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Interoperability for Networked Lighting Controls

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EXECUTIVE SUMMARY

Building systems, including Networked Lighting Control (NLC) systems, increasingly need to cooperate and communicate with other systems beyond their boundaries to achieve a higher level of operational efficiency and energy savings. The ability to exchange actionable information between two or more systems is called “interoperability”. Interoperability among building systems is the key enabler for unlocking benefits from cross-system operation and optimization.

The goal of this report is to illustrate how the broad topic of interoperability can be addressed by focusing on use cases with specific stakeholder value, market barriers, technical gaps, and necessary supportive interventions. Three use cases are explored in depth, and the methodology is described so that this approach can be applied to additional use cases in the future.

This report describes the need for NLC interoperability and the ways that interoperability can improve outcomes for building owners, operators, and other key stakeholders. It provides a foundation of common understanding about NLC interoperability by clarifying:

- The definition of interoperability
- The importance of interoperability for energy savings and other value-added services it enables
- The barriers, opportunities, and value propositions associated with greater interoperability for various stakeholder groups

From a catalog of 32 use cases, the three use cases in **Table 1** were chosen for initial focus based on stakeholder support, technical feasibility, energy savings potential, and the ability to deliver value in the next three to five years.

Table 1: Top Three Use Cases Identified as Initial Focus for Interoperability

Use Case	Highlighted Use Case Example
External systems integration	Use occupancy data from NLC to inform HVAC operation
Load shedding/demand response	Real-time dispatching and reporting for demand management, between NLC and another system (EMS, utility, etc.)
Energy monitoring	Energy data reporting to a utility incentive program to verify savings

The three use cases described here are interconnected and support one another. While products that support these use cases will provide more value to various stakeholders, the stakeholders with the most to gain will need to drive adoption. Industry standards will be essential in order to realize these three use cases more fully. The framework outlined in this report can be applied to additional use cases, for future research, and to support product selection and/or specification.

Based on this report, various stakeholders, including lighting designers, engineers, architects, distributors, contractors, and facility managers, can frame design criteria and ask the right questions when specifying interoperability related to NLC systems. The findings will also serve to advance the state of NLC interoperability using the DLC NLC Technical Requirements and Qualified Products List (QPL).

INTRODUCTION

The DLC's role in supporting broader adoption of networked lighting controls (NLCs)

The DesignLights Consortium (DLC) is a non-profit organization dedicated to accelerating the widespread adoption of high-performance commercial lighting solutions. The DLC promotes high-quality, energy-efficient lighting products in collaboration with utilities and energy efficiency program members, manufacturers, lighting designers, and federal, state, and local entities. Through these partnerships, the DLC establishes product quality specifications, facilitates thought leadership, and provides information, education, tools, and technical expertise.

Networked Lighting Controls (NLCs) present untapped opportunities for energy savings beyond energy-efficient LED lighting; and for operational and business insights leveraging the rich data sets from NLC sensors. End users, specifiers and system integrators have started to recognize the benefits of NLCs. Utility energy efficiency programs across North America have started to reap additional lighting end use energy savings by accelerating the adoption of NLCs in LED conversion and new installation projects. Building systems such as NLC increasingly need to cooperate with other systems beyond their boundaries to create value-added insights and solutions. While these emerging solutions have significant potential to bring new value and insights to building owners, operators, designers, and other stakeholders, they all require cross-system interoperability.

There are many instances where improved interoperability among building components and systems will generate value. However, making devices and systems interoperable requires a significant commitment of time and effort across many market actors. Therefore, interoperability should be driven by use cases[1] prioritized in order of their scale of adoption and total potential value. The DLC's goals for this project were to identify a few feasible use cases that are likely to create high value for stakeholders in the next few years, and to sketch a roadmap for their realization. This report explores three specific use cases, as practical applications of interoperability.

The DLC's support for interoperability

The DLC is dedicated to accelerating the widespread adoption of high-performing commercial lighting solutions. Interoperability is essential for this mission, supported by tools such as the NLC Technical Requirements document and the NLC Qualified Product List (QPL). The QPL is used by utility energy efficiency programs to determine program eligibility. In addition, the QPL is used by end users, specifiers, contractors and other practitioners in the industry to select products that meet their project needs. Beginning with this report, the DLC is developing a multi-year, phased strategic plan to encourage higher levels of interoperability of systems listed on the DLC's NLC QPL, by reporting capabilities that support various interoperability use cases, and by developing new initiatives in the NLC program.

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[1] A "use case" describes a scenario where a system is used to achieve a specific goal or goals. For instance, in one of the use cases an NLC system is used to generate an energy report that is delivered to an energy efficiency program, supporting an incentive payment that covers some of the cost of the NLC system. The main goal of the building owner is to reduce the net cost of the NLC system, while the main goal of the efficiency program is to save energy.

Objectives: identify critical use cases and how the industry can advance them

The goal of the research documented in this report was to identify critical interoperability use cases and develop a strategic framework for the DLC to help advance the state of those use cases. The research took a bottom-up approach, identifying a wide range of interoperability use cases and then applying qualitative analysis along with various metrics to prioritize and select three use cases for initial focus. The metrics considered include stakeholder value (through meetings, interviews and surveys as outlined in the appendices), market size, energy savings, cost savings, performance enhancement, and technical feasibility. The prioritized use cases were then further characterized for their market status and barriers, technical feasibility and gaps, and feasibility of supportive interventions.

This report provides a foundation of common understanding around NLC interoperability by clarifying:

- The definition of interoperability
- The importance of interoperability for energy savings and other value-added services it enables
- The barriers, opportunities, and value propositions associated with greater interoperability for various stakeholder groups

This will guide stakeholders—including lighting designers and specifiers, distributors, contractors, and facility managers—to frame design criteria and ask the right questions when specifying these and other interoperability use-case needs, as demonstrated in Appendix E.

The full catalog of 32 use cases identified in this research as well as the prioritization details are included in the appendices. While three use cases were selected for initial focus, future work will explore and prioritize additional use cases to expand beyond these initial ones.

INTEROPERABILITY OVERVIEW

DEFINING INTEROPERABILITY

Interoperability for lighting systems is defined by the American National Standards Institute (ANSI) as the ability of systems or system components to transmit, receive, interpret, and/or react to data and/or power and function in a defined manner[2]. Defined more concisely by the Smart Electric Power Alliance (SEPA), interoperability is the ability to exchange actionable information between two or more systems[3]. For many electrical systems including NLC, interoperability can unlock additional, often higher, value.

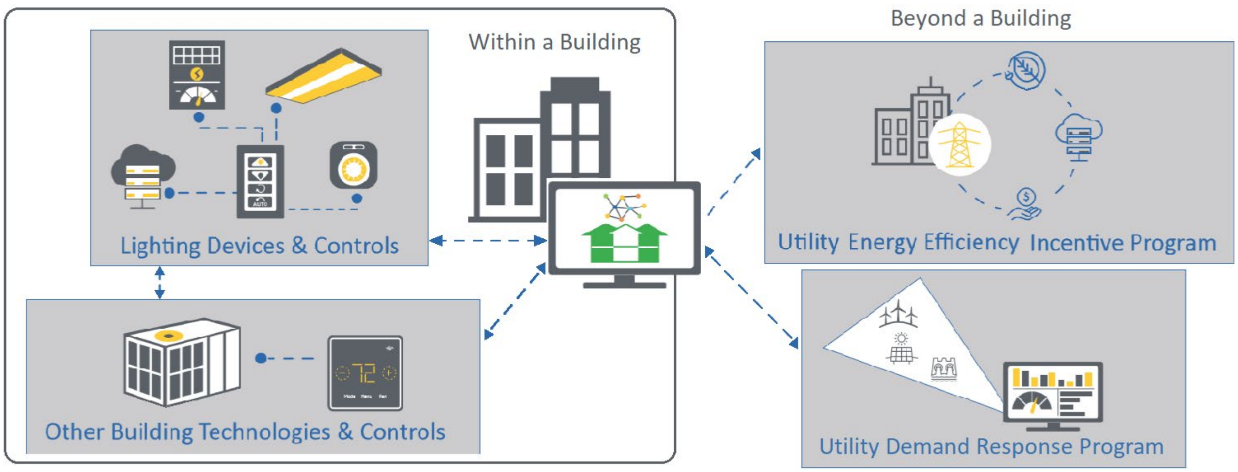

Figure 1: Interoperability examples, within and beyond a building

Interoperability for a clear purpose or "use case"

Devices or systems do not necessarily need to be interoperable across all types of services or functionalities – only where there is a clear need for communication for a defined purpose. For example, the occupancy status from a lighting system may be useful for increasing the temperature and ventilation control effectiveness of an HVAC system. In that case, communicating occupancy information between lighting and HVAC systems would be a defined interoperability purpose. In other words, interoperability should be driven by "use cases", where the functionalities, data sets, and communication pathways between two devices or systems are defined to achieve meaningful impacts on cost savings, operational efficiencies, user satisfaction, or other organizational benefits. For example, occupancy status (e.g. occupied vs. unoccupied) can meaningfully inform HVAC operation, whereas other NLC data such as light levels (e.g. 100% vs. 50%) cannot.

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[2] ANSI C137.0-2017, American National Standard for Lighting Systems- Lighting Systems Terms and Definitions.
[3] "Interoperability Profiles-A Better Way to Buy Grid Technology", 4/2/2020 Daisy Chung, https://sepapower.org/knowledge/interoperability-profiles-a-better-way-to-buy-grid-technology/

The three primary types of interoperability

At a high level, interoperability can be divided into three broad categories:

- **Device-to-device interoperability** between two NLC system components, typically from different vendors, or between an NLC component and a device beyond an NLC system, such as between an NLC's occupancy sensor and a furniture-mounted temperature sensor.
- **Device-to-system interoperability** between an NLC component and a different NLC system.
- **System-to-system interoperability** between an NLC system and another system, which may be another NLC system, a building subsystem, an integration and management tool, or an enterprise system or software application.

