Bringing Efficiency to Light℠

Energy Savings from Networked Lighting Control (NLC) Systems

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Prepared for the DLC® by Energy Solutions

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ABOUT THE DESIGNLIGHTS CONSORTIUM

Bringing Efficiency to Light.

The DesignLights Consortium (DLC) is a non-profit organization dedicated to accelerating the widespread adoption of high-performing 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.

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DEFINITIONS

BUILDING INFORMATION

Building type: A building classification. Commonly designated and referenced to characterize energy consumption based on the building's primary purpose.

Space type: A classification of a subspace within a building. Commonly designated and referenced to characterize energy consumption for a specific use within a building (e.g. open office, hall, breakroom).

Personally identifiable information (PII): Any data that could potentially identify a specific individual or organization.

POWER / ENERGY MEASUREMENT

Energy monitoring: The capability of a system, luminaire, or device to report its own energy consumption or the energy consumption of any controlled device via direct measurement or other methodology (i.e. true, apparent, or correlated power).

True power measurement: Power measurement method where instantaneous voltage measurement is multiplied by instantaneous current measurement, then accumulated and integrated over a specific time period of at least one complete cycle.

Apparent power measurement: Power measurement method determined by multiplying root mean square (RMS) voltage measurement and RMS current measurement.

Correlated power: The power consumption calculated from the supplied control signal based on a known dimming signal versus power curve.

Dimming level: Amount of delivered light relative to maximum output, typically reported as a value of the dimming signal from 0-100%.

Power-dimming curve: A curve representing the relationship between a dimming signal and corresponding power output as a function of control signal from zero to 100%.

Rated power: Maximum rated luminaire or zonal wattage without controls enabled.

Control factor: The fractional energy savings achieved by NLCs to the light source they are controlling. This excludes any energy savings resulting from changes to light sources.

Sampling interval: The interval between which discrete power measurements occur. NLC sampling intervals are typically less than five seconds.

Reporting interval: The interval in which power and/or energy measurements are reported as a single value (e.g. every 5 minutes, every 15 minutes, hourly, or daily).

State change: Change in luminous output caused by a triggering of control strategy (e.g. occupancy, scheduling, daylighting, etc.). An event-based interval reporting method utilizes state changes, rather than defined time intervals, to report power or energy data.

NETWORKING AND LIGHTING CONTROL STRATEGIES

Networking of luminaires and devices: The capability of individual luminaires and control devices to exchange digital data with other luminaires and control devices on the system.

Daylight harvesting: The capability to automatically affect the operation of lighting or other equipment based on the amount of daylight and/or ambient light present in a space, area, or exterior environment.

Occupancy sensing: The capability to automatically affect the operation of lighting equipment based on the detection of the presence or absence of people in a space or exterior environment.

Personal control: The capability for individuals to adjust the illuminated environment of a light fixture or group of light fixtures in a specific task area to their personal preferences, via networked means.

High-end trim (aka "task tuning"): The capability to set the maximum light output to a less-than maximum state of an individual or group of luminaires at the time of installation or commissioning.

Scheduling: The capability to automatically affect the operation of lighting equipment based on time of day, week, month, or year.

EXECUTIVE SUMMARY

While connected lighting currently comprises less than 1% of all luminaires in the United States, the Department of Energy (DOE) estimates that it represents up to 45% of total lighting energy savings potential (DOE 2017). By 2035, more than a third of installed luminaires in commercial buildings are estimated to have network connectivity (DOE 2016).

This research project collected, aggregated, and analyzed zone- and fixture-level energy monitoring interval data from networked lighting controls (NLC) systems in 114 buildings across a variety of building types in North America, representing over 1,200 zones with an average of 60 days of monitoring data per building. Overall, the study found average energy savings from NLCs to be 47%, although values are highly site-specific (see **Table 1** below).

Table 1: Summary of inferred NLC savings by building type results.

Building Type	Total Buildings	Unique Manufacturers	Control Factor (% savings)	
			Average	25^{th} – 75^{th} Percentile
Assembly	5	1	0.23	0.10 - 0.29
School	7	1	0.28	0.09 - 0.57
Manufacturing	28	3	0.30	0.09 - 0.43
Retail	29	1	0.44	0.39 - 0.49
Restaurant	2	1	0.47	0.41 - 0.53
Office	39	3	0.63	0.43 - 0.82
Warehouse	4	2	0.82	0.78 - 0.85
Overall	114	5	0.47	0.28- 0.76

This project reflects an important step towards "M&V 2.0" by moving from generalized engineering calculations to leveraging building-specific, standardized energy data collected by building systems to predict, measure, and verify NLC energy savings. This summary provides key findings to inform energy-savings estimates used by the building design and construction, lighting controls, and utility efficiency program industries, as well as recommendations for improving methods for collecting and analyzing NLC monitoring data.

This report represents a first step. With additional funding, DLC hopes to conduct an update study in 2018, which will build on the findings, implement recommendations where possible, and expand the project sample size.

Finding #1: The portfolio-level average energy savings across all buildings in this study was 47%. However, energy savings are highly site-specific and the data does not demonstrate a clear correlation between building type and energy savings due to NLCs.

While there is generally some degree of similarity within building types, actual site characteristics are one of the greatest drivers of NLC energy savings, as they interact with enabled feature-settings of the NLC. **Figure 1** shows that site-specific variation is a much larger driver of energy savings than general factors such as building type, as exemplified by the large spread in savings within most building types. Warehouses may be a promising exception to this rule, as the four warehouses in the dataset represent two NLC products and multiple end-users that achieved energy savings in the range of 75% to 88%.

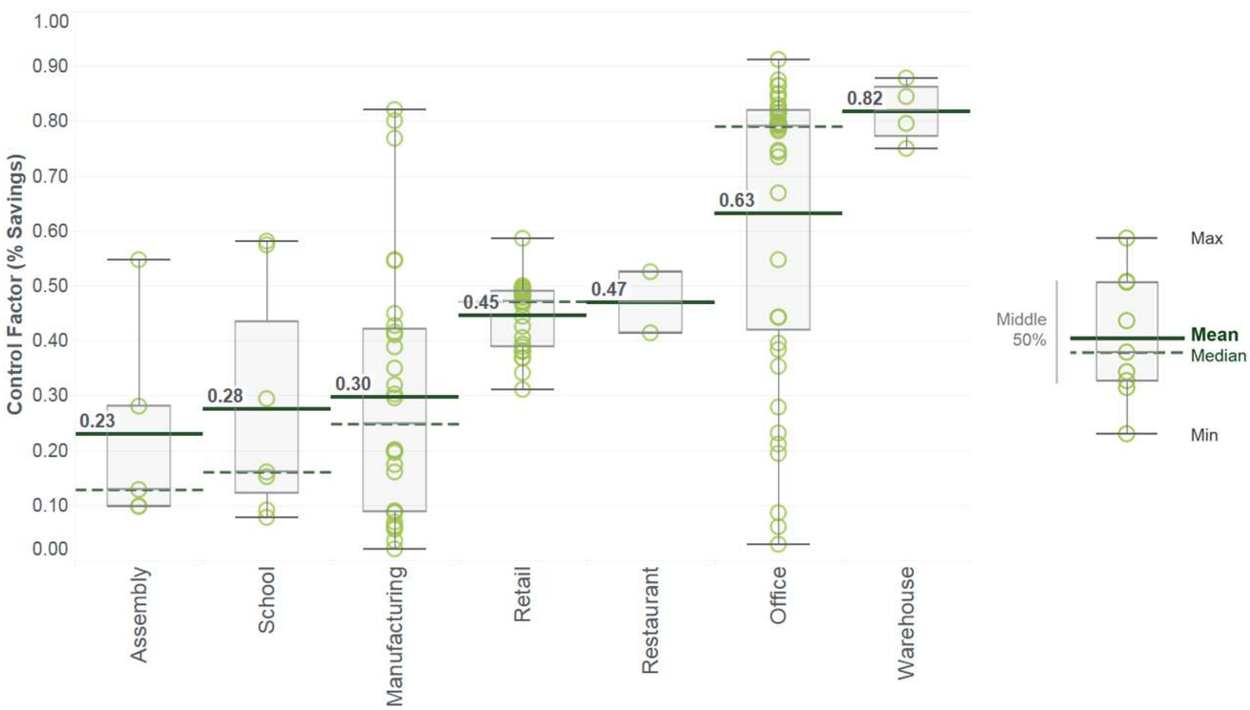


Figure 1. Box and whisker plot of control factor by building type relative to an inferred baseline. Each circle represents a building, while the box shows the interquartile range (25^{th}-75^{th} percentile). Whiskers extend to the minimum and maximum values. The solid horizontal line is the average (mean), while the dashed line is the median.

Better understanding of the causal factors that influence energy savings is an important consideration for future study and to help develop industry best practices. This will require a significantly larger dataset and the collection of additional site information, but is certainly feasible as utilities, manufacturers, and building systems begin collecting this data in a standardized fashion.

Finding #2: In this study, buildings with NLC systems have substantially longer occupied hours than typical prescribed estimates of building operating hours. However, this observation requires further study and a larger sample size to confirm.

In general, the average occupied hours for buildings in this study's dataset are substantially longer than the average lighting system operating hours assumed by many utilities throughout the US in their Technical Reference Manuals (TRMs). **Figure 2** compares hours found in this study and operating hours for fixtures across a number of TRMs, including California, Illinois, New York and the Mid-Atlantic region.

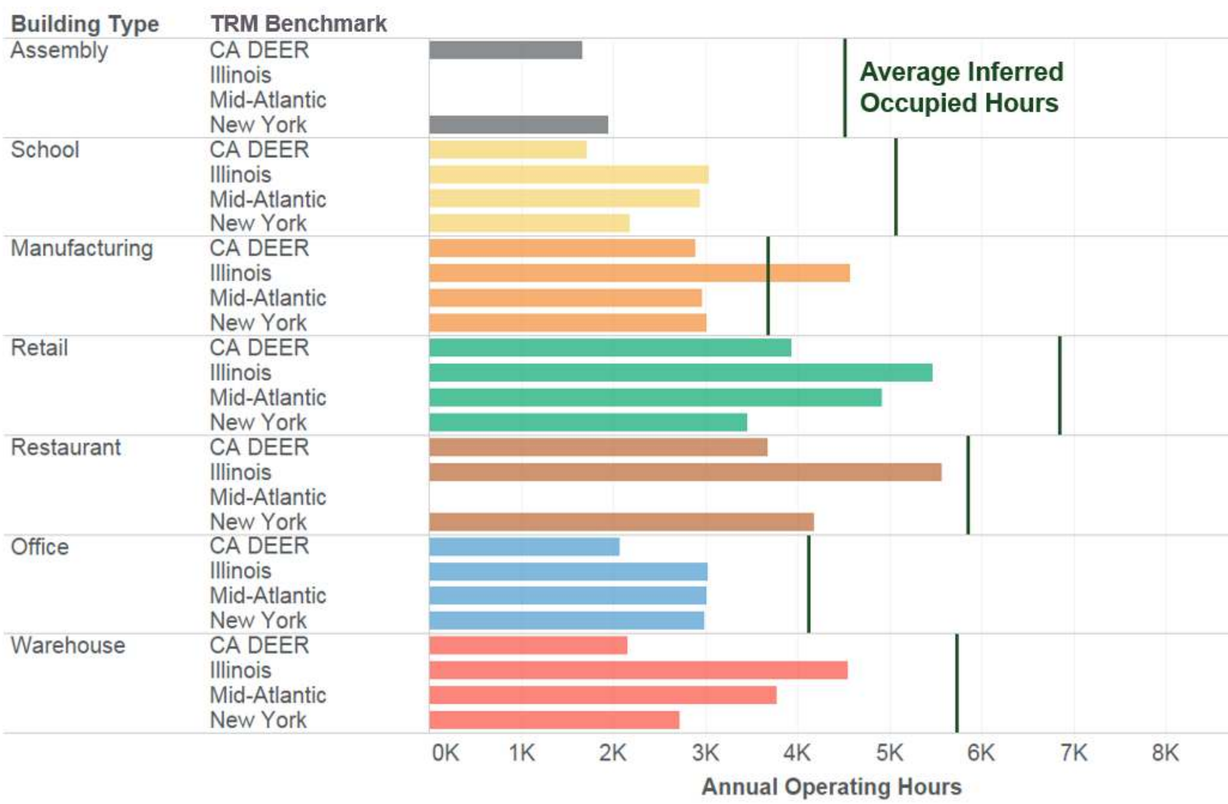


Figure 2. Comparison of occupied hours and sample deemed TRM operating hours.

This discrepancy between hours calculated in this study and TRM assumptions could be due to one or both of the following reasons:

- Buildings with longer core hours may be more likely to implement NLC systems because of the stronger value proposition associated with longer operating hours.

- The methodology of this study may have a systematic bias toward overestimating operating hours. However, the known biases tend to underestimate operating hours.[1]

This finding has implications to utility energy efficiency programs that typically rely on historical average assumed operating hours rather than site specific operating hours to estimate project energy savings.

Finding #3: Data authorization approval must be streamlined to facilitate data collection on future projects.

Although manufacturers have an installed base of thousands of sites with networked lighting controls, obtaining customer authorization for receipt of anonymized data was a major obstacle to the collection of data for this project. Initial data review and authorization took between one and four months for most projects, as it required multiple levels of management review and approval to determine the appropriate data authorization contacts. This barrier was typically not due to customer reticence to share anonymized data, but rather the logistical challenge of finding the right person to provide approval (only one organization explicitly noted customer reticence as a barrier to providing data). This broader data authorization barrier can be broken down into four specific issues:

- Lack of existing authorization
- Lack of bandwidth to obtain retroactive authorization for multiple sites
- Lack of existing relationship with customers
- Lack of remote data access

Finding #4: Most manufacturers do not have an existing mechanism to easily export the data required for utility program evaluation.

