites. Make relationships with multiple host sites and understand their interests, wants, and needs out of a potential long-term partnership. NGLS found that universities can often lead to successful host partnerships because they may have many similar spaces for consistent evaluation and may have access to students or professionals interested in the topic. A living lab environment, as opposed to a typical laboratory-controlled environment exposes pressure points from the perspective of everyday users in a familiar environment.

Documenting Observations

After the technology is selected and relationships are established, begin developing research goals and methods. Identify existing and known metrics to be systematically documented and plan to capture these in real time, either in person or from video footage. Relying on memory of evaluators or installers to summarize actions at the end of the work or activity may result in inaccurate or anecdotal data. In addition to specific metrics, time stamped, free-form narrative data collection tools not only allow for continuous data collection, which goes along with continuous observation, but also captures information that was potentially not considered ahead of time. Do not assume actions, behaviors, or issues are unimportant; narrative observations should be as objective and detailed as possible. As appropriate, consider setting up a long term, possibly remote, data collection strategy for investigations that will act as living labs or will be conducted over a long time period.

The documentation, evaluation procedures, templates, and data collection tools should be specific enough that they are repeatable by multiple evaluators. It is important to form a structured approach, including evaluator instructions, to ensure rigorous and equitable evaluations across multiple evaluation teams and systems. To move past anecdotal experiences, evaluations must be consistent and impartial, and a strategy for removing observer and participant biases should be considered during project planning. Collecting information from multiple perspectives during the evaluations is one way to dilute potential biases and can strengthen outcomes, conclusions, and recommendations. Evaluating a technology with observational research can quantify the extent of problems, provide resolutions in realistic settings, identify strengths or weaknesses, and provide a clear path forward for manufacturers and practitioners designing and implementing the technology.

It's important to document a realistic troubleshooting period – who do people call? Do they have the right information? How long does it take to get the solution? Is it a “typical” solution? A one-off patch? This documentation – encountered during and after installation – provide a way to assess the operational impact of system design and configuration complexities and to record solutions to the specific issues encountered throughout the process. This information can be provided to the facilities team in the form of a system status report to aid the facilities team with decision making in the future.

It is also important to synthesize data collected into a consistent account, which enables observational research to progress beyond description and characterization, ultimately producing reportable and actionable conclusions. Without careful documentation and synthesis, observational research risks accumulating a mass of essentially anecdotal information.

Allocation of Resources for Observational Research

Another consideration in applying observational research to other technologies is the time and resources needed for the process. Although the process can be time consuming and costly, it can be considerably less costly and time consuming than waiting for people focused deployment barriers to be discovered and mitigated ‘on their own’. And the recovery from market ‘lash back’ from widespread deployment failures can be significantly more costly in the long run. In order to determine time and resources for observational research, it's important to consider both the internal research team activities and the time needed for external coordination and administration.

Figure 4 shows how project resources were allocated during each phase of the process. Research team workload is consistent throughout the process but is greatest during on-site evaluations and during project planning. These two phases (project planning and evaluations) align with the greatest amount of external coordination and collaboration with the host sites and manufacturers. For NGLS, spending time on site with a team of evaluators was a planned large expenditure of project resources, as it was necessary to accomplish a large scale, real time observational research study that produced tangible outcomes. It is important to form a structured approach considering resource allocation, specifically people and time, when trying to equitably evaluate through observation.

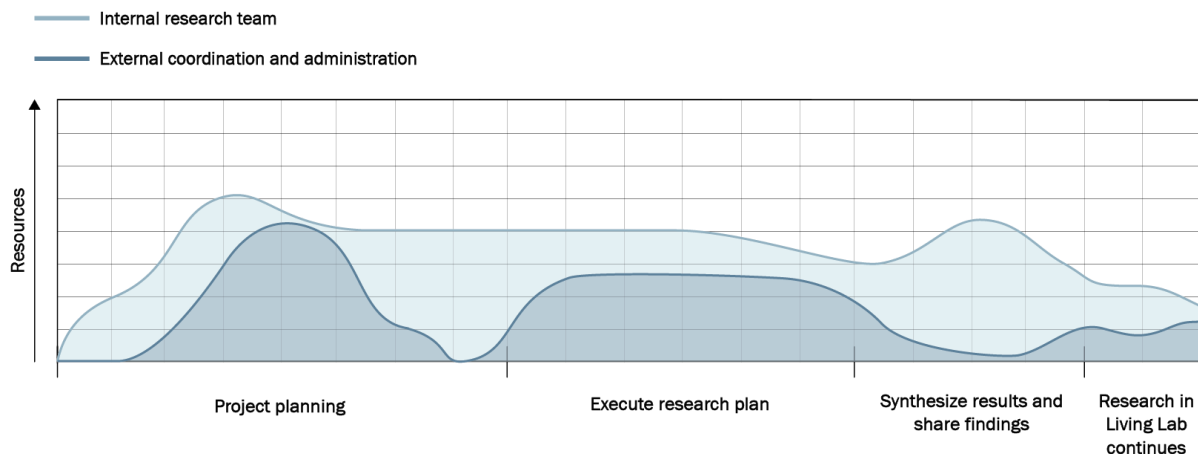


Figure 4. Different tasks throughout the project require different amounts of time, personnel, and therefore resources. The project planning phase is intensive in research coordination as well as external relationship building; many evaluators and participants spent time on site during the evaluation period; coordination with the installation sites continues as the living lab continues on.

Conclusion

The proposed observational research methodology allowed the research team to quickly identify human factors issues associated with the installation of advanced lighting systems, provide system specific feedback to manufacturers, and disseminate broadly applicable outcomes and best practices for working with new lighting systems. As the nature of building systems and technologies continue to become more capable, connected, and integrated, evaluation of the variety of ways humans encounter and influence the performance of systems will be invaluable to the energy-efficient future the technologies promise. To date, the research team has successfully utilized observational research methods to uncover the human factors, some of which are planted as early as product design and specification, that influence the success of installation and therefore subsequent operation, acceptance, and adoption of advanced lighting systems. Future observational studies could be directed to address other process and people related issues affecting the efficiency of the design and construction of buildings or to further understand the facility hand-off and ongoing maintenance processes.

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