Examples of use cases in all three categories are described in Appendices C and D. However, the three main use cases highlighted in this report are all examples of system-to-system interoperability.

INTEROPERABILITY AND NLC SYSTEMS

Networked Lighting Control (NLC) systems provide sophisticated energy and non-energy features that enable building owners and operators to derive significantly more value from their systems than standalone controls. For instance, an NLC system can report its own energy use to a utility program, supporting efficiency incentives without the need to install, monitor and remove expensive dataloggers. Likewise, information from other systems may be provided to the NLC to harmonize operations and increase efficiency across systems. **Table 2** illustrates examples of information that may be shared between NLC and other systems, and how it may be used.

Table 2: Data shared between NLC and other systems and potential applications of the data*

Data to or from the NLC	How the data can create additional value
Occupancy status from NLC sensors	• Used by BMS to adjust HVAC setpoints to generate additional energy savings without compromising occupant thermal comfort • Used by the elevator control systems to optimize car dispatch to shorten the wait time and increase energy performance • Used by enterprise applications to optimize space utilization
Energy usage data from NLC	• Aggregated by an Energy Information System (EIS) to dashboard real-time energy usage across all building systems to streamline facility performance monitoring and extract operational insights • Used by analytics applications to identify anomalies and improvement opportunities • Used by efficiency programs to support incentives and verify savings
NLC component information	• Used by maintenance management system to dispatch work orders and order replacement parts in advance of a failure
Demand response signal from BMS	• Used by NLC to participate in demand response events by shedding lighting load, to reap additional event participation incentives
Operation schedules from BMS	• Used by NLC to align control schedules to streamline facility schedule enforcement and increase operational efficiency
Personalized light level control information	• Provided to the NLC by an enterprise or mobile application that optimizes occupant comfort in workspace environments

**Please note that the list in this table is non-exhaustive.*

THREE HIGH PRIORITY USE CASES

USE CASE SELECTION AND PRIORITIZATION

Many interoparability use cases have the potential to create valuable impact eventually. A selection and prioritization exercise was conducted to identify three use cases with the potential to deliver high value in the timeframe of three to five years.

Developing a catalog of use cases

To identify high priority interoperability use cases, the DLC conducted outreach to (a) define interoperability use cases, and (b) identify their potential value to stakeholders. The Project Team first brainstormed a catalog of 32 specific use cases (shown in Appendix C) based on the available literature as well as team members' experience and observations in the field. This catalog, while not exhaustive, was meant to cast a wide net before focusing on near-term priorities. The Project Team subsequently conducted six interviews with industry experts from different stakeholder groups in the U.S. and Canada, to vet the use cases and narrow the number of use cases from 32 down to ten.

Conducting outreach to identify stakeholder priorities

The Project Team then conducted an online survey to solicit input from a wide range of stakeholders involved in lighting and building projects. 40 individuals completed the survey. The survey asked the participants to identify themselves among the six categories in **Figure 2**; to prioritize the importance of each of the ten use cases for their practices and businesses; and how soon the participants need or expect each use case to be put in practice. For participants belonging to the NLC manufacturer stakeholder group, the survey additionally asked them to assess the technical complexity of each use case. The survey is described in more detail in Appendix A. Note that "End Users" includes facility managers, building owners, and real estate portfolio managers.

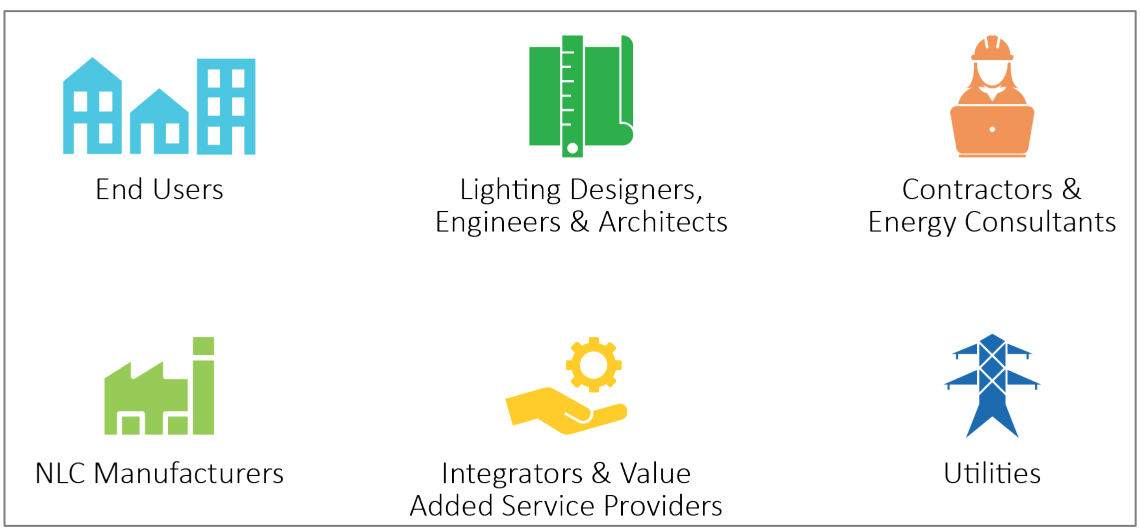

Figure 2: NLC Interoperability Survey Participants by stakeholder type (n=40)

To select the top use cases for initial analysis, a use case prioritization framework was developed considering the following qualitative metrics:

- Stakeholder value
- Anticipated market size
- Energy savings potential
- Cost savings
- Performance enhancement (occupant satisfaction, operational efficiency)
- Technical feasibility

Each of the metrics was evaluated on a 0-5 scale (with 0 as the lowest score and 5 as the highest) and was assigned a weighting factor such that the overall score of a use case was the weighted sum of the rating along the metrics. The stakeholder value for each stakeholder group was derived from the responses of the online survey participants. The anticipated market size, energy savings, cost savings, and performance enhancement for each use case were qualitatively ranked and rated based on the consensus of the Project Team members. The technical feasibility of the use cases was derived from the technical complexity self-assessed by the NLC manufacturer stakeholder group in the online survey.

This exercise resulted in the following top three use cases as the initial focus:


External systems integration


Load shedding/demand response


Energy monitoring

The top three use cases selected for initial focus are all examples of “system-to-system” interoperability (as discussed above on page 8, and below in Appendix D). The use cases align closely with NLC capabilities defined in the DLC NLC Technical Requirements, and therefore, the NLC capability names are used as the use case titles. This alignment will enable the DLC to specify the technical details for these NLC capabilities to support the interoperability use cases when developing future versions of the NLC Technical Requirements.

Each of the three use cases discussed below starts with a general description portraying the interoperability between NLC and other systems and devices. Recognizing that the general description requires significant advancement in order to realize all potential applications, each use case focuses on realizing a highlighted example; a very specific, high-value application. This approach allows the research to focus discussion on concrete technical designs and to devise actionable interventions. “Realization” of an interoperability use case refers to the existence of a process which is supported by clearly defined interoperability objectives, enough information on how to achieve them, and readily available technologies to complete a project in a replicable manner.

USE CASE 1: EXTERNAL SYSTEMS INTEGRATION

General use case description

Data from NLC components, such as luminaires, sensors, and controllers, is made available through an Application Programming Interface (API) and can be utilized by other building systems to improve their operational efficiencies. Accessing the NLC component data using the API allows integration with other building systems, including the Heating, Ventilation and Air Conditioning (HVAC) system, Building Management System (BMS), security system, etc.

Highlighted use case example: use occupancy data from NLC to inform HVAC operation

Zone-level real-time occupancy status from NLC occupancy sensors is used by the BMS through an API to control HVAC parameters at the HVAC zone level, such as ventilation rate and thermostat reset. The BMS can roll up the zonal data to inform system-level controls and operations, including but not limited to chilled/hot water temperature reset and chilled/hot water flow rate reset.

Stakeholder value

In Appendices A and B, this use case is "6 – NLC data access and integration through API". After the survey was completed, the highlighted example was chosen as a popular example of external systems integration via API. External systems integration via API was a high priority for stakeholders surveyed: 68% of respondents identified this use case as important to their business practices, with particularly strong support among integrators, value-added service providers, manufacturers, and utilities. Most survey respondents (95%) wanted or expected this use case to be realized in less than three to five years. 43% of end users rated this use case as critically important; however, lighting designers, engineers, and architects found limited value, as did 57% of end users. While no explicit reason was provided, this may be due to the siloed nature of current practice, where the electrical (including lighting) and mechanical (including HVAC) teams typically do not interact or collaborate to optimize across systems. Based on interviews, surveys, and literature, the key values for each stakeholder group include the following:

Use Case 1: Key Values by Stakeholder Group	
	End users and real estate portfolio managers: Lower hardware and installation costs by utilizing NLC sensors for other building systems rather than duplicate sensors; less complexity and variability across products. Centralized analysis across vendors, building systems, buildings, and regions.
	Lighting designers, engineers, and architects: Greater system design efficiency and cross-domain communication while providing enhanced operational metrics for owners.
	Contractors and energy consultants: Simpler, lower cost installation, configuration, management, and training.
	Manufacturers: Less product development time and cost, and more consistency between users.
	Integrators and value-added service providers: Offer new and improved services such as fault detection and diagnostics, work order processing, and asset management.
	Utilities: Efficiency programs can focus on cross-system integrations and controls to realize deeper energy savings and have direct system data as a feedback/validation mechanism.

Energy savings potential

Energy savings opportunities lie primarily in the ability to optimize BMS control based on additional input (granular occupancy status information) provided by NLCs. A carefully-designed sequence of operation for the HVAC system, accounting for the real-time occupancy status in each control zone, will allow the BMS to maximize the potential energy savings without jeopardizing occupant thermal comfort. When this interoperability is considered during the design phase, it might lead to different decisions on system configuration and component choices for the HVAC system, which result in a more energy-efficient system and more effective control sequences from day one.