NLC reporting functionality for existing customers does not have the level of granularity required for utility evaluation. Thus, nearly all organizations had challenges exporting data in the appropriate format for use in the study. Existing manufacturer reports focus on delivering insight to building owners and facility managers, both of whom have data reporting needs and interests that are different from those of a utility. Developing generalized reporting guidelines specifically for utility programs could significantly streamline the data normalization process by enabling scripted data transformations and formatting changes.

[1] For a more detailed discussion for why this approach may underestimate operating hours, see the "Findings and Recommendations" section.

RECOMMENDATIONS

Recommendation #1: Based on this dataset, the best estimate of average portfolio-level energy savings for utility NLC programs is 47%.

The portfolio-level average energy savings across all 114 buildings in this study was 47%. Because the buildings included in this study were not identified through a random sample, it is not possible to make statistical inferences about a broader building stock; however, the 47% value represents average savings from NLC systems across five manufacturers, seven building types, and 114 buildings and is therefore the best available estimate of average NLC performance.

Recommendation #2: Utility NLC programs should consider requiring and/or incentivizing anonymized data sharing for all participating projects.

Going forward, utility NLC programs should strongly consider including clauses in their customer participation agreements that authorize the share of anonymized data. Anonymized data sharing is common in many software applications, and authorization is typically written into the usage terms and conditions or specifically requested during the installation process. It is recommended that utilities either (a) explicitly require reporting as part of receiving utility incentives, or (b) incentivize energy monitoring and data reporting by providing an additional per-kWh "adder" for data sharing. It is recommended that the initial year of program data collection be voluntary and incentivized while manufacturers, vendors, and utilities continue to refine both utility-focused reporting functionality and determine which party (manufacturers, vendors, or customers) ultimately provides the data to utilities.[2]

Recommendation #3: Manufacturers and vendors should support utility program reporting needs by incorporating data sharing authorization clauses and service-level agreements into their customer contracts.

Many manufacturers, vendors, and utilities also do not have existing data sharing authorization agreements in place with customers. Data reporting is a critical element of utility incentive programs, and it is recommended that manufacturers add clauses into their customer contracts to going forward to enable data sharing. Additionally, manufacturers and vendors should consider adding data authorization clauses into customer contracts and data sharing terms into service-level agreements (SLAs) that identify the parties responsible for providing data to utility programs.

[2] This is particularly true for NLC systems which are operated on-site without a cloud-based connection and for which manufacturers and vendors have little or no access to system data. This scenario would require building data to be pulled by a facility manager who may have limited familiarity with the NLC system and thus would require simplified reporting functionality.

Recommendation #4: Utility NLC programs should consider adopting a standardized reporting format to facilitate program participation and streamline the process. Based on these reporting guidelines, manufacturers should consider developing utility-specific reporting functionality that customers, vendors, or manufacturers can easily export.

There are no existing guidelines for how manufacturers, vendors, or customers should report data to utility programs, making it difficult and time-consuming to fulfill utility data requests. It is recommended that utilities adopt standardized reporting guidelines to facilitate data collection such as those provided in Appendix A. Based on such guidelines, manufacturers should consider developing automated, utility-specific reporting through which multiple system users, such as facility managers, vendors, or manufacturers, can easily generate reports.

Recommendation #5: Future data collection efforts should focus on increasing the sample size, monitoring duration, and building operational characteristics to identify drivers of best-in-class NLC performance.

NLC energy savings are highly site-specific. Future data collection efforts should focus on understanding how building characteristics and operational profiles affect energy savings. These findings can support the development of NLC program best practices and system configuration/operation recommendations to maximize energy savings. For example, there may be a relationship between building size and control factor, as larger spaces may have greater potential for occupancy savings. Similarly, business models such as Lighting-as-a-Service (LaaS) may be correlated with higher savings due to a third-party's financial interest being aligned with building performance. Developing these inferences requires a significantly larger dataset; however, streamlined data authorization and standardized reporting should significantly increase potential project sample size in the future.

ADOPT A BUILDING PORTFOLIO APPROACH

NLC energy savings vary by site, but across the portfolio of all buildings they were 47%

IMPLEMENT DATA SHARING AGREEMENTS

Utility NLC programs and manufacturers should support anonymized data sharing

ADOPT A STANDARDIZED FORMAT

Utility NLC programs and manufacturers should adopt a standardized reporting format

COLLECT ADDITIONAL PROJECT DATA

Increase sample size and collect more types of data for each NLC installation

Figure 3. Report recommendations.

INTRODUCTION

WHY IS QUANTIFYING THE ENERGY SAVINGS OF NLC SYSTEMS IMPORTANT?

While connected lighting currently comprises less than 1% of all luminaires in the United States, the Department of Energy (DOE) estimates that connected lighting represents up to 45% of total lighting energy savings potential (DOE 2017) and, by 2035, more than a third of installed luminaires in commercial buildings will have network connectivity (DOE 2016).

Although NLCs are expected to be a major driver of future energy savings, historically, the impact of lighting controls has been difficult to measure at scale. As the market penetration of connected devices with energy monitoring capabilities continues to grow, building owners and utilities are gaining new levels of insight into how energy is used within buildings. Using highly granular data, building owners and utilities are transitioning away from using static engineering calculations and moving toward the ongoing system monitoring to measure and verify performance over time.

While this radical shift toward "M&V 2.0" has dramatic potential to improve understanding of building energy use, unlocking the value from this data requires the development of a standardized framework for collecting, aggregating, and analyzing energy monitoring data. By collecting and analyzing zone-level interval data for NLC systems in over 110 buildings, this project represents an important first step toward the development of such a framework.

WHY IS BETTER QUANTIFICATION NECESSARY?

In order for incentive programs to better support the adoption of NLC systems, two key elements are required: (1) access to information and (2) reliable third-party quantification and verification of energy savings. As a trusted industry resource, the DLC Networked Lighting Controls Qualified Product List (NLC QPL) provides a key information resource to consumers, utilities, and other stakeholders to learn about NLC system capabilities. However, reliable savings estimates at scale have been lacking.

Though many studies have attempted to quantify energy savings from lighting controls, they have typically been limited to a small number of sites and third-party case studies (DLC 2015; Wei et al. 2015; Mutmansky & Berkland 2013). Small sample sizes and limited sampling duration combined with high variability in control savings by building type has made it difficult to confidently predict savings achievable by NLC systems. To date, the best available large-scale dataset on controls energy savings comes from a

2011 meta-analysis from Lawrence Berkeley National Lab (LBNL) (Williams et al. 2011).[3]

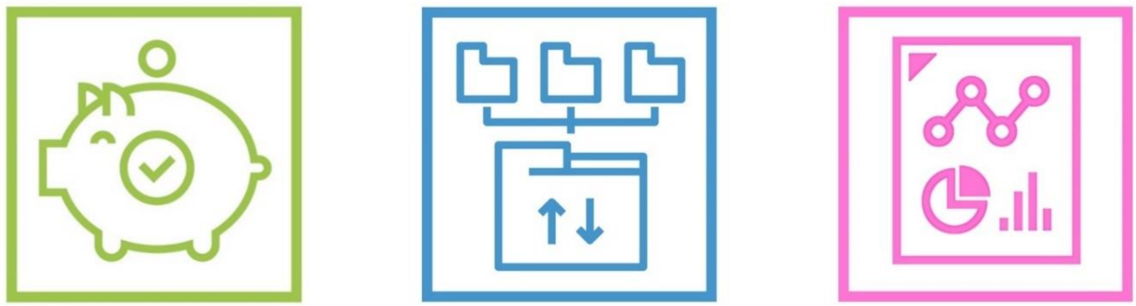
The DLC's NLC QPL, along with better quantification of NLC savings, aims to build consumer confidence and support the continued development of utility NLC incentive programs. Additonally, NLC systems enable users to gather non-energy performance data and use it to inform and optimize business processes, achieving significant value beyond a simple luminaire-only retrofit.

PROJECT OBJECTIVES

The objective of this project is to provide utilities, regulators, manufacturers, and potential customers with better estimates of interior NLC energy savings by leveraging embedded energy reporting capabilities and anonymized performance data from NLC systems across existing and future installations. To support this broader objective, this report has three core goals (see **Figure 4**):

1. **Improve existing NLC energy savings estimates.** Improve industry understanding of NLC energy savings and reduce performance risk to utilities, regulators, and customers through a detailed analysis of available project interval data.
2. **Create a database to collect performance data.** Establish a database of NLC performance data, with the potential to grow in size and sophistication, to further support NLC adoption and industry advancement.
3. **Develop reporting guidelines for utilities and NLC manufacturers.** Establish guidelines to create a standardized framework and format for future NLC data reporting to utility programs.

[3] This study reviewed 240 savings estimates from 88 papers and case studies from 1982 to 2011, categorizing each study by control strategy to estimate the savings from individual control strategies and their potential when implemented together (Williams et al 2011). In order to integrate such a wide range of studies into one analysis, the authors did not filter or standardize baselines, so that savings may be measured over different time periods (e.g., weekday core hours vs. a 24/7 baseline).



SAVINGS ASSUMPTIONS
Improve savings assumptions for NLC systems

DATABASE COLLECTION
Create a database to collect performance data

REPORTING GUIDELINES
Develop reporting guidelines for utility programs

Figure 4: Overview of NLC data project goals

INTENDED USES FOR THIS STUDY

NLC energy monitoring data and this report have three primary intended uses:

1. **Quantifying savings claims of interior NLC systems to potential customers:** While many manufacturers, manufacturer representatives, and contractors typically use their own literature and calculators estimating energy savings, reliable third-party estimates improve customer confidence that NLC systems can achieve the savings claims touted by a manufacturer or salesperson. Although energy savings are highly site-specific, improved quantification and a larger dataset can provide both a range of expected savings and an average of what a portfolio of buildings might be expected to achieve.
2. **Improving the utility evaluation process:** Historically, incentive programs have based controls savings claims on engineering calculations and deemed savings assumptions: occupancy sensors save X% in building type/space type Y. To validate these calculations, evaluators at times conduct time-intensive and costly metering studies of a small subset of installed systems for a short period, then extrapolate those results to an entire portfolio. NLC systems enable more thorough and granular data collection at every site and provide the potential to capture that data more economically, which can significantly increase both utility and evaluator confidence in NLC system energy savings claims.
3. **Supporting utility program planners:** Utility program planners can leverage energy monitoring data to better estimate savings claims, align incentives with performance, and predict program cost-effectiveness. All the while increasing the likelihood of a successful program. In addition, program planners can use the findings and recommendations to inform their NLC program policy and strategy.

TECHNOLOGY AND MARKET OVERVIEW

TECHNOLOGY OVERVIEW

While NLC system architecture varies by manufacturer, they are generally composed of the following components:

- **Sensors:** Measure occupancy, light levels, and a wide (and growing) range of environmental data such as temperature and humidity at the fixture or zone level.
- **Network connectivity:** The capability of individual luminaires and control devices to exchange digital data with other luminaires and controls devices on the system.
- **Processing:** The incorporation of inputs from the sensors with programmed information (such as scheduling, occupancy timeouts, etc.) to identify and execute a control to optimize lighting. This processing and decision-making can be done at either the local level, on a site-based server, or in the cloud.
- **Web or app-based user interface:** Enables the configuration of specific controls settings, review of energy monitoring reports, and remote controllability of fixtures, based on the information received from the sensors and lighting.

To meet DLC's QPL requirements for NLCs, each interior system must have Occupancy Sensing, Daylight Harvesting, and High-End Trim as outlined in **Table 2**.[4]

[4] For a complete list of DLC's requirements for NLCs, see: https://www.designlights.org/lighting-controls/qualify-a-system/technical-requirements/

Table 2. NLC Definition of Control Strategies (as defined by the DLC).

CONTROL STRATEGY	DLC DEFINITION
Daylight harvesting	The capability to automatically affect the operation of lighting or other equipment based on the amount of daylight and/or ambient light present in a space, area, or exterior environment.
Occupancy Sensing	The capability to automatically affect the operation of lighting equipment based on the detection of the presence or absence of people in a space or exterior environment.
High-end trim	The capability to set the maximum light output to a less-than maximum state of an individual or group of luminaires at the time of installation or commissioning.
Scheduling (reported, not required)	The capability to automatically affect the operation of lighting equipment based on time of day, week, month or year.
Personal control (reported, not required)	The capability for individual users to adjust the illuminated environment of a light fixture or group of light fixtures in a specific task area to their personal preferences, via networked means.

Presently, energy monitoring is a reported capability on DLC's NLC QPL. While the vast majority of currently listed systems on the NLC QPL have energy monitoring capabilities, the sophistication of their reporting functionality and methods for calculating energy use (and savings) vary widely by manufacturer. This inconsistency is in part due to end-users with varying degrees of sophistication or interest in energy data being the primary consumer of this information. Because utilities have not been a major consumer of NLC reporting data to date, there has been no driver to standardize the industry's data reporting and measurement practices explicitly for utility use.[5]

[5] The ANSI C137 Lighting Systems committee is currently developing guidelines for energy reporting for a wide variety of energy reporting use cases. Although the timeline is not certain, these guidelines are generally expected to be released in the next 1-2 years.

MAJOR DRIVERS OF NLC ENERGY SAVINGS

There are two major drivers of NLC energy savings within a building, both of which are often relatively independent of building or space type (Williams et al. 2011; Asif ul Haq et al. 2014):

- **Site characteristics and occupancy patterns:** While there is generally some degree of similarity within building types, actual site characteristics are one of the greatest drivers of NLC energy savings, as they interact with settings for the enabled features. NLC systems produce the greatest savings at sites with long-operating hours, large swings in occupancy throughout the day, and that are less than 100% occupied, resulting in lower overall traffic. Daylighting has an important but often secondary influence on energy savings.
- **Control strategies enablement and control settings:** Energy savings are highly dependent on which control strategies are enabled and the specific settings to which each control strategy is set. For example, enabling and implementing high-end trim has a tremendous impact on energy savings. Similarly, one-minute occupancy timeouts deliver significantly greater savings than fifteen minute timeouts. However, proper commissioning is critical to achieving energy savings. If configured improperly, NLCs can have minimal impact and even increase energy use in some cases.

MARKET ADOPTION OVERVIEW

Lighting controls have been installed for decades, but primarily as individual components such as occupancy sensors or dimmers installed within specific parts of a building. However, total stock penetration of lighting controls remains low, and over two thirds of US buildings have no lighting controls in place (see **Table 3**).

Table 3. US installed stock penetration of lighting controls, 2015 (DOE 2016).

INSTALLED STOCK PENETRATION (%)	COMMERCIAL
None	68%
Dimmer	3%
Daylighting	<1%
Occupancy Sensor	6%
Timer	4%
Energy Management Systems	15%
Multiple Strategies	4%
Connected	<1%

The expected increase in lighting controls adoption is primarily driven by the sophisticated sensing and processing capabilities of connected NLC systems, which provide more insight into how buildings are used and operated. This insight creates three distinct overarching value propositions:

- Deeper energy savings from the optimization of multiple control strategies and improved quantification of energy use.
- Increased insight into facility operation that can result in reduced maintenance costs.
- As NLC products mature, an emerging suite of Internet of Things (IoT) use cases that can help optimize building operations, improve employee productivity, and increase revenue and business efficiency.

While emerging IoT use cases will provide significant benefits beyond lighting and become increasingly important over time in business decision-making, energy savings and monitoring capabilities are the currently major drivers of NLC system adoption today. Because of energy savings' critical role in business decisions and making project economics work, increasing customer and utility confidence in savings claims is critical to increasing NLC adoption in the nearterm.

Figure 5 provides an overview of specific use cases for NLC monitoring data (both energy and non-energy) as function of NLC product maturity.

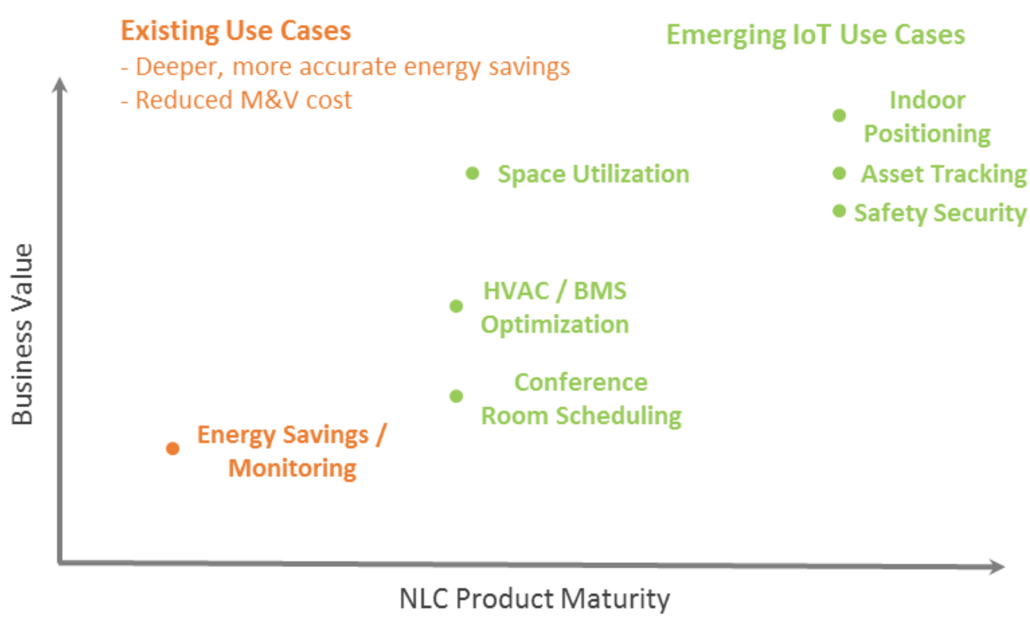


Figure 5. Overview of NLC use cases and value propositions.

Even as IoT use cases gain prominence in the market, energy monitoring capabilities will be crucial so that utility incentive programs can support—and customers can choose—products that will provide both energy savings and IoT benefits.

METHODS

Using large-scale collection and analysis of NLC system energy monitoring data is a relatively new method for estimating energy savings to inform utility programs and end-use customers. Moreover, it reflects the transition from a previously static and relatively simple approach to calculating energy savings to a significantly more complex, robust, and granular approach using building-specific usage data. There are no previous studies of similar size and scale using building-specific monitoring data to calculate NLC energy savings. To further industry standardization and lay the groundwork for future refinement, the entire process of data collection, aggregation and normalization, and analysis is presented below.

OUTREACH AND DATA COLLECTION

Outreach and data collection was conducted in three sequential phases: (1) initial outreach, (2) detailed discussions of data authorization, access, and format, and (3) data collection. **Figure 6** provides an overview of the total number of organizations that participated in each phase. Overall, authorization issues were the primary barrier preventing manufacturers from proceeding through to Phase 3 or providing data from additional buildings.

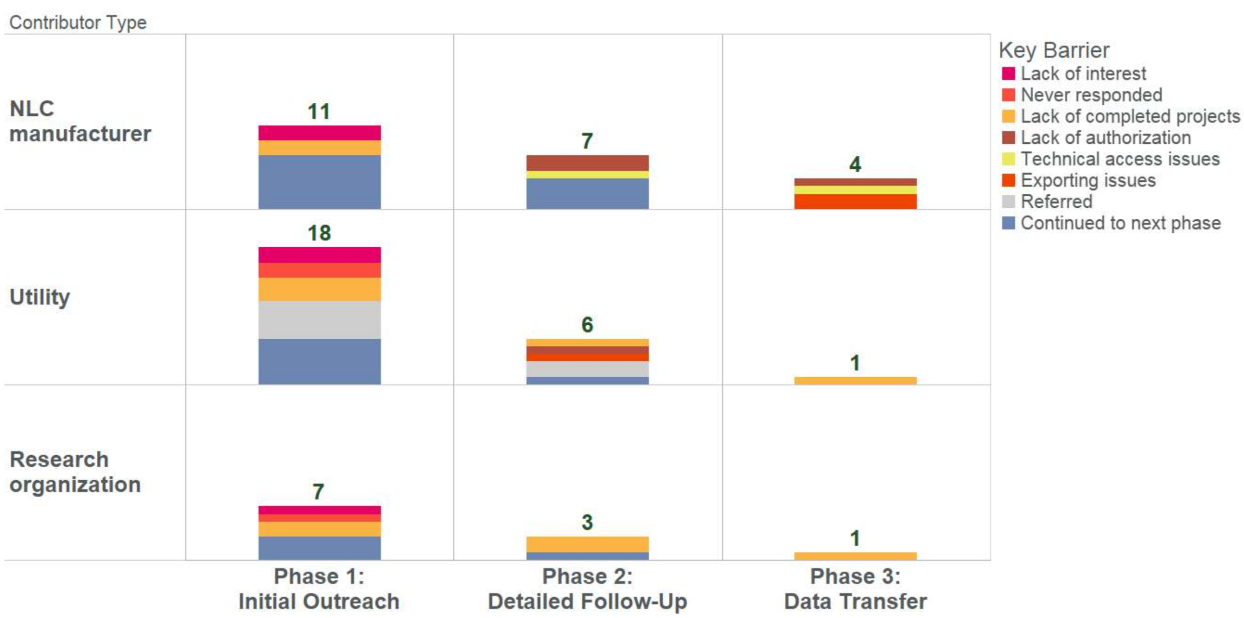


Figure 6. Organizations in each phase and barriers to providing data.

PHASE 1: INITIAL OUTREACH

Starting in December 2016, outreach was conducted to over thirty utilities, NLC manufacturers, and research organizations with existing or previous NLC projects to solicit anonymized project performance data. Approximately 44% of organizations contacted (16 of 36) had access and authorization to data from completed projects. The twenty organizations that were unable to provide data did so largely for the following reasons:

- Five requested that the project team work directly with manufacturers to collect their project data.
- Seven had ongoing NLC projects and did not yet have completed project monitoring data.
- Two had projects that used NLC systems that did not record energy use.
- Five were not interested in participating due to perceived lack of benefit relative to the time and effort requirements to support the data request.

PHASE 2: DETAILED DISCUSSION OF AUTHORIZATION, ACCESS, AND FORMAT

After confirming the availability of project data, detailed follow-up conversations were scheduled with each organization to discuss issues surrounding data authorization, access, and format. Questions posed included the following:

Authorization

- Does the organization have customer authorization to provide anonymized data?
- If not, is their customer relationship such that they could request authorization?

Access

- In what fraction of buildings is the NLC system logging energy monitoring data?[6]
- Where is the data stored, and what is the level of effort required for retrieval?
- What is the spatial and temporal granularity of the data?[7]

Format

- In what format is the data generally exported from the NLC system?

[6] Several manufacturers noted that in some cases, customers chose not to enable energy monitoring capabilities and therefore monitoring was not occurring at the site.

[7] Due to the sheer volume of fixture or zone level data, most companies roll up granular data after a short period and store at daily intervals, which is typically the greatest level of granularity that a customer might want for historic review purposes.

- Are static project characteristics (such as location and building type) in the same database as the lighting energy use data?[8]

Based on these conversations, each potential participant was sent a formal data request outlining three types of project data, including specific fields preferred format and granularity (see **Figure 7**). Each participant was also surveyed to understand their power measurement method (true, apparent, or correlated power) and sampling rate.

Building-Level Characteristics

- Building ID
- Building type
- Geographic location (e.g., state, not a specific address)
- Baseline operating hours

Zone / Fixture Level Characteristics

- Building ID
- If fixture-level data, Fixture ID and Zone ID for each fixture
- Space type description (could be the zone name)
- Rated power
- Daylight enabled (Y/N)
- High end trim %
- Occupancy timeout (min)

Lighting Energy Use Interval Data

- Building, zone, or fixture ID (depending on the spatial scale of the time series data)
- Timestamp
- Average power in each interval

Figure 7. Data request fields by category.

The surveyed organizations had widely varying data formats and no existing mechanisms to export data at the granularity required for the purposes of this study or that of utility program evaluators.[9] To reduce reporting burden on participating utilities and manufacturers, a sample dataset was obtained to determine if it met the project criteria. The sample dataset was typically made up of one to four buildings worth of data. Once the data format was agreed upon and any outstanding issues were resolved, each contributing organization confirmed the number of buildings to be shared and exported the data from their system.[10]

8 For example, several manufacturers had challenges in exporting linking databases which housed separate attributes such as interval data and building characteristics. In some cases, interval data was provided but the building type was unknown, limiting the applicability of that building's interval data in the study.

9 For further discussion on the lack of mechanisms to export highly detailed energy data, see the "Project Findings and Recommendations" section.

10 While many organizations initially expressed interest in providing project data, a large number of them were unable to proceed due to data authorization issues or the challenge of exporting relevant data. A more detailed discussion of authorization issues is included in the "Project Findings and Recommendations" section.

PHASE 3: TRANSFER OF ANONYMIZED PROJECT DATA

Ultimately, data specialists from six organizations provided anonymized interval data for the project. Due to the size of the files being shared, this process required close coordination to ensure a viable and secure file transfer. Once received, all datasets were evaluated to ensure that critical information required to appropriately categorize the building and calculate energy savings was present.

Since this was the first time most participating organizations had supported this type of data request, most of them had not developed specific reporting functionality to easily fulfill the data request and therefore requirem them to develop a series of custom queries. Some manufacturers had difficulty exporting such granular data for more than two weeks' duration.

DATA COLLECTION OVERVIEW

In total, monitoring data was collected from 212 buildings. Of those buildings, 114 were of relevant building types and had sufficient data quality to be included in the present analysis. **Figure 8** provides an overview of those 114 buildings, grouped by building type. Key takeaways include:

- **Representation among NLC manufacturers was highly variable:** Due to the voluntary nature of data-sharing and the challenges outlined above, there was broad but uneven representation among NLC manufacturers. Roughly 90% of all the building data came from three NLC manufacturers, while all retail building data came from a single manufacturer. Office building data had the most diverse representation with three manufacturers contributing data.
- **Sample size varied by building type due to data availability:** Manufacturing, retail and office buildings had the largest representation (n = 28 to 39), while warehouse, schools and assembly buildings had less representation (n = 4 to 7). Restaurants were represented by only two buildings.

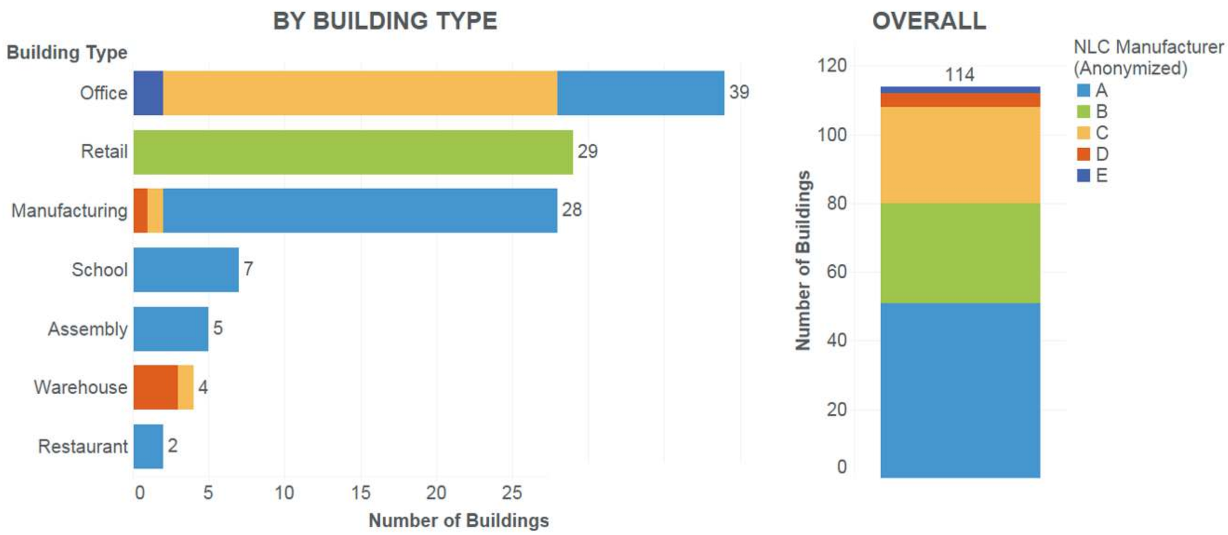


Figure 8. Number of buildings collected by building type and NLC manufacturer. This does not include buildings that were removed from the dataset due to data quality issues.