Market status and barriers

***Current standard practice**:* Data from the lighting system is seldom shared with the BMS or HVAC systems. Consulting engineering designs typically lack any cross-system integration specification instructions or requirements, instead restricting controls data to within the specific subsystem only. A contributing factor is that HVAC controls are typically defined in CSI (Construction Specification Institute) Division 23 "Heating, Ventilation, and Air Conditioning (HVAC)", while lighting controls are defined in CSI Division 26 "Electrical"; and integrated cross-functional controls would be defined in CSI Division 25 "Integrated Automation". For instance, for demand control ventilation, HVAC systems typically use occupancy sensors installed and operated separately from the lighting system. In some cases, a dual relay occupancy sensor may be used: one relay signals the lighting system and the other signals the BMS or HVAC system. This type of occupancy sensor is typically not part of an NLC system nor is it digitally addressable; it relies on physical wiring for the control of each zone. It also often requires coordination between multiple contractors and integrators, complicating the effort.

***Market barrier**:* State-of-the-art solutions exist that can interface the NLC system and the HVAC system such that the occupancy status from the lighting system can be used to control the HVAC system and possibly support other monitoring and diagnostic purposes. The solutions typically rely on the API provided by the NLC manufacturers to access the occupancy sensor data. The extent of the integration, such as mapping between lighting zones and thermal zones, data granularity, and update/reporting frequency and format are dependent on the type of information exposed via the API and thus vary by NLC manufacturer.

Technical feasibility and gaps

***Existing capability of NLCs to support this use case**:* Of the 47 qualified systems on the DLC NLC QPL in March 2020[4], 21 NLC systems (45%) provide zone-level or luminaire-level occupancy status data through an API. Most APIs use a common architectural style (REST) and data representation (JSON or XML).

***Technical challenges**:* Two major technical challenges are the initial API development and the subsequent ongoing support. In the online stakeholder survey, 47% of NLC manufacturer respondents stated that supporting the external systems integration use case would be complex and require a long development time. Nearly half of surveyed manufacturers have already implemented APIs; however, the survey data is unclear on how many of those manufacturers believe that achieving this use case will nevertheless be a long and complex process versus how many manufacturers without any API believe that creating an API will be a long and complex process. In terms of feasibility of API integration, responses were somewhat mixed. One respondent noted that API is vastly more reliable and customizable compared to standardized BMS protocols. A lighting designer noted that most APIs are poorly documented, and the documentation is often not updated along with an API update, requiring confirmation after each API update that nothing breaks, which requires extra effort.

The main challenge is creating a consistent representation of occupancy status exposed through the API across different NLC systems. Vendors may have proprietary logic and control sequences to help optimize system performance and may be reluctant to expose certain methods and information to other vendors. This highlights the need for a standardized occupancy information representation so that vendors can support the external systems integration use case while maintaining a competitive edge with proprietary controls and analytics for more advanced benefits.

Supportive interventions

The Project Team identified six possible interventions to support external systems integration, which fall into three different opportunities for industry leadership:

Policy groups

- Standards Developing Organizations (SDOs) develop a standard for sharing occupancy status data through API.
- Specify integration of NLC/HVAC occupancy control as an eligible pathway for building energy codes and green building programs.

[4] The QPL analysis is based on the NLC QPL published on March 5th, 2020.

Manufacturers

- Public documentation of product integrations from two or more manufacturers.
- Make APIs part of the NLC system purchase without restrictive terms and conditions (i.e. open API, at least for standard occupancy data).

Trade associations

- Publish large-scale studies of cost savings from integration.
- Provide training and certification for specialists in lighting/HVAC/BMS integration. Provide basis of design for integration proficiency and best practices (installation, integration, startup, configuration).

USE CASE 2: LOAD SHEDDING/DEMAND RESPONSE (LS/DR)

General use case description

A building modifies its real-time energy consumption in response to a signal. The signal might be a demand response signal or real-time price update from an electric utility, or a request from a microgrid or onsite Distributed Energy Resource. The building's centralized load shed controller orchestrates the response of various subsystems such as lighting, HVAC, onsite generation, etc. The building may report the results to the originator of the signal.

Because intermittent renewable energy sources are becoming more prevalent, load flexibility is valuable for grid stability and low carbon emissions. As LS/DR becomes more automated and widespread, it becomes useful across more time scales.[5]

Highlighted use case example: Real-time dispatching and reporting to support demand management

Demand Response (DR) signals have traditionally been one-way inputs into the BMS or NLC. However, smart grid applications may require access to a building's energy-consuming systems with two-way communication, so that the building shares current and forecasted energy usage patterns with a demand control originator. A request for load shed may be met with a real-time report of the response or an automated bid into the market as a price-quantity pair.

The NLC participates in this ecosystem as one of the load-responding building systems, as depicted in **Figure 3**. In this example, the various systems within a building, outlined as a dashed gray box (NLC, HVAC, water heater, onsite generation, etc.), communicate their real-time and forecasted energy usage or generation with the Facility DR API, which coordinates and manages the facility demand and interacts with the grid. A DR signal is dispatched from the grid operator's Demand Response Automation System (DRAS) to the Facility DR API. The Facility DR API subsequently requests each of its downstream building systems to shed load based on their respective real-time and forecasted demand. The visibility into the demand of each building system enables the Facility DR API to report real-time and forecasted facility-level load reduction capacity to the grid operator, enabling the grid operator to more effectively orchestrate DR events and manage grid demand.

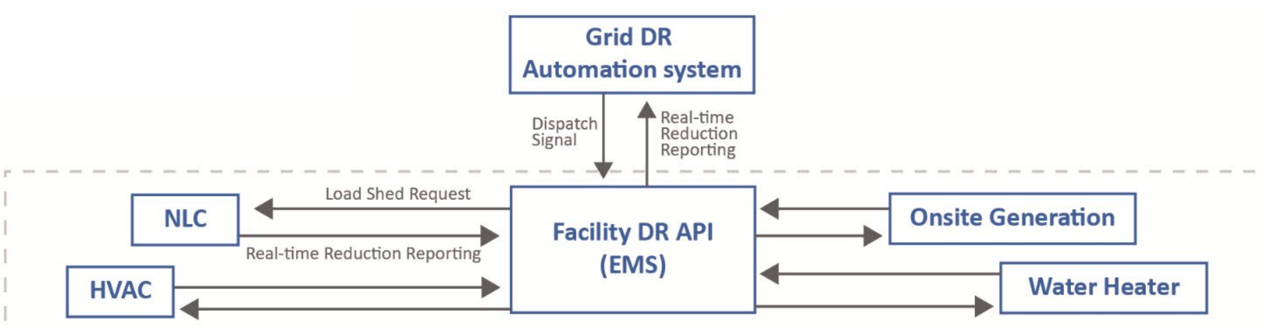

Figure 3: Demand response ecosystem example

[5] https://gridworks.org/wp-content/uploads/2018/02/Shift-Demand-Response-Primer_Final_180227.pdf

Stakeholder value

Load shedding use cases have broad support among all stakeholders surveyed, particularly among stakeholders working directly with utilities, such as contractors, energy consultants, and NLC manufacturers. Most survey respondents (95%) wanted or expected the general use case to be realized in less than three to five years. Some respondents might have assumed that this use case involves basic one-way demand response, which is readily available, rather than a two-way exchange of demand data, which is still in development. There was skepticism among the manufacturer, lighting designer, engineer, and architect stakeholder groups over this use case, primarily around the perceived small amount of lighting load available for demand management within a single building, especially when a NLC system controls only lighting, rather than lighting plus plug load. This highlights the varying levels of motivation amongst different stakeholder groups. As the chief beneficiaries, utilities and possibly demand aggregators will need to drive this use case, based on the value of the grid services available from aggregated flexible loads. Based on interviews, surveys, and literature, the key value of a common schema for reporting energy data and grid response for each stakeholder group includes the following:

Use Case 2: Key Values by Stakeholder Group	
	End users: Potentially lower utility bills due to LS/DR participation and successful energy management, operational efficiency, load balancing, and accurate incentive reporting and validation. **Real estate portfolio managers and DR aggregators**: Centralized analysis and aggregation of significant lighting loads across vendors, buildings and regions.
	Lighting designers, engineers, and architects: Compliance with energy codes, meeting incentive program requirements as part of a project specification requirement and ensuring appropriate interoperability between building systems during the design process.
	Contractors and energy consultants: Simplified integration of energy management/ monitoring functionality.
	Manufacturers: Less product development time, cost, and variability between users.
	Integrators, value-added service providers, **energy service companies (ESCOs):** Better performance contracts and service packages to end users
	Utilities: Access to flexible and predictive loads for DR event management, scalable by aggregation. Preparation for future transactive energy scenarios with finer granularity and direct end-user engagement. Higher incentives for energy efficiency combined with LS/DR. Grid stability using demand side management programs. Deferral of upgrades to generation/transmission/distribution systems.

Energy savings potential

Rather than energy savings in kilowatt-hours, the main benefit to energy producers and consumers is well-organized and well-controlled demand reduction at both the building- and the grid-level. The visibility of real-time and forecasted demand reduction capacity at the end-use system level will allow the building to control its own demand to optimize the use of on-site renewables and storage, and the timing of grid energy use from cheaper and cleaner sources. The visibility of real-time and forecasted demand reduction capability at the building level will enhance the grid operator's ability to more accurately match supply and demand – generating cost savings and reducing greenhouse gas emissions.