Figure 9 shows the geographic distribution of the buildings analyzed in this study, comprised of buildings from 26 US states and five Canadian provinces. While building locations were generally well distributed across states, there were particular concentrations in the US state of Illinois and the Canadian province of Ontario.

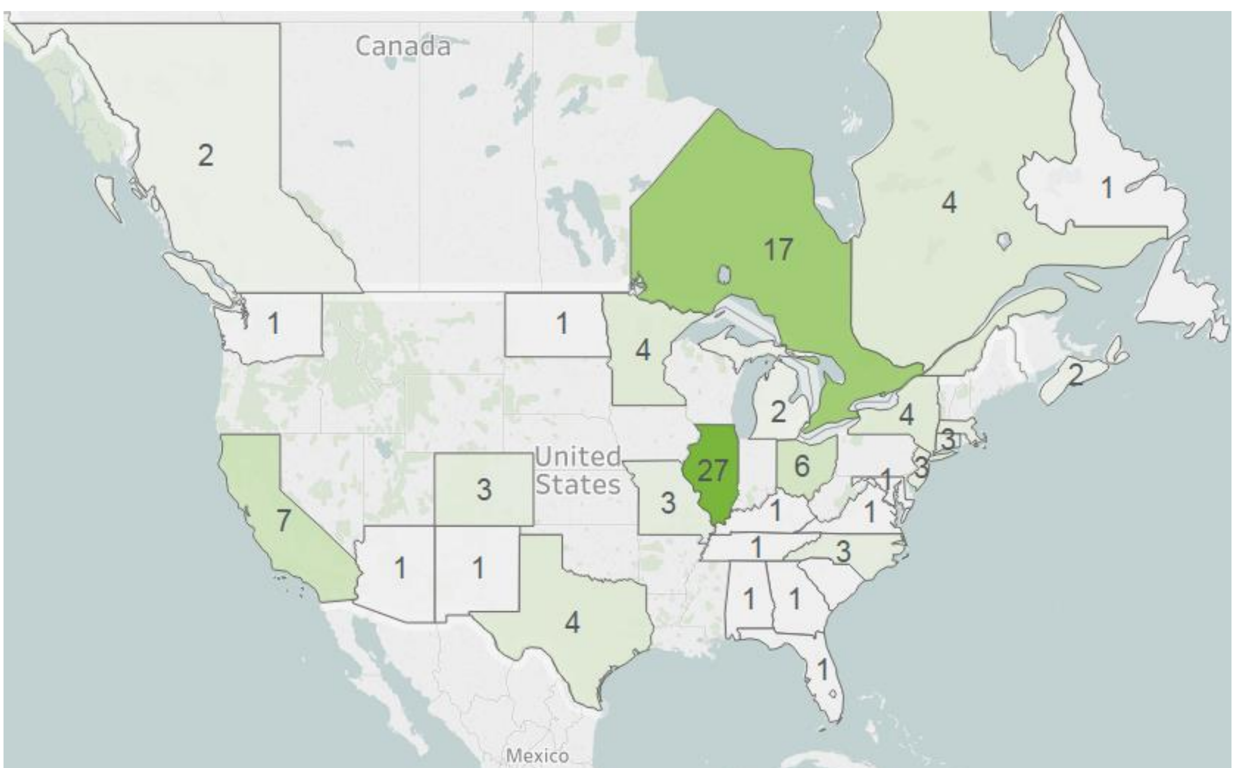


Figure 9. Geographic distribution of buildings with location information. This only includes buildings with high quality data and locational information (n=110).

DATA NORMALIZATION AND AGGREGATION

This section of the report outlines the data normalization process, from receiving the data from contributing organizations to normalizing and integrating each dataset into the NLC project database. Due to a lack of existing reporting guidelines, all available data was accepted in disparate formats, which required significant data normalization to integrate it into the database. **Figure 10** summarizes the distribution of data formats received across the dimensions described below.

Figure 10. Summary characteristics of energy monitoring data collected across all sites.

- **Duration:** The median duration of monitoring data was 60 days (8.5 weeks), with a range of three to thirteen weeks. On average, this is somewhat longer than standard utility M&V monitoring practices, which typically monitor spaces for two to four weeks post-retrofit to estimate energy savings. One contributor provided data for a three-month period for each building. None of the data collected had a duration greater than four months.[11]
- **Spatial resolution:** While data was provided at the whole-building, zone, or fixture levels, the data was split evenly between zone- and fixture-level. A small fraction of the original dataset was whole-building data which was ultimately discarded from the analysis as buildings rarely operate as a single zone and therefore makes it difficult to accurately estimate baseline.

[11] To preserve consistency and data quality, all sites with a monitoring duration of less than two weeks (a total of three sites) were removed from the analysis.

- **Space types:** Mapping zones into meaningful space types was not possible for all the data provided. In some instances, zone descriptions can identify the type of space the lights are in (e.g., "third floor restroom"). However, in other cases they provide little context (e.g., "zone 18"). The lack of space type information for almost half the dataset and the lack of uniformity in the space type descriptions that were available was a barrier to estimating savings by space type within each building.
- **Reporting Interval:** Several participants provided data in regular intervals, which were reported in hourly or more granular frequency. Others provided state change information based on irregular, event-based intervals, in which a row of data is recorded for every change in dimming signal or binary on/off status. Data provided for this project was split roughly evenly between regular and event-based intervals.
- **Power measurement:** The majority of buildings used correlated power, which records the dimming level at each sampled interval, then calculates power draw based on a dimming curve. While true power is the most accurate because it is based on actual current and voltage measurements, few organizations provided data in this manner.[12]
- **Savings by control strategy:** Few data contributors provided this information. When it was provided, it was difficult to meaningfully compare across organizations because the order in which each control strategy is applied affects its savings attribution, and thus makes it highly specific to each contributor.

STANDARDIZATION OF DATA FORMATS

Data was submitted by six contributors in eighteen unique data formats. Data from the sole utility contributor was particularly heterogeneous in its format, because it came from a variety of NLC manufacturers and previous savings verification analyses. Data was normalized into a standard format using the following steps:

- **Anonymization of Personally Identifiable Information (PII):** As part of the data intake process, each dataset was reviewed for any references to personally identifiable information such as site addresses and names of customers, manufacturers, and contractors. PII may have appeared either as explicit fields or embedded in zone names or comments. All forms of PII were scrubbed and eliminated from the datasets.
- **Construct time series of energy use over time (as necessary):** One data contributor provided dimming level over time (including data to indicate when the lights were off) and power-dimming curves for each zone rather than energy consumption. The data on dimming level over time was combined with the

[12] Correlated power is less accurate than true power, although this difference can vary widely by manufacturer and method (CLTC 2015). Several manufacturers noted that existing installations used correlated power, upcoming versions of their product would use true power measurements.

power-dimming curve to generate energy use over time for each zone. Another contributor, a research organization, had already conducted a similar analysis and provided raw data on dimming level over time, a power-dimming curve, and their resulting estimates of energy use over time for each zone.

- **Determine rated power of each fixture without controls (as necessary):** Correctly identifying maximum power draw without controls is important for accurately attributing high-end trim energy savings to the NLC system. However, not all manufacturers were able to report rated power as a static variable. For example, one contributor reported the power used and dimming level in each time interval as well as the rated power of the *pre*-retrofit fixture but not the *post*-retrofit fixture. To identify the rated power of each *post*-retrofit fixture, post-NLC power used was divided by the dimming level in each interval, generating many estimates of the post-retrofit rated power for each fixture. For each fixture, these estimates were averaged to calculate an assumed rated power without controls.
- **Standardize building and space types:** To create consistency in the reporting conventions, the reported building types and space types were mapped to those in the commonly used Database for Energy Efficient Resources[13] (DEER), aided by visual analysis of the lighting energy interval data and total zone power where necessary. Consistent reporting will play an important role in future data collection, and it is recommended that building types are standardized to facilitate future data collection and analysis. For a detailed example of building and space type standardization, see Appendix E.

DATA AGGREGATION INTO THE NLC DATABASE

For each dataset, scripts were used to map normalized project data into fields in the NLC database. This included two overarching data types, each collected at the fixture-, zone- and/or building-level:

- **Static attributes – fixed attributes of the building, zone, or fixture.** For example, rated power and space type are fixed attributes of a zone or fixture. Geographic location, building type, gross floor area, and NLC system installed are examples of fixed attributes of a building. The reported baseline operating hours were almost always reported at the building level.
- **Time series data – interval data with lighting energy use and other time-varying attributes.** Contributors typically provided average power during each interval (at the fixture- or zone-level); however, some provided average

[13] The Database for Energy Efficiency Resource (DEER) is a directory of energy efficient technologies and their associated savings estimates and usage assumptions. (http://www.deeresources.com/). In the future, it is recommended that building and space types be standardized using national formats such as the Building Energy Data Exchange Specification (BEDES), which provides a comprehensive dictionary of common terms and definitions to enhance the continuity and effectiveness of energy efficiency related programs, policy and investments. (https://bedes.lbl.gov/)

dimming level in each interval which was combined with power-dimming curve data or an assumed linear relationship between dimming level and energy use.

The database has a hierarchical structure of fixture, zone, and building IDs that enables linkage between static attributes and time series data and across spatial scales. Because data is mapped to space types and building types, it can be rolled up from:

- Individual fixtures to individual zones
- Individual zones to all zones of the same space type in a building
- Space types in a building to the individual building
- Individual buildings to all buildings of the same building type

The primary function of the database with respect to this report is to generate savings estimates by building type, but its structure allows for a wide array of custom queries. For example, the database could be queried for savings within a specific geographic region, within certain hours of the day, or relative to other baselines. **Figure 11** represents the process of assimilating diverse datasets into the database, provides examples of database fields grouped by spatial scale and whether they change over time, and highlights the primary outputs of the database.

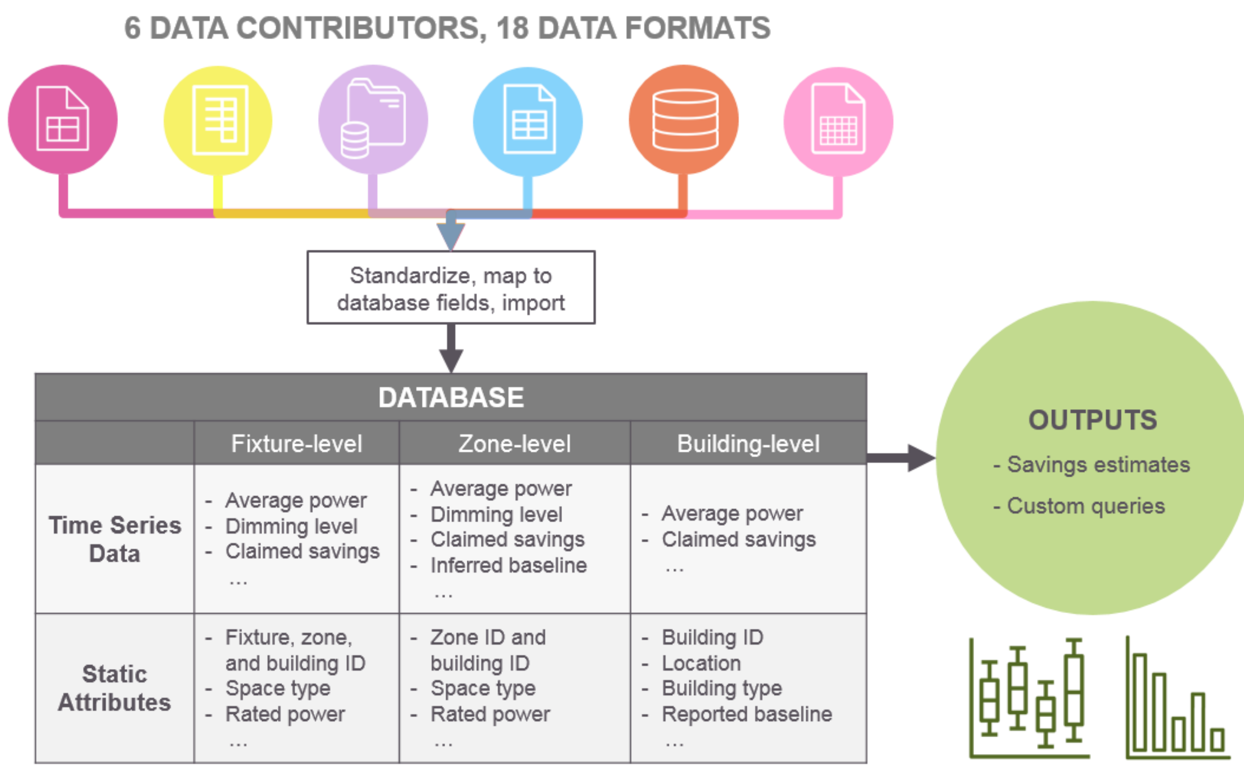


Figure 11. Diagram of data assimilation in the database, example database fields, and resulting outputs.

CALCULATING BASELINES AND ENERGY SAVINGS

CONTROL FACTOR DEFINITION AND CALCULATION

All results were calculated and presented in terms of a Control Factor (CF), defined as the fractional energy savings directly attributable to NLC systems. This does not include any increases in luminous efficacy of the light sources due to retrofits. **Equation 1** describes the general formula for a control factor: the control factor of an NLC system relative to a given baseline is equal to the change in energy use from baseline to the NLC system normalized to the baseline energy use.

Equation 1: $$CF_{NLC,Baseline} = \frac{Energy_{\,Baseline} - Energy_{\,Post-NLC}}{Energy_{\,Baseline}}$$

Where:

$CF_{NLC,Baseline}$ is the control factor of the NLC system, relative to some baseline;
$Energy_{\,NLC}$ is the post-NLC lighting energy use during the collection period; and
$Energy_{\,Baseline}$ is the estimated baseline lighting energy use during the collection period.

BASELINE SELECTION

Calculations of control factors and energy savings are highly dependent on baseline operating assumptions, which can be determined in several ways. Four potential methods were identified to estimate baseline energy use, as outlined in **Table 4**. These include:

- **Post-NLC "listening" mode**: The NLC system collects baseline operation data during a "listening" period in which the system monitors energy consumption and occupancy but does not implement control strategies. While this is optimal to capture "business as usual" operational behavior, it is not feasible for most projects because of the implications on additional commissioning efforts and delay in code compliance tests, if required.
- **Pre-NLC audit or interview**: This approach relies on expert interview to establish baseline hours of operation. While it provides a project-specific baseline, a pre-NLC audit or interview has several disadvantages. On-site observers are very unlikely to be able to accurately estimate hours of operation at the level of space type or even zone, which becomes the limiting factor for the granularity of savings calculations. Furthermore, on-site observers cannot precisely quantify the effect of personal control or occupancy controls on the energy use of a space. Baselines reported in this way function best for buildings with coarse, simple controls, such as facilities that are always on[14] or have a

[14] For several buildings in the dataset the data contributors reported that the baseline operation was that the lights were always on due to malfunctioning controls.

fixed, building-level schedule. Audit or interview data can also be used as a validation check when inferring hours of operation from monitoring data.

- **Deemed hours baseline**: In the deemed hours approach, the post-NLC energy use is compared to the energy the lights would have consumed if they were operating at maximum light output for the hours that are typical of that space or building type. Typical hours are calculated by normalizing the annual deemed hours for that space or building type (e.g., as listed in the relevant Technical Resource Manual) to the duration of the NLC lighting energy collection period. A chief drawback of this approach is that it is not project-specific, and tends to over-or under estimate savings relative to the actual hours of operation. For example, if an NLC system is installed in a building with unusually long operating hours, the post-NLC data would have significantly longer hours than the baseline and this approach would yield a negative savings estimate.
- **Post-NLC inference method:** This method describes any baselining approach in which data from the NLC system is used to infer the baseline energy use. The simplest version of a post-NLC inference method is to use post-NLC energy use in each time interval as a proxy for occupancy and then apply a pair of assumptions about the baseline energy use during occupied and unoccupied hours

Ultimately, the post-NLC inference method was selected[15] to calculate savings because it is:

- Unobtrusive (unlike post-NLC listening)
- Yields spatially and temporally granular baseline assumptions (unlike pre-NLC audits or interviews)
- Project-specific (unlike deemed hours)
- Can be systematically scaled across many buildings once the data is in a common format.

While the inferred baseline was selected for the present analysis, the database is built with the requisite fields, inputs, and calculations to also output control factors relative to a reported or deemed annual hours assumptions (i.e., approaches 2 and 3).

[15] This approach was vetted with three technical experts who had experience in NLC operation, installation, and baseline construction, who all agreed that it was the most practical and accurate way to establish a standardized method of estimating energy savings across multiple projects. This approach is also the calculation method used by some of the existing utility NLC programs in the US.

Table 4. Overview of potential baseline calculation methodologies (selected approach highlighted in green).

Approach	Data Collection Method	Description	Benefits	Drawbacks
Post-NLC "listening" period	NLC monitoring data	Post-NLC "listening" period (typically 2-4 weeks) that records energy consumption with control strategies disabled	• Likely to be the most accurate • Granular (across time and space)	• Not feasible for most projects • Assumes pre- and post-installation operational behavior are identical
Pre-NLC audit or interview	User Reported	Based on audit or interview data with someone familiar with operating hours	• Project-specific	• Often unavailable • Not granular (annual, whole-building) • Less reliable • Requires quantification
Default hours assumption	Default value, not site specific	Calculate savings relative to a deemed average hours of operation for the building or space type	• Easy • Scalable • Consistent with utility methods of determining hours of operation	• Not project-specific • The savings can be very unrealistic for a given building if it has unusually long or short operating hours
Post-NLC inference	NLC monitoring data	Leverage post-NLC monitoring data to estimate baseline hours of operation; assumes lights are on during occupied hours and no savings during unoccupied hours.	• Unobtrusive • Project-specific • Granular (across time and space) • Scalable	• Requires assumptions about baseline controls system (e.g., fully on during occupied hours)

INFERRED BASELINE METHODOLOGY

This section outlines the specific steps to calculate an inferred baseline using energy monitoring data pulled from the NLC system.

Zone-level energy consumption data reported by the NLC system was used to infer post-NLC occupied hours for each zone. It was assumed that in the baseline condition, each zone had the same occupied hours as were inferred from the post-NLC data but operated at its rated power. **Figure 12** provides a sample savings calculation relative to the inferred baseline for a single zone in a manufacturing facility for a week-long period. If the post-NLC average hourly power (gray) exceeds the "occupied threshold," the zone is assumed to be occupied. To define the occupied threshold, the post-NLC interval data is first normalized by removing any base load.[16] "Occupied hours" were defined as the hourly average power being greater than ten percent[17] of the zone's maximum power draw.[18] During occupied hours, baseline power draw was assumed to be equal to the rated power (which was either provided by the contributor or derived, as discussed above in the "Standardization of Data Formats" section).

As shown in **Figure 12**, the rated power may be substantially higher than the maximum measured power if the zone employs high-end trim. During unoccupied hours, it is assumed that baseline power draw was the same as the post-NLC power draw. In other words, it is assumed that any ancillary lighting services (such as security and emergency lighting) that use energy during unoccupied hours were also present in the baseline and thus no savings are achieved during unoccupied times. The inferred savings (green) are simply the difference between inferred baseline energy use and post-NLC energy use during occupied hours.

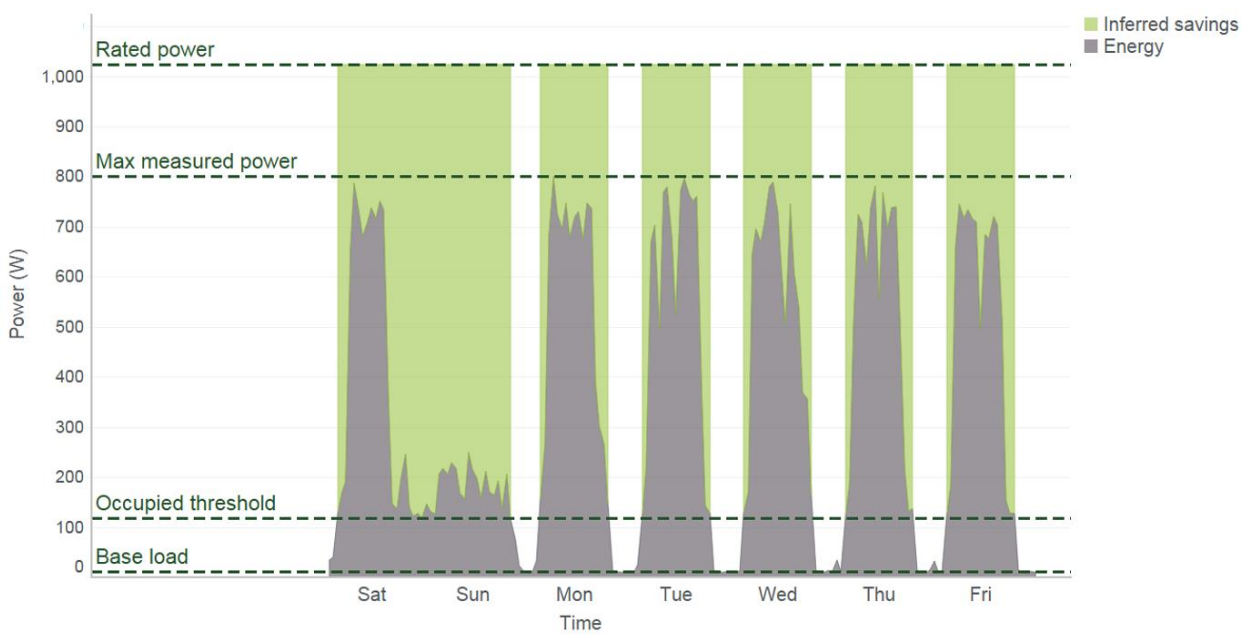


Figure 12. Sample savings calculation relative to an inferred baseline.

After calculating the inferred baseline and savings for each zone in a building, savings can be aggregated across zones or, if space type is known, across all zones of the same space type within a building. At a minimum, savings can be aggregated across all zones

[16] Base load was defined as the 10th percentile of post-NLC average power draw in a zone, when analyzed on an hourly basis. This definition captures the lights that are almost always on in a zone and therefore do not give information about occupancy. Although most zones had minimal or no base load, it was important to remove base load for some zones otherwise the algorithm would assume constant occupancy.

[17] For an analysis of how the savings depend on the choice of this parameter, see Appendix C.

[18] Maximum power draw for each zone was defined as the 98th percentile of power draw attained by that zone during the entire collection period. This is functionally a measure of the highest power draw, excluding outliers due to measurement error.

to calculate building-level savings. **Figure 13** shows an example of the inferred baseline algorithm being applied to each zone within an office individually and then aggregated to the building-level.

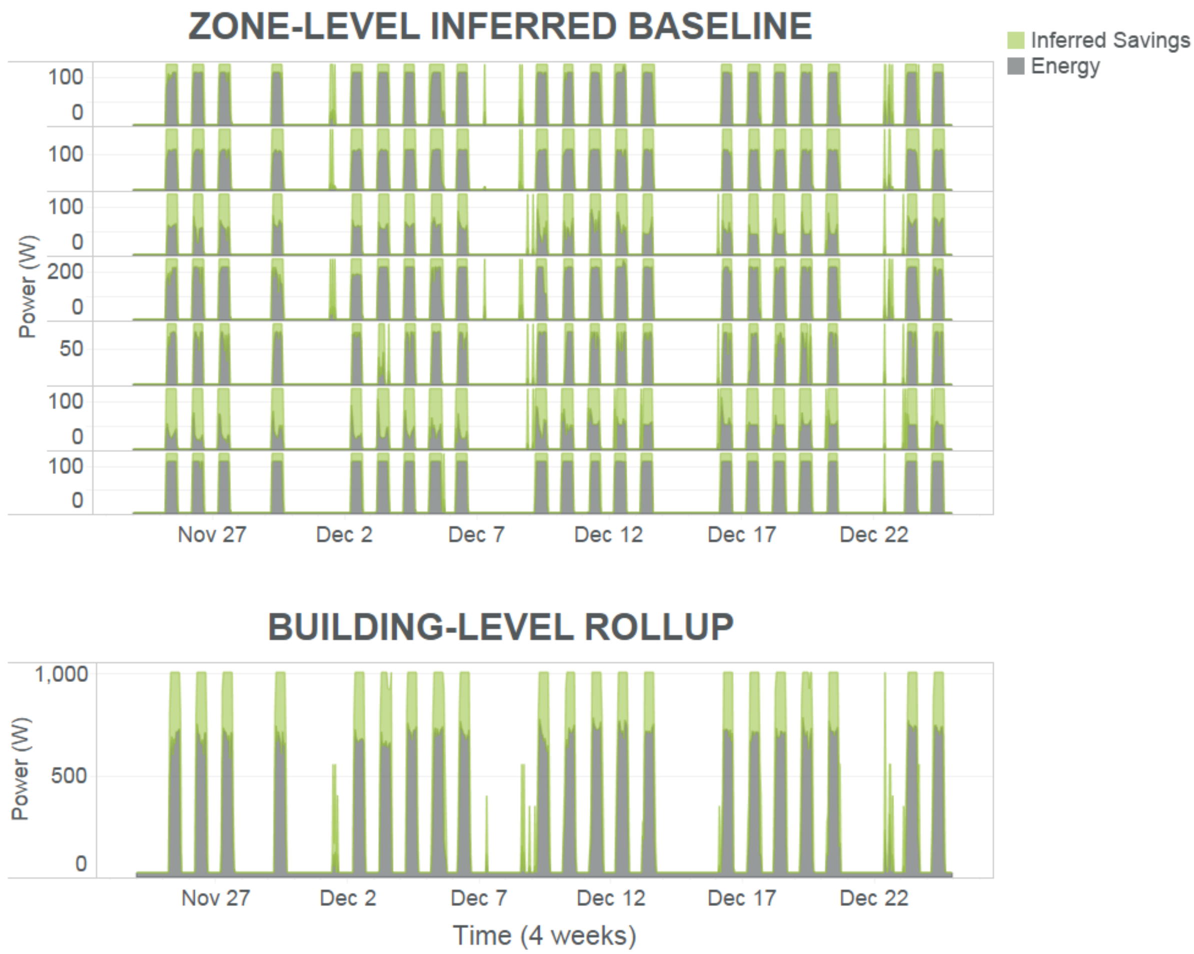


Figure 13. Baseline energy use is inferred at a zone level but can be rolled up to calculate building-level savings. This figure presents seven zones within a building as well as the aggregated profile across the entire building.

Using a zone-based roll-up approach is far more representative of actual building lighting usage than treating a building as one single zone, which is unrealistic and would overestimate savings.

There are two key caveats to this approach: (1) it removes all energy savings occurring during non-occupied hours which may be substantial;[19] and (2) it does not account for existing controls that may have reduced building energy use during occupied times, such as building occupants manually switching lights off. These caveats create opposite sources of bias. Whether they tend to create a net under- or overestimate of savings

[19] Based on conversations with controls manufacturers across lighting, HVAC, and plug load end uses, anecdotal evidence from manufacturers suggests that a substantial portion of energy savings occur due to unintended equipment operation, such as schedules being overridden or cancelled and not set up again and occupants leaving lights on all night.

depends on the details of the baseline controls system, which were rarely included in the data. To the extent that the true baseline had unnecessarily long scheduled hours of operation, this inference method will underestimate savings. To the extent that the true baseline had existing occupancy and daylight sensors or active use of personal controls such as wall switches, this inference method may overestimate savings.