Market status and barriers

Current standard practice*:* Some sophisticated energy aggregators can initiate demand response with two-way communication[6] using proprietary devices and infrastructure, whereby an event is dispatched from a DRAS to the participating load and the real-time performance is reported from the participating load back to the DRAS. However, the target customers for these aggregators are typically predictable industrial process loads or HVAC loads in large commercial buildings. Connected lighting loads are seldom included because the loads are too small to justify customized, non-scalable attention. Most retail DR programs are one-way dispatching[7]. Even though OpenADR 2.0b supports real-time reporting from the load to the DRAS, this feature has not been actively utilized due to implementation complexities. Simpler models implementing two-way transactive energy systems may emerge for specific use cases by energy aggregators, larger end users with multiple owner-occupied facilities, and local transactive energy markets.[8]

California Title 24 building energy standards require that NLC systems be capable of receiving a DR signal and reducing lighting load by at least 15%. The most sophisticated NLC systems have a native OpenADR 2.0 client (an OpenADR 2.0 virtual end node, VEN) and programmable DR settings or scenes for a reduced lighting service during DR events. Other NLC systems meet the code requirement by providing network support that needs to be programmed as a network accessible "point" to receive DR signals from the BMS. While some outdoor streetlighting projects participate in DR programs, there are few documented DR projects in interior lighting. Potential high value applications include warehouse high-bay lighting with high energy costs, where dimmable fixtures have replaced traditional on/off fixtures. Similar opportunities exist in large retail applications, large public space applications, parking lot and large venue pathway lighting for municipalities, campuses, etc.

Market barriers*:* The key barrier to the load shedding/demand repsponse use case lies in the lack of a well-established ecosystem of responsive loads within a facility (Figure 3) and a defined hierarchy for acting on a demand reduction request in response to a grid-initiated DR event, a microgrid event, or addressing onsite generation intermittency. An intra-facility responsive load ecosystem relies on interoperability between NLC and the DR API, typically a BMS, such that the DR API can effectively communicate with the grid operator and successfully execute a DR event. Likewise, interoperability

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[6] Two-way communication refers to a feedback loop of data, where the dispatch signal is sent from the DRAS to the participating load, and the real-time load reduction performance is reported back to the DRAS from the participating load. It does not refer to a duplex or bi-directional communication at the protocol level such as OpenADR 2.0, in which data sent from the server (an OpenADR virtual top node, VTN) to the client (an OpenADR virtual end node, VEN) receives an acknowledgment from the client.

[7] In one-way dispatching, the grid operator sends a dispatch signal to the participating load, and, other than a confirmation of receipt, the grid operator has no visibility whether the load is delivering the expected reduction until after the fact from the meter read or by monitoring an aggregated feeder line.

[8] https://guidehouseinsights.com/news-and-views/finally-a-realworld-transactive-energy-pilot-debrief

between the NLC and the DR API is the key ingredient for the DR API to manage the building demand to maximize utilization of onsite generation and minimize grid dependency.

Technical feasibility and gaps

***Existing capability of NLCs to support this use case**:* Of the 47 qualified systems on the DLC NLC QPL in March 2020[4], 30 NLC systems support demand response in some way. 29 systems can receive external signals through BACnet, dry contacts, digital switches and the Internet (including OpenADR). 16 systems can report real-time power reduction. Real-time reports from seven systems can be consumed by another system through BACnet or an API (others are likely reported only on the dashboard display).

***Technical challenges**:* The number of DLC-listed NLC systems suggests that basic one-way DR is readily achievable. 75% of the manufacturers who responded to the online stakeholder survey were optimistic and estimated supporting simple one-way DR with their NLC systems to require less than two years of development time. However, real-time forecasting, accurate embedded energy metering usage data, and energy reporting will all be needed for the highly coordinated two-way DR use case.

Supportive interventions

A concerted effort by grid operators, building subsystem manufacturers, commissioning providers, and building operators could support this use case via the following opportunities for industry leadership:

Policy groups

- Develop a standard for facility-level DR practice and architecture.
- Develop a standard for NLC energy submetering and reporting requirements.
- Develop a standard protocol and data model for communications related to load response across building end-use systems as well as onsite generation and storage systems.

NLC Manufacturers

- Provide LS/DR "recipes" of recommended light level reductions for specific building zones, types, and usages, and their impact on occupant comfort and productivity.

Trade associations

- Provide training to incorporate facility-level DR capability as part of configuration practice.

Lighting designers

- Factor LS/DR dimming into designs to balance the effectiveness, comfort, and environmental conditions for a space (with daylighting, color balancing, etc.).

Utilities

- Conduct LS/DR pilot programs: two-way and/or real-time pricing.
- Combine energy efficiency and LS/DR incentives for equipment and integrations that form a responsive load for facility-level LS/DR.

Building managers and operators

- Provide DR program initiation information to occupants to "engage" them and reduce comfort-related operational issues, such as through BMS Kiosks and notifications.

USE CASE 3: ENERGY MONITORING (EM)

General use case description

Lighting system energy data is reported by the NLC and shared with authorized entities over the Internet. For example, utility energy efficiency programs for NLCs can access the energy data to verify energy savings. The lighting energy data may also be accessed for central display of facility energy end-use status or for a building portfolio management provider to benchmark energy performance. Ideally, the data uses a standardized data model.

Highlighted use case example: Energy data reporting to a utility for incentive savings verification

A utility's lighting energy efficiency program for networked lighting controls requires an NLC to report the system-level energy usage at a 15-minute interval in standard API format (such as the Green Button format) for the duration of one year. The energy data is transmitted to the repository provided by the utility over the Internet at a regular interval, such as daily or weekly. The energy data from all program participants is used by the utility to verify the energy performance of individual incentivized systems and to calculate program-level energy savings as one of the metrics for evaluating program effectiveness and cost-benefit ratio.

Stakeholder value

Energy monitoring has strong appeal to almost all stakeholders: 80% of all respondents identified this use case as a high-value opportunity, particularly among end-users, integrators, and value-added service providers. All survey respondents expected this use case to be realized in less than three to five years. The only caveat was that some expressed concern about the added complexity and cost of energy monitoring for utility purposes, especially with simple LED retrofit solutions. Panel- or circuit-level energy data appears to meet vendor and user expectations for the short term, rather than individual fixture-level data. Based on interviews, surveys, and literature, the key values for each stakeholder groups include:

Use Case 3: Key Values by Stakeholder Group	
	End users and real estate portfolio managers: Lower installation costs via easier access to efficiency incentives across vendors, buildings, and regional utility programs. Continued energy performance improvement and better maintenance, via historic energy data.
	Manufacturers, lighting designers, engineers, architects, contractors, energy consultants: Leverage incentive programs to help clients afford NLCs at a more attractive price and/or with more advanced features.
	Integrators and value-added service providers: Provide value-added services to utilities and/or end-customers leveraging the collected NLC energy data.
	Utilities: Deploy scalable efficiency programs for NLCs with streamlined M&V process to verify energy savings. Document appropriate incentive levels based on energy savings.

Energy savings potential

The primary opportunity for energy savings lies in the ability to ensure and verify that the intended energy savings from installing an NLC is realized based on the reported NLC energy data. The sponsoring utility can work with the customer to take corrective actions if the expected energy savings is not achieved. In the long term, when energy usage is continuously monitored and trended, either by the utility or the customer, energy savings can be sustained throughout the life of the NLC regardless of changes at the installation site, such as tenant turnover or space usage reassignment.

Market status and barriers

Current standard practice*:* Many NLCs already have energy monitoring capability; some are supported natively and enabled by default and some require additional hardware or software activation. Typical NLC installations seldom utilize the energy monitoring and reporting functionalities. For installations with energy monitoring enabled, the energy data is primarily used as one of the display features on the system dashboard user interface. Depending on the system architecture, the energy data may be reported at the luminaire, zone, branch circuit (phases), panel, or system level.

A .csv file export is the predominant method (and in many cases the only method) of extracting energy data from NLC systems. Cloud-based NLC systems allow remote access to the data by the data owner, manufacturer (if authorized), and other authorized parties either through a web portal, mobile application, or an API. For either energy data export or direct access through an API, there is currently no standard or convention for the content, format, or accuracy of the energy data reporting.

Various NLC products report energy at various accuracies. Few NLCs report true power by measuring both current and voltage. Most NLCs either (a) measure current draw and report the apparent power based on nominal voltage, or (b) record the light output level and report the correlated power using a lookup table to map light output levels to power consumption. Some lookup tables are populated automatically, while others require manual input at the project level.

Several utility NLC programs require submissions of NLC energy data to verify energy savings. Some programs enforce a minimum requirement on the acceptable NLC energy data reporting interval, but there is currently no specific requirement on the accuracy of the energy data due to the lack of a standard and verification method. Data intake is typically a manual process, and the utilities adapt their calculations to the data type and format exported from each NLC system.

***Market barriers**:* The main barrier to realizing the energy monitoring use case is the lack of consistent data access and reporting format requirements from utilities. Utility energy efficiency programs currently accept NLC energy data in .csv files in a manufacturer-provided format and review manually, which is not a sustainable approach to scale up and increase program participation. There is a lack of a proven track record of NLC energy data availability providing value to owners and utilities. While energy reporting data has clear benefits for utilities, the actual value (and corresponding incentive to obtain it) is still unclear. Relatively few utilities have NLC energy reporting incentives at this time—so the rationale for manufacturers to invest in automating energy reporting is still marginal.

Technical feasibility and gaps

***Existing capability of NLCs to support this use case**:* Of the 47 qualified systems on the DLC NLC QPL in March 2020[4], 41 NLC systems support energy monitoring in various spatial and temporal granularity. The energy-related data included in an NLC energy report also vary from system to system and may include energy, energy savings, peak power, luminaire light output percentage, luminaire power percentage, space type, etc. Ten NLC systems allow API access to recorded energy data, potentially supporting the use case of automatic energy data intake and consumption by the utility or another system. Six additional NLC systems support energy monitoring, but the DLC database has not been updated for those systems since questions about APIs were added to the application form.

***Technical challenges**:* More than 70% of the manufacturer respondents in the online stakeholder survey felt that this use case may be supported by their NLC with less than two years of development time, while the rest saw this as more complex but still achievable. There is no standard for automatic data intake mechanism and process, or spatial granularity. A relevant standard for temporal reporting granularity is in ASHRAE 90.1-2016 and -2019.