QUALITY CONTROL PROCEDURES

To ensure that the underlying data supporting the control factor calculations was robust and the inferred baseline was reasonable, the following analytical filters were applied. To be included in the final analysis, all buildings had to:

- Have a defined building type
- Use a DLC qualified system
- Report energy monitoring data reported at the fixture or zone level (rather than a building level)
- Include a minimum of two weeks of monitoring data
- Contain no data gaps or anomalies upon visual inspection[20]

All zones and buildings that did not meet the quality control criteria were removed from the dataset. While 212 buildings were initially collected, 98 were ultimately removed from the analysis because they did not pass one or more of these criteria.

[20] Over 1,400 zones were reviewed to identify data gaps, measurements errors, or other anomalies. The time series of both the post-NLC energy use and the inferred baseline were analyzed for errors or anomalies, visually checking to see whether the inference method was defining occupied hours in an intuitive manner.

RESULTS AND DISCUSSION

The following sections provide an overview of findings, a discussion of how these results can be applied to utility incentive program design, and comparisons to previous research.

APPLICATION OF RESULTS

This study provides grounding in the current state of NLC energy monitoring, including data availability, data quality, and analysis across a portfolio of NLC projects. It also identifies important next steps in standardization, aggregation, and data handling to enhance results in support of greater utility and market participation. There are two key applications of the results to both utility program design and evaluation and the broader industry:

1. **Establishing average energy savings from NLC systems**
   Because the buildings included in this study were not identified through a random sample, it is not possible to make statistical inferences about a broader building stock or the drivers of NLC savings in buildings. However, this represents a largest-to-date sample size of 114 buildings across five manufacturers and seven building types. Energy savings vary widely by individual site, and thus utility program managers should treat the average values found below as a best estimate of what a portfolio of projects might achieve, rather than an individual building.
2. **Establishing consistent data reporting guidelines**
   It is recommended that all NLC utility energy efficiency programs include project reporting of energy monitoring as part of their programs, either as an explicit program requirement or as an optional program element with incentives for sharing data. This will increase the overall sample size of projects with monitoring data, enabling deeper understanding of the building variables correlated with high energy savings. It is recommended that utilities consider adopting standardized data reporting guidelines, as outlined in Appendix A.

ESTIMATED SAVINGS BY BUILDING AND SPACE TYPE

SAVINGS BY BUILDING TYPE:

Overall, the results indicate an average control factor of 0.47 across 114 buildings, with a tremendous variation across individual buildings ranging from 0.02 to 0.91 as shown in **Figure 14**. This wide variation indicates that DLC NLC-qualified products can achieve extremely high energy savings but are not guaranteed to do so. As discussed in the section "Major Drivers of NLC Energy Savings," the existing literature suggests that savings are highly dependent on site characteristics, occupancy patterns, which control strategies are enabled, and how control settings are configured.

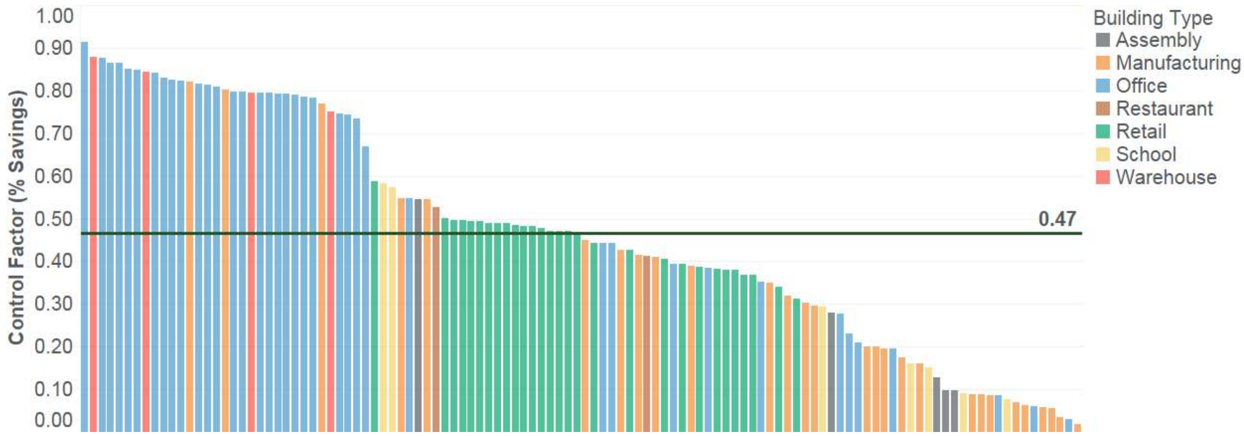


Figure 14. Distribution of NLC savings across all buildings analyzed (n=114).

Figure 14 indicates some patterns of building types within the largest, smallest, and mid-range savings. The largest savings were generally found in warehouses, office buildings, and manufacturing/industrial facilities ("manufacturing"); however, some of the lowest savings were also found in the office and manufacturing building types. Savings in big box retail buildings ("retail") were consistenty clustered in the mid-range of the distribution. The consistency of savings in retail applications can most likely be explained by homogeneity of the retail buildings in the dataset: all 29 retail buildings represent a single NLC manufacturer's product and one customer.

Average savings by building type ranged from 0.23 in the assembly to 0.82 in the warehouse building type. Consistent with previous studies (Williams et al. 2011; Asif ul Haq et al. 2014), there was significant variability in energy savings within each building type. **Figure 15** shows the distribution of control factors by building type, while **Table 5** includes additional information about the sample size, number of manufacturers represented, and values for the interquartile range (i.e., the 25th and 75th percentiles).

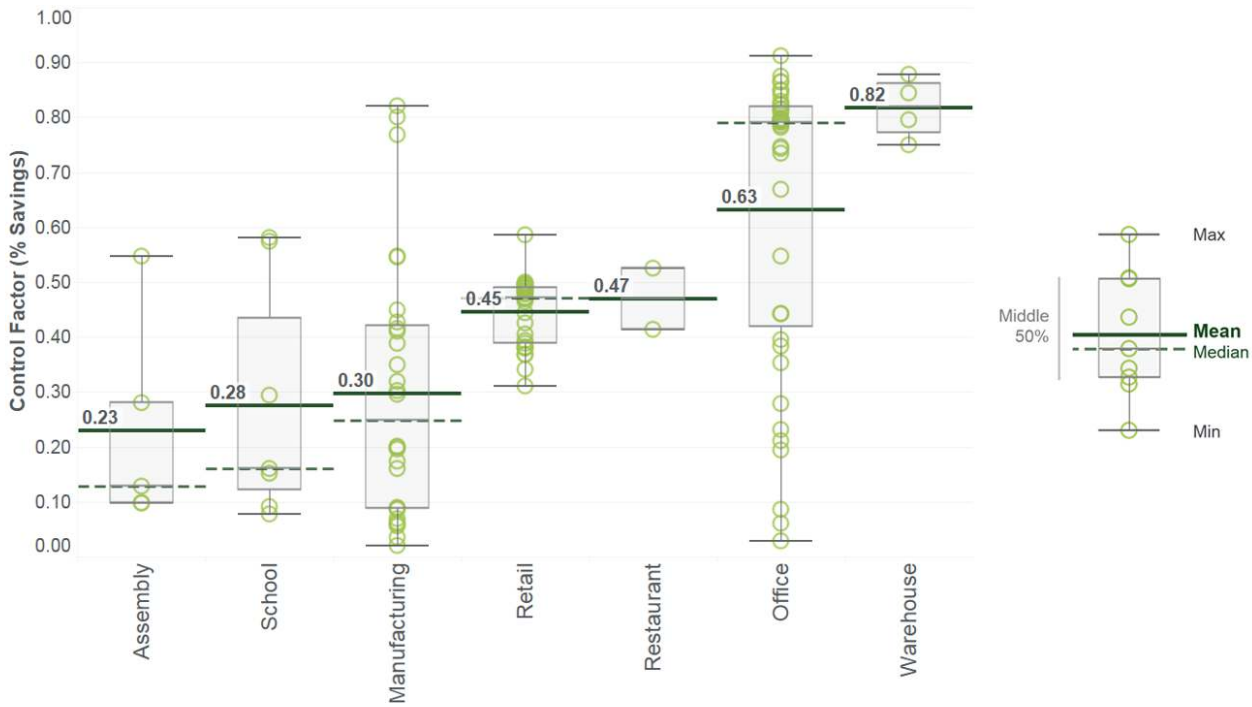


Figure 15. Box and whisker plot of control factor by building type relative to an inferred baseline. Each circle represents a building, while the box shows the interquartile range (25^{th}-75^{th} percentile). Whiskers extend to the minimum and maximum values. The solid horizontal line is the average (mean), while the dashed line is the median.

Table 5. Summary of inferred NLC savings by building type results.

Building Type	Total Buildings	Unique Manufacturers	Control Factor (% savings)	
			Average	25^{th} - 75^{th} percentile
Assembly	5	1	0.23	0.10 - 0.29
School	7	1	0.28	0.09 - 0.57
Manufacturing	28	3	0.30	0.09 - 0.43
Retail	29	1	0.44	0.39 - 0.49
Restaurant	2	1	0.47	0.41 - 0.53
Office	39	3	0.63	0.43 - 0.82
Warehouse	4	2	0.82	0.78 - 0.85
Overall	114	5	0.47	0.28- 0.76

The highest savings are found in warehouses, albeit with a small sample size (n=4). Despite the small sample size, the result is generally consistent with previous findings that manufacturing and warehouse have some of the highest potential savings opportunities (Bisbee 2014). The largest spread of control factors was within office, which had an average control factor of 0.63 but a spread of 0.03 to 0.91. Manufacturing had a similarly large spread, with an average of 0.30 but a spread of 0.02 to 0.82. This wide distribution in manufacturing and office is likely due to the variance in how controls are implemented at each site. In a number of facilities with low savings it appears—based on visual analysis of the time series data—that the NLC system is acting primarily as a scheduling control without occupancy or high end-trim enabled, minimizing energy savings. High outliers may represent the potential of NLC when implemented with multiple strategies, aggressive settings (e.g., short time outs), beneficial site characteristics (e.g., good natural lighting), occupancy patterns, and/or user behavior. In the highest performing sites, a combination of aggressive high-end trim and occupancy sensing were likely the major factors contributing to the high savings results.[21] In particular, the cluster of office buildings with higher savings that is evident in **Figure 15** tend to have much more aggressive high-end trim levels than the cluster of office buildings with lower savings (based on analysis of the time series data). Morever, the cluster with higher savings are controlled at the fixture level, which may contribute to higher savings, as discussed in the section "Comparison of Fixture- and Zone-Level Controls" below.

SAVINGS BY SPACE TYPE:

In theory, space types should show less variance than building types, as occupancy patterns tend to be more similar within space types than within building types. Daylighting may also play a greater overall role in specific space types than an entire building (e.g., a private office typically has more windows and day-lit space than an open office or restroom). As shown in **Figure 16** and **Table 6** below, savings by space type do vary less than savings by building type, but this is also due in part to the increased homogeneity of the buildings that had space type data. As shown in **Table 6**, most space types represent only a single manufacturer and in many cases a single building.

Savings by office space type

Savings by space type in offices tend to be higher than average savings for all offices (63%). This is because the office buildings that had space type data generally came from the higher-savings cluster of office buildings visible in **Figure 15**. As previously discussed, one factor that contributed to the high savings for these buildings is their aggressive high-end trim settings.

A trend that is evident in **Figure 16** is that office space types with less occupied time tend to have higher savings. For example, storage and restroom space types had consistently high savings (86% on average for both space types), private office had intermediate average savings (75%), and open office had the lowest average savings

[21] High-end trim values of 30-60% in office environments are fairly common depending on employee preferences. In many office lighting retrofits, the base case fixtures such as parabolic troffers have poor luminaire efficiency. Occupants accustomed to the previous low light levels (well below IES guidelines) often request significant reductions in light output, even if fixtures are specified to meet IES guidelines and the space is not technically over lit.

(63%, which is still quite high in absolute terms likely due to aggressive high-end trim settings).

Savings by space type in warehouse, manufacturing and retail

The small sample size for warehouse and manufacturing limit the broader applicability of these findings, however, the findings are similar to those in office buildings: space types with less occupied time appear to be ideal for maximizing NLC savings.

The savings results for retail space types run contrary to the trend for office, warehouse and manufacturing, with retail sales saving more than stock room even though retail sales tends to be a higher occupancy space type. This could be because in the highly homogenous sample of retail buildings in the dataset (29 buildings from a single customer) the retail sales floor is generally daylit and the NLC system employs some daylight harvesting.

Figure 16. Control factor by space type relative to an inferred baseline. Each dot represents all the zones of a given space type in an individual building (e.g., each dot for private office represents the weighted average of all private offices within a single building). Lines represent the mean savings for a given space type across all buildings.

Table 6. Summary of inferred NLC savings by space type results.

Building Type	Space Type	Total Buildings	Unique Manufacturers	Control Factor (% savings)	
				Average	25th - 75th Percentile
Office	Open office	5	2	0.63	0.38 - 0.81
	Entrance	1	1	0.73	-
	Private office	11	2	0.75	0.74 - 0.85
	Hallway	11	2	0.76	0.77 - 0.85
	Break	5	1	0.82	0.79 - 0.84
	Storage	9	1	0.86	0.81 - 0.91
	Restroom	10	1	0.86	0.84 - 0.87
	Conference	1	1	0.90	-
Warehouse	Office	1	1	0.59	-
	Warehouse	1	1	0.79	-
Manufacturing	Break	1	1	0.36	-
	Work	1	1	0.38	-
Retail	Office	1	1	0.46	-
	Stock room	1	1	0.53	-
	Rest room	1	1	0.76	-
	Stock room	29	1	0.28	0.27 - 0.30
	Retail sales	29	1	0.36	0.31 - 0.43

COMPARISON OF FIXTURE- AND ZONE-LEVEL CONTROLS

Compared to zone-level controls, fixture-level controls (also known as luminaire-level lighting controls or LLLC) provide a higher level of granularity for control strategies to be implemented. In some situations, this can potentially lead to a higher degree of savings by refining operational profiles at the individual fixture level.