Supportive interventions

Interventions that could support energy reporting overall may involve more than the lighting community, since energy reporting is becoming ubiquitous in building systems, equipment, and devices. Therefore, while the interventions listed below center around NLC energy reporting, they may be considered as a subset of larger-scale interventions for the broader ecosystem of commercial building end uses. The interventions to support energy monitoring fall into two different opportunities for industry leadership:

Policy groups

- Develop a standard data model for NLC energy data reporting to utility efficiency programs, owner/tenant energy dashboards, etc.
- Develop standard NLC energy monitoring accuracy test procedures, and accuracy recommendations for different applications.

Utilities

- Establish an energy data repository and an automatic data intake process under utility energy efficiency programs for collecting NLC energy data from program participants.
- Promote energy load monitoring and management of NLC systems as paramount to owner needs and utility incentive program eligibility/effectiveness.

DISCUSSION

These three use cases are interdependent

NLC interoperability can enhance energy and cost savings, operational efficiency, and ease of system design and installation. This research identified three high-impact use cases likely to mature in the next three to five years: external systems integration, load shedding/demand response, and energy monitoring. While these use cases were discussed separately, they are interconnected and support one another. The LS/DR use case relies on a specific implementation of the energy monitoring use case for real-time load-shed reporting. The demand response event is dispatched to the NLC from another system, as a variation on external systems integration. Similarly, NLC energy data from the energy monitoring use case may be exchanged with other systems, as another variation on external systems integration.

These use cases will increase energy savings, cost savings, and the operational efficiency of both the facility and the grid. However, significant industry investment is needed in terms of data requirements, project development, and product development, to realize these benefits.

Bridging the gaps: key areas to support increased interoperability

Data requirements – All three use cases (and many more) lack a well-defined format and temporal and spatial granularity so that standardized data can be readily exchanged with the party the NLC interoperates with. Stakeholders involved in each aspect of interoperability will need to clearly articulate, specify and standardize the type and granularity of data needed for each use case.

Project development – Consensus-based data standards need to be supported by experience on actual projects. The industry can push the boundary of interoperability through small-scale deployment to refine use cases and specific data needs. Demonstrations, pilot programs, and case studies[9] conducted through collaboration among stakeholder groups are a promising immediate next step to further quantify and solidify the values of the interoperability use cases, and to resolve any conflicts amongst stakeholder groups. The results will inform standardization and other policy-making efforts, creating a virtuous cycle to accelerate realization of the interoperability use cases.

Product development – While a few examples have been accomplished with considerable effort in customized integration, significant market barriers and technical gaps must be addressed to create scalable solutions. Most individual building systems today are not designed or specified with foresight for interoperability. Mechanical systems (HVAC) and electrical systems (lighting) are often designed and specified independently, so that sharing data across the systems and utilizing the shared data are costly and high-effort afterthoughts. Standardized intake mechanisms for NLC energy data, either by a utility repository system or another automated receiver, such as BMS or EIS, have not been established to make NLC energy data sharing a critical value proposition. Each individual building system is not

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[9] Use case #1: IBS https://www.ibs-cal.com/news/, Enlighted https://bit.ly/2KmvPR7, Philips https://philips.to/2xJF636.
Use case #2: AEP Ohio, residential https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23192.pdf.
Use case #3: AEP Ohio https://www.aepohio.com/save/business/programs/AdvancedLightingControls.aspx, ComEd https://bit.ly/3f5rPCU (page 6), Consumers Energy https://bit.ly/3c1psiF (page 18), Focus on Energy https://bit.ly/3f6T4Nd, Energy Trust https://www.energytrust.org/wp-content/uploads/2020/02/NBE_FM0520WB.pdf

equipped with the functionality to participate in a load ecosystem that can respond to the real-time demand condition of either the grid (demand response) or the building itself (demand management).

While many stakeholders recognize the importance of interoperability, the stakeholder groups that will benefit most from each use case are often not the same ones who need to conduct the most legwork to realize the use case. For instance, while energy monitoring is relevant to all stakeholders, utilities will likely be the greatest beneficiaries, while much of the investment will need to come from manufacturers. This separation of benefit and investment requires the chief beneficiaries to drive the use case by setting clear performance requirements and addressing potential conflicts among different actors, so that the additional cost and effort for interoperability is justified in product development.

Design recommendations for specifying interoperability

This report describes three use cases with an overview of their value, energy savings potential, market status and barriers, technical feasibility and challenges, and supportive interventions needed. When specifying NLC interoperability, it is important to first describe the actual interoperability needs; and then to use these needs as guidance to specify system capabilities and features. For example, for each of the three use cases, Appendix E shows technical design criteria derived from interoperability needs. A similar approach can be used to develop specifications related to other interoperability use cases.

For system-to-system interoperability like the three use cases described in this report, the ultimate best practice may be to specify interoperability in the Construction Specification Institute's (CSI) Division 25 – Integrated Automation document. While Division 25 already exists in the CSI MasterFormat, no example or template is available yet. There are ongoing activities to define consensus-based examples for Division 25 across building systems, including lighting systems.

Before examples of CSI Division 25 or other interoperability specification templates are available, the stakeholder can refer to this report when considering NLC interoperability. For the three use cases described here, the respective subsections plus technical design criteria in Appendix E provide a foundation for specifying interoperability. For variations on these three use cases, or other NLC interoperability use cases, the following steps can help frame needs and requirements:

1. Precisely describe the scope of the use case, such as the "general use case description" plus the "highlighted use case example" in the examples above.
2. Outline relevant market actors, such as shown in Figure 2; and technical needs.
3. Involve the entire project team to detail the technical design criteria.
4. Use available tools, such as the DLC NLC QPL, to identify technologies and products that can meet the technical design criteria.
5. Involve relevant market actors, such as manufacturers or technology providers, to ensure that technical design criteria can be met, and to plan alternatives if some cannot be met.
6. Where possible, prove out the interoperability use case in a small-scale mockup or pilot, such as a few rooms within a large building, before proceeding with full deployment.

CONCLUSION

The broad topic of interoperability can be addressed by focusing on use cases that deliver specific stakeholder value, and then identifying market barriers, technical gaps, and necessary supportive interventions. Three use cases were explored in depth. This report's approach can be applied to additional use cases in the future. Interoperability has the potential to improve outcomes for utilities, building owners, building operators, and other key stakeholders with some key innovations. While products that support these use cases will provide more value to various stakeholders, the stakeholders with the most to gain will need to drive adoption. For instance, energy reporting and HVAC integration will deliver energy savings to utilities, while demand response will deliver flexible aggregated loads to utilities and demand aggregators. Industry standards will be essential in order to realize these three use cases more fully.

This report provides a foundation of common understanding about NLC interoperability. It will guide stakeholders, including specifiers, distributors, contractors, and facility managers, to frame design criteria and ask the right questions when specifying interoperability related to NLC systems. The findings will also serve to advance the state of NLC interoperability using the DLC NLC Technical Requirements and Qualified Product List (QPL).

The following interventions will help to realize the three use cases:

EXTERNAL SYSTEMS INTEGRATION

Policy groups

- Standards Developing Organizations (SDOs) develop a standard for sharing occupancy status data through API.
- Specify Integration of NLC/HVAC occupancy control as an eligible pathway for building energy codes and green building programs.

Manufacturers

- Public documentation of product integrations from two or more manufacturers.
- Make APIs part of the NLC system purchase without restrictive terms and conditions (i.e. open API, at least for standard occupancy data).

Trade associations

- Publish large-scale studies of cost savings from integration.
- Provide training and certification for specialists in lighting/HVAC/BMS integration. Provide basis of design for integration proficiency and best practices (installation, integration, startup, configuration).

LOAD SHEDDING AND DEMAND RESPONSE (LS/DR)

Policy groups

- Develop a standard for facility-level DR practice and architecture.

- Develop a standard for NLC energy submetering and reporting requirements.
- Develop a standard protocol and data model for communications related to load response across building end-use systems as well as onsite generation and storage systems.

Manufacturers

- Provide LS/DR "recipes" of recommended light level reductions for building zones, types, and usages; and impact on occupant comfort and productivity.

Trade associations

- Provide training to incorporate facility-level DR capability as part of configuration practice.

Lighting designers

- Factor LS/DR dimming into designs to balance the effectiveness, comfort, and environmental conditions for a space.

Utilities

- Conduct LS/DR pilot programs: two-way and/or real-time pricing.
- Combine energy efficiency and LS/DR incentives for equipment and integrations that form a responsive load for facility-level LS/DR.

Building managers and operators

- Provide DR program information to occupants, to reduce comfort-related operational issues, e.g. through BMS Kiosks and notifications.

ENERGY MONITORING (EM)

Policy groups

- Develop standard data model for NLC energy data reporting to utility efficiency programs, owner/tenant energy dashboards, etc.
- Develop standard NLC energy monitoring accuracy test procedures and accuracy recommendations for different applications.

Utilities

- Establish an energy data repository and an automatic data intake process under utility energy efficiency programs for collecting NLC energy data from program participants.
- Promote energy load monitoring and management of NLC systems as paramount to owner needs and utility incentive program eligibility/effectiveness

APPENDIX A: SURVEY QUESTIONS

The research team compiled a list of 61 individuals across all stakeholder groups with experience and insights into NLC interoperability. With the generous help of several professional organizations and trade associations related to the lighting and building industry, the online survey was also announced to their membership through their respective mailing lists. The survey announcement was also posted to the DLC's LinkedIn page, the research team members' personal LinkedIn pages, and the LinkedIn pages of groups with special interests in commercial building, building automation, grid modernization, and engineering consulting. The survey invitation outreach yielded 40 completed responses.

The use case survey was designed such that each use case was described as a statement. Participants were asked to identify the primary stakeholder group to which they belong. To avoid different understanding and interpretation of interoperability by the survey participants, the statement was deliberately formulated without directly mentioning "interoperability". After reading the statement, the survey participants were asked to choose a response for each of the following two questions:

The ability described in the statement is or will be:

- ☐ *Not applicable – don't have enough insight to provide an answer*
- ☐ *Never needed in my practice*
- ☐ *Of minimum use to my practice*
- ☐ *Nice to have for my practice although not necessary*
- ☐ *Occasionally needed in my practice*
- ☐ *Critical to my practice*

Note that these sample responses were for respondents in the stakeholder group of contractors, energy consultants, end users, integrators, value-added service providers, specifiers, and architects. The responses were worded slightly differently for the utility and NLC manufacturer groups.

I can anticipate the need for this ability in the time frame of:

- ☐ *Not applicable – don't have enough insight to provide an answer*
- ☐ *Never*
- ☐ *More than 5 years*
- ☐ *In 3-5 years*
- ☐ *In 1-2 years*
- ☐ *Immediately or already exists*

For respondents who identified themselves as NLC manufacturers, an additional question was asked:

Providing this ability in our NLC system is technically:

- ☐ *Trivial*
- ☐ *Straightforward and simple; implementation time < 1 year*
- ☐ *Straightforward but effortful; implementation time > 1 year*
- ☐ *Complex but doable; implementation time > 2 years*
- ☐ *Complex; may or may not be doable; implementation time TBD*
- ☐ *Not possible; requires development of new product*

The ten use case statements included in the survey are listed in the table below.

No. and Tagline*	Use Case Statement
1 – Access lighting system fault detection data	The ability of an enterprise software app or tool, provided by a lighting or 3rd party vendor, to access fault detection data (e.g., input voltage out-of-range, below lumen maintenance threshold) from a lighting system, regardless of lighting system vendor, and utilize that data to manage and optimize system maintenance.
2 – Access lighting system operational usage data	The ability of an enterprise software app or tool, provided by a lighting or 3rd party vendor, to access lighting use data (e.g., hours-of use, user settings of dimmed level or color temperature when given personal control) from a lighting system, regardless of lighting system vendor, and utilize that data to manage and optimize system lighting performance.
3 – Access and adjust lighting system configuration parameters	The ability of a remote software app or tool, provided by a lighting or 3rd party vendor, to access and adjust configuration parameters in a lighting system, regardless of lighting system vendor, to adjust default or pre-configured settings or customize a personal environment.
4 – Integrate multi-vendor lighting devices and components	The ability of lighting devices and components (e.g., luminaires, sensors, software user interfaces) to be integrated together into a lighting system, regardless of lighting system vendor, that delivers the basic lighting functionality enabled by the constituent devices and components (e.g., zoning, occupancy sensing, energy reporting).
5 – Data sharing for revenue generation or loss prevention	The multi-sensor data from the networked lighting system, such as occupancy, traffic flow, ambient light level sensor data, is shared with other enterprise systems for business revenue-generating or loss-prevention purposes, such as point-of-sale, asset and inventory tracking systems.
6 – NLC data access and integration through API	The ability to access all lighting system data from a manufacturer's IoT platform via an Application Programming Interface (API) – in addition to or instead of access of data from a Building Management System (BMS).
7 – Receive dispatching signal and respond to DR events	The ability of a lighting system to receive demand response (DR) signals sent using standardized protocols (e.g., OpenADR), respond to those signals in various ways, taking into account configuration parameters (e.g., only respond when price changes by X%), and verify the impact of any response taken (e.g., reduction in power or energy consumption).
8 – Access lighting system energy data	The ability of an enterprise software app or tool, provided by a lighting or 3rd party vendor, to access energy data from a lighting system (e.g., cumulative energy consumption, average power), regardless of lighting system vendor, and utilize that data to manage and optimize system energy performance.
9 – Access lighting system asset data	The ability of an enterprise software app or tool, provided by a lighting or 3rd party vendor, to access asset data from a lighting system (e.g., luminaire make and model, nominal power, minimum dimming level), regardless of lighting system vendor, and utilize that data to manage and optimize system maintenance.
10 – Remote non-lighting purpose sensor integration	The ability of a lighting system to collect data from a remote (i.e., not integrated into a device provided by the lighting system vendor) sensor, regardless of sensor vendor, and utilize that data in all ways that data produced by the lighting system can be utilized (e.g., to influence lighting settings, shared with other systems via API)

* The taglines were not part of the survey and are provided as a shorthand for the readers to easily remind themselves about each use case when reading other appendix sections.

APPENDIX B: USE CASE SURVEY RESULTS

Table B1 shows the average scores for the stakeholder value, where the survey respondents rated the relevance and criticalness of each use case to their businesses and practices on a scale of 1 to 5. While there does not seem to be an obvious winner, use cases 8, 6, and 7 have the highest average scores.

Table B1: Aggregated stakeholder value across all stakeholder groups

Use Case	Average Score
1 – Access lighting system fault detection data	3.27
2 – Access lighting system operational usage data	3.82
3 – Access and adjust lighting system configuration parameters	3.84
4 – Integrate multi-vendor lighting devices and components	3.85
5 – Data sharing for revenue generation or loss prevention	3.61
6 – NLC data access and integration through API	3.95
7 – Receive dispatching signal and respond to DR events	3.95
8 – Access lighting system energy data	4.08
9 – Access lighting system asset data	3.58
10 – Remote non-lighting purpose sensor integration	3.82

Table B2 shows the average scores for the expected timeline, where the survey respondents rated how soon they expected each use case to be realized or be useful to their businesses and practices. Use cases 8, 4, and 7 scored the highest among the 10 use cases, although most scores are fairly similar.

Table B2. Aggregated results for expected timeline across all stakeholder groups

Use Case	Average Score
1 – Access lighting system fault detection data	3.63
2 – Access lighting system operational usage data	3.92
3 – Access and adjust lighting system configuration parameters	3.90
4 – Integrate multi-vendor lighting devices and components	4.03
5 – Data sharing for revenue generation or loss prevention	3.59
6 – NLC data access and integration through API	3.90
7 – Receive dispatching signal and respond to DR events	3.97
8 – Access lighting system energy data	4.28
9 – Access lighting system asset data	3.61
10 – Remote non-lighting purpose sensor integration	3.64

For each use case, the survey asked the respondents self-identified as NLC manufacturers to assess the technical feasibility and complexity of supporting each use case in their NLC systems. **Table B3** below shows the average score. Use case 7 seemed to be the most straightforward use case to support, followed by use cases 8, 3, and 6. The technical feasibility assessed by the manufacturer stakeholders coincides well with the overall ranking of stakeholder value in Table B1.

Table 5. Technical achievability assessed by the manufacturer stakeholder group

Use Case	Average Score
1 – Access lighting system fault detection data	2.88
2 – Access lighting system operational usage data	2.82
3 – Access and adjust lighting system configuration parameters	3.00
4 – Integrate multi-vendor lighting devices and components	2.53
5 – Data sharing for revenue generation or loss prevention	2.41
6 – NLC data access and integration through API	2.94
7 – Receive dispatching signal and respond to DR events	3.47
8 – Access lighting system energy data	3.35
9 – Access lighting system asset data	2.82
10 – Remote non-lighting purpose sensor integration	2.71

APPENDIX C: CATALOG OF 32 USE CASES

#	Interoperability Category	Use Case Definition
1	System-to-system	A system integrator provides sophisticated cross-system control and diagnostic software tools. The tool needs to access the sensor data from the NLCs (mostly occupancy data at the zone or room level) to run analytics and trend individual system load for diagnosis purposes. Based on the occupancy status from the NLCs, the tool can also dispatch or control parameters of other connected systems, such as the HVAC temperature setpoints and VAV damper positions, to optimize the energy usage of other systems.
2	System-to-system	An organization with a campus of buildings or a national chain with geographically distributed branches requires operational data from each NLC installation to be reported and displayed on a management dashboard that is in the central back office of the organization. The data is used to benchmark the energy performance of each building/store and make recommendations for (organizational or site-specific) operational improvements. The central back office also needs the ability for basic dispatch, e.g. turn on lights in key areas, in the case when special needs arise.
3	System-to-system	A value-added service provider offers an employee-facing app focusing on improving workplace experiences. Part of this app empowers personalized control of the environment, including setting a customized light level, in both private and shared working spaces. The app also leverages the occupancy information from the NLC to help app users find and book meeting rooms and unoccupied workstations. The backend of the app also provides analytics on space utilization, which can help the organization optimize workstations and resources.
4	System-to-system	Several NLCs were installed in a multi-tenant mixed-use large commercial/industrial building at different phases of lighting upgrade during tenant turnover. The NLC installations also cover large outdoor areas, including parking lots, loading docks and other activity areas. The facility operations team desires to have a single centralized interface to monitor and control, both on-site and remotely, all the lighting systems, including 1) trending the lighting energy consumptions across the tenants, 2) modifying the schedule of different zones, 3) setting the light level for each space, and 4) setting policies/strategies to participate in demand response events. The building operations team expects to continue to update the lighting systems during tenant turnover and bring the newly installed NLCs into the centralized interface.