A preliminary savings analysis of the two identified that, on average, fixture-level controls appear to save more energy than zone-level controls. However, there are several confounding factors that limit the ability to draw generalized conclusions about fixture-level vs. zone-level controls. Chiefly, (1) there is no overlap between the NLC manufacturers represented in the fixture-level and zone-level categories, making comparisons difficult, and (2) the two categories comprise a very different mix of building types. In a future study with a larger dataset, it is recommended to statistically control for confounding factors to isolate the effect of fixture-level controls as compared to zone-level controls.

COMPARISON TO PREVIOUS RESEARCH

This section compares this study's findings to previous research and identifies key factors that may contribute to observed differences.

COMPARISON TO CASE STUDIES OF THE BUILDINGS WITHIN THE DATASET

As part of the sample of building data received, data was obtained for three sites from contributors that had already been studied as part of an independent analysis with detailed pre-retrofit baseline information. Using this data, the "inferred baseline" results for these three sites were compared to those calculated separately by independent consultants. **Table 7** provides a comparison of the results found in this study and the previous independent analyses.

Table 7. Savings from inferred baseline approach compared to independent analysis.

SITE ID	BUILDING TYPE	INFERRED BASELINE	INDEPENDENT ANALYSIS
1	Manufacturing	40%	32%
2	Office	38%	32%
3	Office	39%	9%

For sites 1 and 2, the values found in this study were similar, but slightly higher. For site 3, the savings value from this study was substantially higher than that measured onsite. The variance is likely due to differences in assumptions and methodology: the inferred baseline used in this study assumes 100% rated power during occupied hours, whereas the buildings at these sites had some incumbent controls operating prior to the installation of NLC systems. For example, site 2 had occupancy controls in many areas and personal controls in the private offices already. Similarly, site 3 used especially advanced control strategies prior to NLC installation, which was cited by the independent consultants as a reason for lower than expected savings; many fixtures were already controlled by occupancy sensors and scheduling controls that performed an evening sweep to turn off any lights left on.

Due to the small sample size of these independent analyses, the results were not used to make any calibrations to the model since the majority (68%) of commercial buildings do not have existing controls (DOE 2016). Further updates to the model may occur as more data from third-party-validated onsite evaluation becomes available.

COMPARISON OF AVERAGE SAVINGS TO PREVIOUS STUDIES

While there are many single-site case studies for lighting controls savings, there have been very few large-scale analyses conducted across multiple buildings and building types. Most comprehensive studies are therefore meta-analyses of smaller individual evaluations. Two of these broader studies include DOE 2017 and Williams et al. 2011.

DOE 2017 developed energy savings estimates for connected lighting as part of a broader effort to forecast adoption of LEDs and connected lighting. Although the study did not estimate overall savings on a per building basis, controls savings associated with interior fixture types ranged from 62% to 71%. Linear fixtures, which comprise the vast majority of the installed base in commercial buildings, were estimated to have 63% savings when integrated with connected controls (DOE 2017). This is consistent with the average for commercial offices found in this study. With the exception of office and warehouse, the estimates from DOE 2017 are generally somewhat higher than the averages found in this study. This likely reflects the difference between potential and actual savings achieved, due to the wide range of site characteristics and varying levels of control strategies implemented.

Another major analysis of lighting control energy savings is a 2011 meta-analysis of lighting controls studies conducted by researchers at LBNL (Williams et al. 2011), based on 240 savings estimates from 88 papers and case studies from 1982 to 2011. Figure 17 provides a summary of findings from Williams et al. 2011 by control strategy as compared to the results from this study, as well as the sample size by building type.

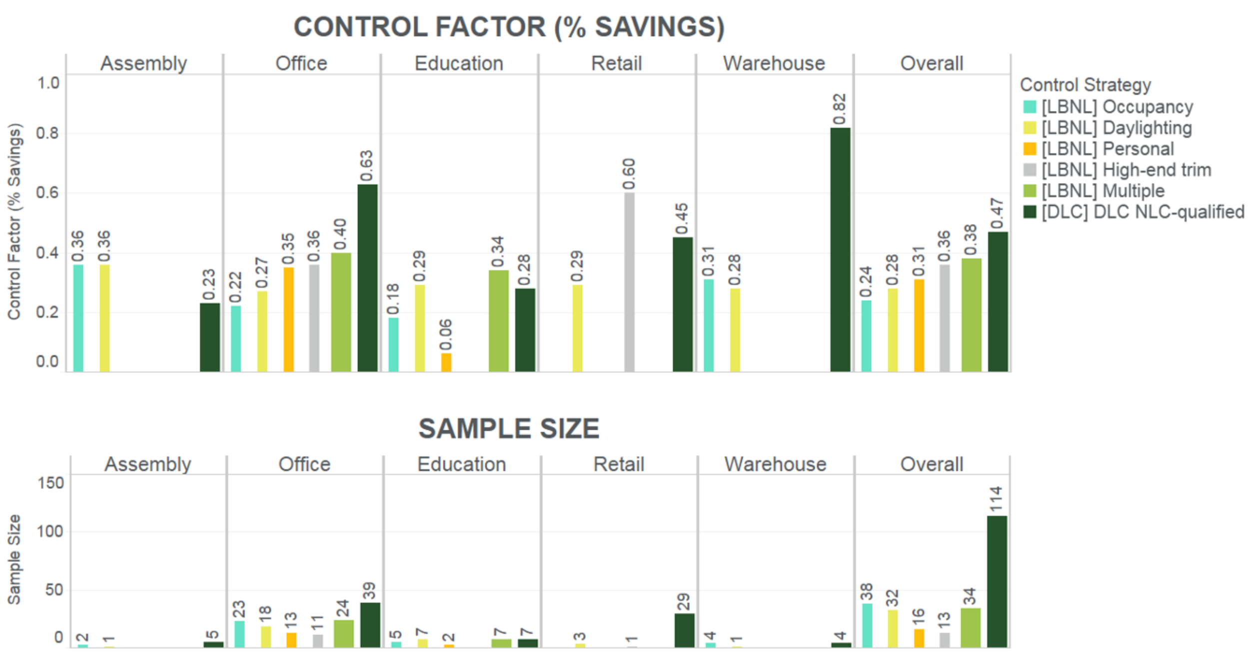


Figure 17. Comparison of % savings values for all control strategies from the LBNL meta-analysis with this study, including sample size. The LBNL meta-analysis did not include a manufacturing building type.

Whereas the present study found an average savings of 47% across all buildings, Williams et al. 2011 found average savings of 38% for buildings with multiple control strategies enabled. There are two main categories of likely explanations for the differences in findings between the two studies, namely:

- **Differences in baseline methodology:** Because Williams et al. 2011 was a meta-analysis, there was no simple way to accurately control for the baseline without significantly decreasing the study's sample size. For example, some savings values were calculated relative to core hours while others were based on a 24/7 baseline. In contrast, the baseline calculations in this study are standardized but hypothetical. They assume the lights were on 100% during the post-NLC occupied hours, and controlled at the zone level in the baseline. To the extent that the LBNL meta-analysis includes savings values relative to a 24/7 baseline, it will tend to overestimate savings compared to this study's methodology. To the extent that the LBNL meta-analysis includes savings that are discounted for occupancy sensors and personal controls in the baseline, this study will tend to estimate higher savings due to methodological differences.
- **Differences in the installed controls technologies:** The other main factor that could explain differences between the LBNL meta-analysis and this study are the types of control systems being studied. This can be further divided into differences in vintage (the present study analyzes newer systems) and the criteria used to include systems in the study.
    - **Vintage of the lighting controls systems:** The controls installations in the LBNL meta-analysis were installed from 1982 to 2011 and therefore a number of advances in lighting controls technology are not reflected in their findings. Chiefly, the installations analyzed in Williams et al. 2011 are less likely to use LED fixtures, high-end trim, fixture-level controls, or user interfaces.[22] All of these differences would explain why this study found higher average savings (and higher maximum savings) than the LBNL meta-anlaysis.
    - **"Multiple" control strategies vs. "DLC NLC-qualified"**: In the LBNL meta-analysis, the term "multiple" means that multiple strategies were confirmed to be in use—most often "occupancy and personal control" or "occupancy and daylighting". In this study's dataset, the criteria for inclusion is that the control system is a DLC NLC qualified product. This means that all systems are capable of implementing multiple strategies (defined in **Table 2**), but there is no guarantee as to which control strategies are enabled. This difference in inclusion criteria may explain why this study has both lower minimum and higher maximum savings values than the "multiple" category of the LBNL meta-analysis.

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[22] Although LED fixtures do not directly contribute to lighting controls savings, they allow for continuous dimming, which makes it easier to optimize light levels, and their form factors enable more uniform light distribution, which allows occupants to see equally well with less light output.

Although the LBNL meta-analysis draws on 34 buildings to derive the "multiple" savings estimate and this study analyzes 114 buildings, neither the LBNL meta-analysis nor this study collected data through random sampling. This limitation of both studies could partially explain the differences in findings, because results can be skewed by the studies that were available for meta-analysis and the buildings that were volunteered for this study. In future iterations of this study, the savings estimates will become more representative of the overall building stock as the size of the dataset grows.

PROJECT FINDINGS AND RECOMMENDATIONS

This project reflects an important step of moving from generalized engineering calculations to a building-specific, data-driven approach to estimating energy savings. There is significant opportunity to build on this analysis and further develop the dataset and insights that can be derived from it. This section provides key findings to inform the continued growth of the NLC industry and utility programs, as well as recommendations for improving how NLC monitoring data is collected and analyzed.

Finding #1: Energy savings are highly site-specific, and there is not a clear correlation between building type and energy savings due to NLCs.

With the possible exception of warehouse and assembly, there is not a clear correlation between energy savings and building type. Site-specific variation is a much larger driver than general factors such as building type.

The variation is likely due to the following factors:

- **NLC system commissioning and identifying which control strategies are actually used.** Some sites appear to implement aggressive high-end trim and optimize their control strategies to achieve deep savings, while others may be using the systems in a more basic manner. For example, visual analysis of load profiles during the quality control process suggested that many sites with lower savings are simply using NLC as a zone-level scheduling control with high-end trim, and not implementing other energy-saving control stragies. For these sites, the hourly average power is consistently either zero or the maximum measured power, without dips in average power due to occupancy, personal control, or daylighting. This suggests that these energy-saving capabilities were not activated. Any savings derived from zone-level scheduling controls are not accounted for in this analysis due to a lack of pre-NLC baseline data.
- **High variation in settings for the strategies that are used.** There is likely significant differentiation in occupancy timeouts or settings such as auto-on versus manual-on. However, there is not sufficiently granular data to help determine which settings play a primary role in driving lighting efficiency.
- **Variation in site characteristics, occupancy patterns, and user behavior.** The degree of available daylight, occupancy patterns, and individual users' tendencies to turn off the lights when not present all have major impacts on energy savings (Asif ul Haq et al. 2014). To date, such factors generally cannot be accurately compared across buildings, as they are not easily recorded or measured.

A better understanding of the causal factors that influence energy savings is an important consideration for future study. This will require a significantly larger dataset and collection of additional site information, which is feasible if utility NLC programs begin collecting this data in a standardized fashion.

Finding #2: In this study, buildings with NLC systems have significantly longer hours than typical prescribed estimates of building operating hours. However, further study and a larger sample size are required to confirm.

The average occupied hours for buildings in this study's dataset are substantially longer than the average lighting system operating hours assumed by many utility efficiency programs throughout the US in their Technical Reference Manuals (TRMs). **Figure 18** compares hours found in this study and operating hours for fixtures across several TRMs, including California, Illinois, New York and the Mid-Atlantic region.

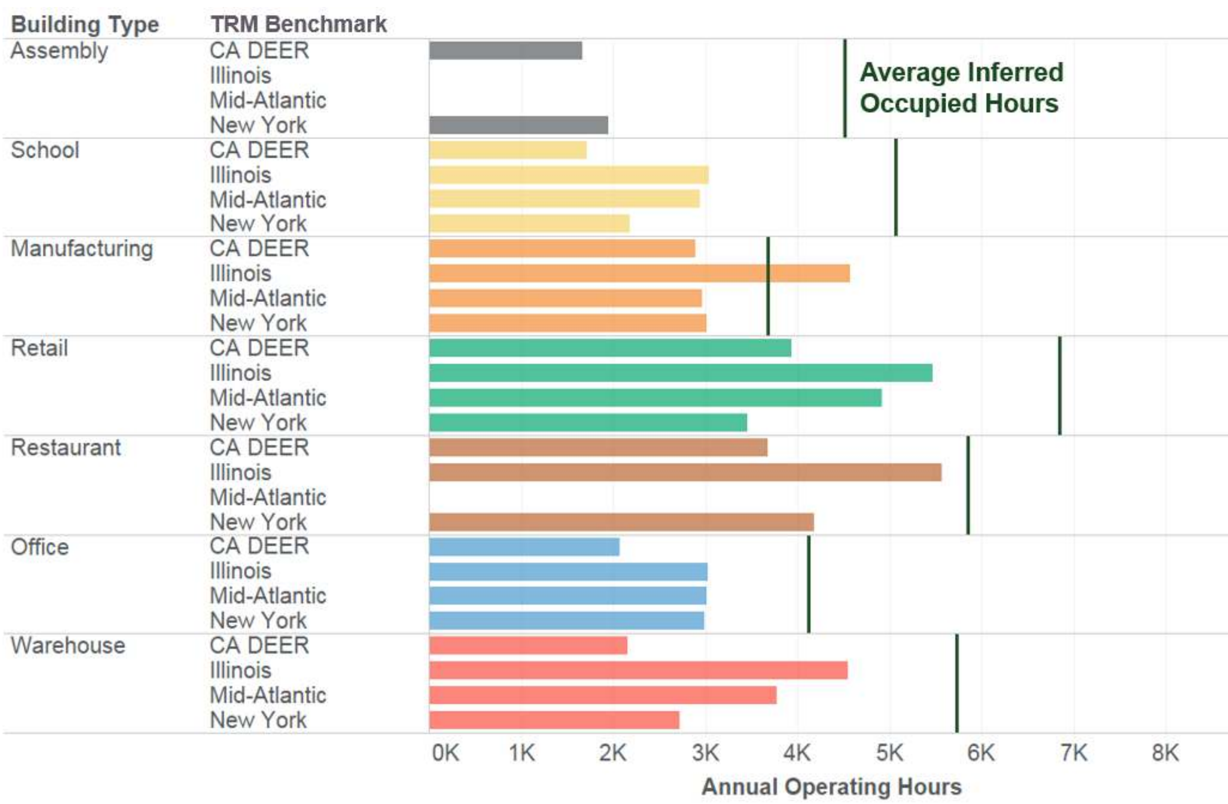

Figure 18. Comparison of occupied hours and sample deemed TRM operating hours.