#	Interoperability Category	Use Case Definition
5	System-to-system	A commercial/industrial facility with large outdoor areas, including parking lot, loading docks and other activity areas, has NLC systems from different manufacturers for controlling interior lighting and exterior site lighting. The facility operator needs to be able to manage, both on-site and remotely, all the lighting systems from a single interface. This includes switching of lights, programing schedules, and monitoring the real-time status for each zone as well as an aggregated view of historical and real-time energy usage.
6	Device-to-device	A specifier is putting together an à la carte networked lighting system using components, possibly from different manufacturers, best suitable, and make most economical sense for a large-scale development project. This includes the use of luminaire light level control (LLLC) in some areas, architectural luminaires in lobbies, auditorium and other areas, linear ambient luminaires (wirelessly) connected to a single occupancy sensor for communal spaces, etc. Some of the luminaires are additionally controlled by in-wall switches/dimmers, and some are controlled by touch panels for more sophisticated functionality like color tuning and scene selection. All the luminaires, sensors and control interfaces need to be included in a single NLC system to meet all the code control requirements as well as utility incentive program requirements, including demand response.
7	Device-to-device	Home improvement center where multiple "smart" products require proprietary interfaces rather than open interoperability.
8	Device-to-system	Meet energy code requirements while enabling multiple suppliers for large scale development projects. Reduce sourcing dependencies. Enable supplier best-of-breed without changing infrastructure to accommodate changes (communication, integration, user interfaces). Comply with utility setback/load shed programs. Improve user experience through system consistency via interoperable components.
9	System-to-system	Home security service providers integrate lighting with security to provide extended services such as light scheduling when no one home, to look like someone is home. Monitor usage and occupancy to automatically dim certain fixtures. Monitor/alarm on fixture failure.
10	System-to-system	Enhance utility energy efficiency programs, rebates, pre-configured systems for homeowners to reduce energy load using a variety of interoperable products - lighting, metering, appliances, smart breakers, smart power strips, etc.
11	System-to-system	Multi-vendor source for both indoor and outdoor systems. Requirements to provide consistent alarming, monitoring, maintenance. Also, adaptable energy conservation for up to 50 groups or more per site. Hundreds to thousands of sites with common interoperability.

#	Interoperability Category	Use Case Definition
12	System-to-system	Traffic pattern information from lighting multi-sensors (PIR, OCC, path/directionality, traffic density/counting shared with POS, inventory, loss prevention, and other sub-systems.
13	System-to-system	Lighting group patterns across multiple supplier systems controlled by one interface requires solid interoperability design and implementation. Scheduling, overrides, alarming require consistent control and communication signaling through use of common data profile and object definitions.
14	Device-to-system	Monitoring of various parking and outdoor signage lighting fixtures for accurate scheduling. Resolve issues with lights on when facility is not occupied (manager forgets to turn off the lights for the fast food or gas station facility).
15	System-to-system	Integration of lighting system with other building subsystems, including security systems, life safety systems, elevators, HVAC, etc., to manage multiple facets of energy conservation, facility operational efficiency, occupant comfort.
16	System-to-system	Lighting system coordinating with elevators providing occupancy and usage information to optimize elevator performance - cars to floors where likelihood of high volume at designated times or conditions.
17	System-to-system	Requirement for integration of lighting into the common BMS front end. Energy management adaptive control, scheduling, on/off/dimming in multiple locations according to usage patterns. Must interoperate with existing BMS and provided by multiple suppliers. No sole sourced solutions.
18	System-to-system	Consistent design and supply of systems across many locations to reduce field service time/costs - spare parts, service variations, reduced training and support. Reduce truck rolls by early system triage and constant CMMS (Computerized Maintenance Management System) interface.
19	System-to-system	High-bay lighting systems work with workflow system to improve lighting in high density areas, dimmable in low density areas for improved energy efficiency.
20	Device-to-system	Fixture failure alarm monitoring through common UI across multiple supplier fixtures - monitor reduced performance, FDD (Fault Detection & Diagnostics), scheduled maintenance, performance degradation.
21	Device-to-system	Optimize task safety compliance through integration of task lighting sensors, fixtures, color, dim level, frequency, and other related factors across many supplier fixture types. Common data model for fixture control. Implement scene control options spanning multiple lighting sub-systems from common configuration tool.

#	Interoperability Category	Use Case Definition
22	Device-to-system	Individual lighting fixtures or sub-components such as sensors, emergency subsystems, high energy consumption and high value asset components like parking lot lighting, high bay lights, lighting sub-panel controllers, have direct communication to Enterprise applications using an IoT model. In certain cases, co-existing with an in-building BMS to provide vendor tech support, predictive maintenance, and other services (outages, performance degradation). Also, to provide on-site configuration and maintenance via manufacturer-specific browser app (phone, tablet) to improve diagnostics and efficiency.
23	Device-to-system	Smart grid applications such as automated demand response require some level of access into the energy consuming devices. Interoperability between demand control "appliances" potentially from grid operators, energy providers, or Distributed Energy Resources (DER) need access to the end fixtures to control dimmable loads. This use case addresses the interoperability of end devices to non-BMS interfaces for device-to-grid interactions. While potentially less common in larger commercial applications where a full BMS exists, this use case addresses smaller and medium sized applications where a full BMS may not exist.
24	System-to-system	Grid operators offer building operators incentives via a contract to automatically shed load on critical grid load days/times. The grid operators enter into a transactive energy contract with the owner. APIs are installed on both ends to automate the process. Lighting panel controllers require adaptive algorithms to manage the safety and optimization of the lighting systems once a DR event request is initiated. The grid API requests a confirmation/denial of load change. Interoperability between the lighting system and the grid API is required.
25	System-to-system	Commercial offices and hotels are providing voice assistants that are designed for commercial applications. The user needs to be able to control the lights in the private office, conference room, or hotel room using voice commands.
26	System-to-system	An organization with a large portfolio of facilities across the country is acting as an aggregator to bid its loads into the regional wholesale market (capacity, energy, reserves, etc.). The operator needs visibility on real-time lighting (and other large end use) energy usage and load shed capability from all facilities to accurately determine how much to bid into the market and to dispatch each facility.
27	System-to-system	Utility energy efficiency programs for NLCs require direct transmission of energy data, in a standardized format, from the NLCs procured and installed leveraging incentives to a utility-managed repository. The energy data is used to verify energy savings.

#	Interoperability Category	Use Case Definition
28	System-to-system	Access to data representing user interaction with user interface devices, e.g., wall controllers, mobile device apps, which can be used by the lighting system owner and manufacturer to evaluate the effectiveness of the user interfaces, and how specific lighting system output options e.g., output, color temperature, chromaticity are being utilized.
29	System-to-system	Access to data representing device level asset information for enterprise-level asset management and maintenance planning purposes. The asset information may include make, model, nominal power, install date, device type, and other attributes, e.g. color, trim, etc.
30	Device-to-device	A remote sensor, e.g. a furniture-mounted temperature sensor, a pavement-embedded parking space occupancy sensor, etc., which is not an integral part of the NLC system, shares its data with the lighting system through one of the system devices, e.g. a luminaire.
31	Device-to-device	Field configuration of NLC system devices is performed, either following initial installation or a maintenance event, via a common general-purpose field configuration tool, e.g. a tablet. The field configuration tool is not provisioned and does not need to be provisioned as part of the NLC system.
32	Device-to-device	Data and a physical layer communication protocol, e.g. Wi-Fi, Bluetooth, etc., for enabling a use to interact with a lighting system, e.g., to set the light level in a personal space via a user interface device, e.g., a mobile phone.

APPENDIX D: NLC INTEROPERABILITY CATEGORIES

Device-to-Device Interoperability

Interoperability between two NLC system components, typically from different vendors, or between an NLC component and a device that is not an integral part of an NLC system, such as between a furniture-mounted temperature sensor and an NLC's occupancy sensor. For example, the device-to-device interoperability may exist between a multi-sensor (a sensor module that can detect and respond to more than one environmental stimulus, including occupancy, light level and temperature) from one vendor and an LED driver from another vendor. The multi-sensor is powered by the LED driver and controls the LED driver to dim or switch on/off the lights based on the occupancy and daylight condition it detects. It can also query the LED driver for the real-time energy usage measurement. Digital Illumination Interface Alliance (D4i) is an example of a standard related to device-to-device interoperability specific to lighting.

Device-to-System Interoperability

Interoperability between an NLC system component and another NLC system. For example, device-to-system interoperability may exist between a multi-sensor from one vendor and the gateway of the NLC system from another vendor. The communication module of the multi-sensor and the gateway use the same data model and protocol such that the occupancy and light level data, as well as the LED driver real-time energy usage data, can be transmitted from the multi-sensor to the NLC system through the gateway, logged by the NLC system, and displayed on the NLC system dashboard.

System-to-System Interoperability

Interoperability between an NLC system and another system, which may be another NLC system, a building subsystem, an integration and management tool, or an enterprise system or software application. For example, system-to-system interoperability may exist between the NLC system and a building management system (BMS). The BMS queries the NLC for the occupancy data periodically, and the occupancy data is shared using a protocol and data model understandable by both systems. The BMS then uses the occupancy information to influence the operation of HVAC for improved efficiency and occupant comfort. Concurrently, the NLC occupancy sensor data may be logged by the security system to inform the presence/absence within a defined space. BACnet is an example of a standard related to system-to-system interoperability.

APPENDIX E: TECHNICAL DESIGN CRITERIA

USE CASE 1: EXTERNAL SYSTEMS INTEGRATION

The primary opportunity to leverage the use case for information exchange of occupancy data between lighting and HVAC systems to inform HVAC operation is replicated below:

> *Zone-level real-time occupancy status from lighting system occupancy sensors is used by the Building Management System (BMS) to control HVAC parameters at the HVAC zone level, such as ventilation rate and thermostat reset. The BMS can roll up the zonal data to inform system-level controls and operations, including but not limited to chilled/hot water temperature reset and chilled/hot water flow rate reset.*

The technical design criteria for this example would include:

- A secure Internet access at the NLC gateway for the NLC system to reach its IoT platform. The NLC gateway may be integrated into a system component within the NLC system architecture, such as controller, control panel, etc.
- NLC device data is pushed to the IoT platform through the gateway.
- An API may be provided in the following places within the NLC system architecture: 1) the IoT platform, 2) the on-premises gateway that brokers the data exchange with the IoT platform, or 3) within the facility BMS server/computer which provides access to an SQL type database for data storage/trending/archiving as well as system integration access.
- The API should adhere to the standardized style, and the most common style is HTTP REST API or, for added cybersecurity, implementing a TLS HTTPS security web browser interface.
- The data in the API should be in a standardized format and easily represented in software tools, such as JSON or XML.
- The communication between source and destination should adhere to open, well documented protocol standards such as an MQTT-based messaging protocol.
- The NLC data returned in response to an API request should represent the real-time or near-real-time latest status instead of cached status.

In addition, the data that needs to be exposed through the API should meet the following basic requirements.

- Occupancy status at the zone level.
- No/minimum latency between changes in occupancy status registered in the NLC and the occupancy status updated through the API. Maximum latency duration should be defined as an acceptable level for occupant/operations response times (on the order of 100 ms max).

- Occupancy status is represented using a structured variable parameter state[10], such as 1:80 where the first parameter (1) is the occupied/unoccupied state and the second parameter (80) is the level/percentage of occupancy (density) from 0 to 100 percent. This assumes the occupancy status is an aggregation of statuses from multiple occupancy sensors within a zone. For a single occupancy sensor, the status would simply be 1:100 (occupied) or 0:0 (unoccupied).
- The timeout (dwell time) counter needs to be exposed in "minutes: seconds" counting down to 0. Before the counter reaches 0, the occupancy status should be treated and presented as "occupied".
- A list of defined occupancy zones and how they are associated with the lighting occupancy zones should be available through the API.

USE CASE 2: LOAD SHEDDING/DEMAND RESPONSE (LS/DR)

The primary opportunity to leverage the use case for real-time dispatching and reporting to support demand management is replicated below:

> *A demand response event is dispatched to the central Energy Management System (EMS) of a building from the grid operator's DR Automation System (DRAS). The grid operator or third-party agent request an estimate of the load reduction the building can commit to. The EMS in turn polls each subsystem, including the NLC, for the predicted load shed capacity and responds back to the grid operator or the agent. During the DR event, the EMS continues to poll the real-time energy consumption from the end-use systems and reports the overall building energy consumption to the grid operator's DRAS. The real-time reporting and forecast shared between the building subsystems and the EMS would be system-level data. This real-time feedback model offers not only look-ahead load shed capacity, but also provides a check and balance between energy cost savings via incentives and occupant comfort under the control of the owner, operator, or utility agent.*

The technical design criteria for this example would include:

- A secure communication interface at the NLC for connecting with a DR API. The DR API may be a BMS, which then communicates with the grid operator. This would be the most likely case. However, the DR API may also be the NLC itself to establish direct communication with the grid operator. In this case, the DR API would be part of the NLC.
- The NLC communication interface is provided through either an API in an industry standard format or native support of a standardized building automation protocol at various places within the NLC architecture, including the gateway, control panel or cloud.
- A standardized format for dynamic load status inquiry and response between the NLC and the DR API.

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[10] The same variable parameter state structure can be extended when multi-sensors are utilized in an NLC, which provide occupancy, ambient light level, daylight level, humidity, temperature, noise level, etc. This would allow all current parameters to be sent in one message, and are parsed on receipt, which helps with propagation delays, bandwidth management, and other networking requirements.

- The capability of monitoring and reporting the current load status within the NLC.
- The reported load status needs to be accurate to the specific usage required – revenue grade or non-revenue grade – depending upon the application requirements.
- The NLC needs to have native energy and power reporting capabilities at the panel and/or circuit level.
- The ability to forecast the load status and load reduction capability within the NLC for the duration of the temporary load reduction period.
- The ability to program the NLC to operate at a specified reduced service level without adversely affecting occupant safety and comfort.
- The ability to set the boundary for the lowest acceptable service level within NLC.

In addition, the NLC should be able to receive the following basic inquiries from the DR API and respond accordingly, and there should be no or minimum latency between the actual current load status and the information reported out by the NLC.

Table E1: API requests and responses

Inquiry from the DR API	NLC response
Current load status	Kilowatt (kW)
Recurring load status update at a specified interval	Periodic kW report at a specified interval
Forecasted load reduction capacity for a specified future time (peak) and duration (accumulated) period	Kilowatt (kW) – peak Kilowatt-hour (kWh) – accumulation over period
Load reduction request for a specified amount starting at the specified time for a specified time period	Acknowledge and execute
Cancellation of load reduction	Acknowledge and execute

USE CASE 3: ENERGY MONITORING (EM)

The primary opportunity to leverage the use case for energy data reporting to a utility is replicated below:

> *A utility's lighting energy efficiency program for networked lighting controls requires the NLCs to report the system-level energy usage at a 15-minute interval in standard API format (such as the Green Button format) for the duration of one year. The energy data is transmitted to the repository provided by the utility over the Internet at a regular interval, such as daily or weekly. The energy data from all program participants is used by the utility to verify the energy performance of individual incentivized systems and to calculate program-level energy savings as one of the metrics for evaluating program effectiveness and cost-to-benefit ratio.*

The technical design criteria for this example would include:

- A secure communication interface at the NLC for pushing energy data to an external receiver.
- The NLC communication interface is provided through an API at various places within the NLC architecture, including gateway, control panel or cloud.
- A standardized data model for reporting energy data such that the receiving entity can correctly parse and interpret the data.
- Definition of energy/power data storage duration, scale, accuracy, and types (voltage, current, power factor, phase, etc.).
- The spatial resolution of the energy data should be at least at the zone or panel level (as opposed to only system level). And the NLC should be able to report room-, zone- or panel-level as well as system-level energy data depending on the needs of the receiver. Also lighting vs. plug load, if the NLC monitors plug load.
- The receiving entity needs to be able to acquire the necessary information about the data source to fully utilize the energy data for the intended use. This may be obtained through offline data entry or a separate online "handshaking" process when the energy data reporting is first established between the NLC and the receiver. The information may include NLC manufacturer, NLC product name and model, building/business type of the NLC installation, total rated wattage controlled by the NLC, space name and type mapped to lighting zones, etc.

In addition, the following basic information should be included in the reported NLC energy data:

Table E2: Key elements for NLC energy reporting

Data Element	Description
NLC ID	Unique identifier for associating the data with the generating source NLC
Spatial resolution indicator	Indicate whether the data is at system-, panel-, zone-, or luminaire-level
Reporting interval	The time interval between consecutive reporting timestamps
Special ID	Unique identifier for each reported system, panel, zone or luminaire as indicated by the spatial resolution indicator
Timestamp	The timestamp when the energy data point is generated
Energy data point	The actual energy reading associated with the timestamp
Energy per period	Accumulated energy over a given period via internal NLC accumulator
Instantaneous peak	Current and historical peak load monitoring and data sharing. (Applicable to system- and panel-level data.)
Accumulated energy	Energy over time with the ability to select date/time range for accurate load profiling, analysis and reporting. (Applicable to system- and panel-level data.)

Note: For system-level data, multiple timestamp-energy data point pairs may be reported in a single reporting instance. For panel-, zone-, or luminaire-level data, multiple special ID- timestamp-energy data point sets may be reported in a single reporting instance.

APPENDIX F: DEFINITIONS

Application Programming Interface (API)
An application programming interface is a set of protocols, routines, functions, and/or commands that is used to facilitate interactions between distinct systems.

Building Management System (BMS)
A building management system is a graphical user interface front end for monitoring and control of one or more building systems relating to the overall operation of the building in which it is installed. It often has advanced capabilities, such as equipment monitoring, protection of equipment against power failure, and building security. The BMS interfaces to the site Building Automation System (BAS) that contains the controllers, control logic, sensor, actuators, sometimes referred to as a Direct Digital Control (DDC) system.

Demand Response Automation Server (DRAS)
A demand response automation server is used to facilitate the automation of customer response to various demand response programs through a communicating client that is connected to a load at the customer site.

Distributed Energy Resources (DER)
Distributed energy resources are electric generation units (typically in the range of 3 kW to 50 MW) located within the electric distribution system at or near the end user. They are parallel to the electric utility or stand-alone units. Common DERs include natural gas backup generators, and roof-top solar, wind, and geothermal systems installed by the user (not a utility) requiring energy flow from the user back into the grid.

Energy Information System (EIS)
An energy information system is the software, data acquisition hardware, and communication systems used to store, analyze, and display building energy data.

Energy Management System (EMS)
An energy management system is a system of computer applications used by building engineering staff to monitor, control, and optimize the building's operating performance (e.g. energy consumption, occupant comfort levels). EMS optimizes building operating performance through supervisory control programs that utilize core BMS functionality.

Internet of Things (IoT) platform
An Internet of Things (IoT) platform is the support software that connects edge hardware, access points, and data networks to other parts of the value chain across the Internet, which are generally the end-user applications. IoT platforms typically handle ongoing management tasks and data visualization, which allow users to automate their environment typically through the use of a variety of web services.

Interoperability, Device-to-device
Interoperability between two NLC system components, typically from different vendors, or between an NLC component and a device that is not an integral part of an NLC system, such as between a furniture-mounted temperature sensor and an NLC's occupancy sensor.

Interoperability, Device-to-system
Interoperability between an NLC system component and another NLC system.

Interoperability, System-to-system
Interoperability between an NLC system and another system, which may be another NLC system, a building subsystem, an integration and management tool, or an enterprise system or software application.

Load Shedding/Demand Response (LS/DR)
Load shedding is a control strategy for selectively reducing the electrical load of a system on a temporary basis to reduce energy usage. Demand response is a change in energy use in response to either a change in the price of electricity or a signal indicating system reliability is jeopardized.

Networked Lighting Control (NLC)
A networked lighting control system is the combination of sensors, network interfaces, and controllers that effects lighting changes in luminaires, retrofit kits, or lamps.

Power, apparent
The apparent power of an alternating current (AC) circuit is the product of the root mean square (RMS) values of the voltage and the current.

Power, correlated
Correlated power of a lighting system is the power consumption calculated from the supplied control signal based on a known dimming signal versus power curve.

Standards Developing Organization (SDO)
A standards developing organization is an organization whose primary activities are developing, coordinating, promulgating, revising, amending, reissuing, interpreting, or otherwise producing technical standards that are intended to address the needs of a group of affected adopters.

Use case
A description of a potential scenario in which a series of related interactions occur between an actor and another actor to achieve a specific goal. Note that this definition is for a general application, and not a formal, technical series of precise steps for programming.