The discrepancy between hours calculated in this study and TRM assumptions could be due to one or both of the following reasons:

- Buildings with longer core hours are more likely to implement NLC sysytems because of the stronger value proposition associated with longer operating hours.

- The methodology of this study might have a systematic bias, although a systematic underestimate of operating hours appears more likely than an overestimate.
    - The method likely underestimates baseline hours when the lights are on. This is because it only accounts for actual detected presence and does not consider the possibility of unnecessarily long lighting schedules where time clocks turn the lights on well before or after occupants are in the building.
    - The method could overestimate baseline occupied hours, because occupancy and energy use are analyzed on an hourly basis. If the lights go on halfway through an hour, the average power draw during that hour will exceed the 10% threshold and that whole hour will be assumed to be on in the baseline. This approach gives some credit for scheduling and was based on discussion with industry experts. However, it is unlikely that this is a major driver of the observed differences in operating hours, as work schedules tend to start and end on the hour, so the potential for overestimating hours in this manner is relatively low.

The large discrepancy between observed hours and operating hours found in TRMs may result in lower overall savings for projects using deemed operating hours. This highlights the potential pitfalls of using deemed operating hours for NLCs, although this observation requires further study to confirm.

Finding #3: Data authorization approval must be streamlined to facilitate data collection for future projects.

Although the manufacturers and utility programs have an installed base of thousands of sites, obtaining authorization for receipt of anonymized data was a major obstacle to data collection. This broader data authorization barrier can be broken down into four specific issues:

- **Lack of existing customer authorization:** Of all the utilities and manufacturers that were contacted for this study, only three organizations had pre-existing data authorization agreements in place that enabled them to share anonymized data. This was the single largest impediment to data collection at scale. Having a customer authorization agreement in place would likely address all resulting barriers.
- **Lack of bandwidth to obtain retroactive authorization for multiple sites:** While many manufacturers were interested in providing data, the effort required to retroactively obtain authorization from customers for many sites was often too time-intensive to consider and greatly diminished the number of sites for which a manufacturer could provide data. For future sites, obtaining customer authorization at the time of purchase would likely be more resource-efficient.

- **Lack of existing relationship with customers:** Without an existing agreement in place, retroactively obtaining approval was challenging in a variety of ways, for example: (1) some utilities had implemented programs but no longer had existing relationships with customers; (2) some manufacturers sold their systems through a supply chain and did not have direct contact with the end-customer.
- **Lack of remote data access:** In some cases, the system was independently hosted onsite on a customer's server, and the manufacturer was unable or unwilling to contact them. To access onsite data requires a facility or IT manager with the expertise and time to export the data. This remains a significant barrier to accessing this portion of existing and future NLC installations. This could potentially be addressed with the development of utility-specific reporting functionality that any user could run from the controls interface.

Finding #4: Most manufacturers do not have an existing mechanism to easily export the data required for utility program evaluation.

Reporting functionality for existing customers does not have the level of granularity required for utility evaluation. Thus, nearly all organizations had challenges exporting data in the appropriate format. Existing manufacturer reports focus on delivering insight to building owners and facility managers, both of whom have data reporting needs and interests that are different from those of a utility. Developing generalized reporting guidelines specifically for utility programs could significantly streamline the data normalization process by enabling scripted data transformations and formatting changes.

RECOMMENDATIONS AND NEXT STEPS

RECOMMENDATIONS

The following recommendations are provided to improve future data collection and further the industry's understanding of NLC performance:

Recommendation #1: Based on this dataset, the best estimate of average portfolio-level energy savings for utility NLC programs is 47%.

The portfolio-level average energy savings across all 114 buildings in this study was 47%. Because the buildings included in this study were not identified through a random sample, it is not possible to make statistical inferences about a broader building stock. However, 47% represents the average savings from NLC systems across five manufacturers, seven building types, and 114 buildings and is therefore the best available estimate of average NLC performance.

Recommendation #2: Utility NLC programs should consider requiring and/or incentivizing anonymized data sharing for all participating projects.

Going forward, utility NLC programs should strongly consider including clauses in their customer participation agreements that authorize the share of anonymized data. Anonymized data sharing is common in many software applications, and authorization is typically written into the usage terms and conditions or specifically requested during the installation process. It is recommended that utilities either (a) explicitly require reporting as part of receiving utility incentives, or (b) incentivize energy monitoring and data reporting by providing an additional per-kWh "adder" for data sharing. It is recommended that the initial year of program data collection be voluntary and incentivized while manufacturers, vendors, and utilities continue to refine both utility-focused reporting functionality and determine which party (manufacturers, vendors, or customers) ultimately provides the data to utilities.[23]

Recommendation #3: Manufacturers and vendors should support utility program reporting needs by incorporating data sharing authorization clauses and service-level agreements into their customer contracts.

Many manufacturers, vendors, and utilities also do not have existing data sharing authorization agreements in place with customers. Data reporting is a critical element of utility incentive programs, and it is recommended that manufacturers add clauses into their customer contracts to going forward to enable data sharing. Additionally, manufacturers and vendors should consider adding data authorization clauses into customer contracts and data sharing terms into service-level agreements (SLAs) that identify the parties responsible for providing data to utility programs.

Recommendation #4: Utility NLC programs should consider adopting a standardized reporting format to facilitate program participation and streamline the process. Based on these reporting guidelines, manufacturers should consider developing utility-specific reporting functionality that customers, vendors, or manufacturers can easily export.

There are no existing guidelines for how manufacturers, vendors, or customers should report data to utility programs, making it difficult and time-consuming to fulfill utility data requests. It is recommended that utilities adopt standardized reporting guidelines to facilitate data collection such as those provided in Appendix A. Based on such guidelines, manufacturers should consider developing automated, utility-specific reporting through which multiple system users, such as facility managers, vendors, or manufacturers, can easily generate reports.

[23] This is particularly true for NLC systems which are operated on-site without a cloud-based connection and for which manufacturers and vendors have little or no access to system data. This scenario would require building data to be pulled by a facility manager who may have limited familiarity with the NLC system and thus would require simplified reporting functionality.

Recommendation #5: Future data collection efforts should focus on increasing the sample size, monitoring duration, and building operational characteristics to identify drivers of best-in-class NLC performance.

NLC energy savings are highly site-specific. Future data collection efforts should focus on understanding how building characteristics and operational profiles affect energy savings. These findings can support the development of NLC program best practices and system configuration/operation recommendations to maximize energy savings. For example, there may be a relationship between building size and control factor, as larger spaces may have greater potential for occupancy savings. Similarly, business models such as Lighting-as-a-Service (LaaS) may be correlated with higher savings due to a third-party's financial interest being aligned with building performance. Developing these inferences requires a significantly larger dataset. However, streamlined data authorization and standardized reporting should significantly increase potential project sample size in the future.

ADOPT A BUILDING PORTFOLIO APPROACH	**IMPLEMENT DATA SHARING AGREEMENTS**	**ADOPT A STANDARDIZED FORMAT**	**COLLECT ADDITIONAL PROJECT DATA**
NLC energy savings vary by site, but across the portfolio of all buildings they were 47%	Utility NLC programs and manufacturers should support anonymized data sharing	Utility NLC programs and manufacturers should adopt a standardized reporting format	Increase sample size and collect more types of data for each NLC installation

Figure 19. Summary of report recommendations

NEXT STEPS

With additional funding, DLC hopes to conduct an update study in 2018 which will build on the findings, implement recommendations where possible, and expand the project sample size and data collection effort to develop a stronger understanding of the drivers of NLC savings in buildings, such as site occupancy patterns or controls settings such as the length of occupancy timeout delays. An expanded dataset could address some of these questions in the future, after product databases and sales contracts have been modified to support that goal (based on guidelines in Appendices A and B, respectively).

REFERENCES

Asif ul Haq, M., M. Hassan, H. Abdullah, H. Rahman, M. Abdullah, F. Hussin, D. Said. 2014. *A review on lighting control technologies in commercial buildings, their performance and affecting factors.* Renewable and Sustainable Energy Reviews. 33. 268-279. 10.1016/j.rser.2014.01.090. https://www.researchgate.net/publication/278663804_A_review_on_lighting_control_technologies_in_commercial_buildings_their_performance_and_affecting_factors

Bisbee, D. 2014. Advanced Lighting Controls: Winners and Losers. Presentation to Midwest Energy Solutions Conference. http://www.mwalliance.org/conference/sites/default/files/pdf/MES_2014_presentations_Bisbee.pdf

[DOE] Department of Energy. 2017. *Adoption of Lighting-Emitting Diodes in Common Lighting Applications.* Prepared by Navigant Consulting. https://energy.gov/eere/ssl/downloads/led-adoption-report

[DOE] Department of Energy. 2016. *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications.* Prepared by Navigant Consulting. https://energy.gov/eere/ssl/downloads/2016-ssl-forecast-report

[DLC] Design Lights Consortium. 2017. Networked Lighting Control System Technical Requirements. Version 2.0. Issued June 1, 2017. https://www.designlights.org/lighting-controls/qualify-a-system/technical-requirements/

[DLC] Design Lights Consortium. 2015. *DLC Advanced Lighting Technology Demonstration: Digital Lumens.* https://www.designlights.org/lighting-controls/case-studies/

Mutmansky, M., and S. Berkland. 2013. *Ace Hardware LED High-Bay Lighting and Controls Project.* Prepared for Pacific Gas & Electric Company. ET Project Number: ET12PGE3361. http://www.etcc-ca.com/reports/led-high-bay-lighting-and-controls-project http://www.etcc-ca.com/reports/led-high-bay-lighting-and-controls-project

Nordman, B. and I. Cheung. 2016. *Data Model Needs for Building Device Interoperation*. Lawrence Berkeley National Lab. https://drive.google.com/file/d/0B8B9XW6B7prlcDVPN1lweWF1UHM/view

Wei, J., F. Rubinstein, J. Shackelford, and A. Robinson. 2015. Wireless Advanced Lighting Controls Retrofit Demonstration. https://eta.lbl.gov/sites/default/files/publications/wireless_advanced_lighting_controls_retrofit_demo_final-508a.pdf

Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein, and E. Page. 2011. *A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings.* Lawrence Berkeley National Lab. https://eta.lbl.gov/publications/meta-analysis-energy-savings-lighting

APPENDIX A: DATA REPORTING GUIDELINES

This section provides guidance for networked lighting control (NLC) systems to report essential energy data to customers and quantify savings for utilities incentive program purposes. These guidelines can also help standardize reporting and reduce evaluation burden. They were created based on the reporting requirements necessary for the development of this report as well as other existing data reporting initiatives such as Nordman and Cheung 2016.

This guideline provides a reference for vendors and manufacturers to prepare NLC systems to report energy data independent of regions, utilities and programs. Specifiers can use this guideline to discuss with the project team and make an informed decision on whether to include energy reporting capability into a project specification (and access potential incentives associated with energy reporting).

Standardized data reporting supports both customers and utility programs in a number of ways:

- **Improves quantification of energy savings.** Better quantification of savings can lead to higher incentives for customers if hours of operation are significantly higher than assumed operating hours in utility TRMs. For utilities, this increases the energy savings they are able to claim.
- **Monitoring persistence.** Customers, utilities and third parties such as ESCOs or LaaS vendors are interested in understanding the persistance of NLC energy savings over time to ensure an appropriate return on their investments. Ongoing data reporting, potentially on an annual basis, would enable utilities to monitor the energy performance and continuously engage with the customers throughout the measure life of the NLC systems.
- **Access non-energy benefits through data.** Granular energy data, along with other data that can be collected by NLC systems, are known to be the enabler for deriving non-energy benefits (NEBs) and business value across a wide variety of facilities and IoT use cases, whose value may far exceed any energy benefit. While not in the scope of this use case, the ecosystem created by this energy data reporting initiative may help utilities, manufacturers, trade allies, and customers collaboratively unlock new NEBs that benefit all parties.

There are some specific data elements that are important for future refinement of energy monitoring but not included in the scope of these guidelines. For example, the ANSI C137 Lighting Systems committee is developing energy monitoring use cases and identifying the relative accuracy required for each use case. Specific guidelines for data elements such as accuracy and sampling rate are important next steps but too detailed for these preliminary guidelines. Instead, these guidelines are focused primarily on standardizing data collection in the near-term while these larger issues being addressed by the C137 committee are still being resolved.

GUIDELINES

DATA ELEMENTS

This document summarizes high-level requirements for the energy data elements in **Tables 8** and **9** below. Each data element is listed under the broader category with which it is associated (e.g., Baseline Information). The data elements are listed as either "required" or "preferred." Required data represents the minimum elements needed to develop an inferred baseline and calculate energy savings, similar to those listed in the report. Preferred data elements are those made available and voluntarily supplied by the manufacturers and customers which enable more accurate and sophisticated savings calculations. The technical details of each data element (both required and preferred), including the definition, unit, format, and specific requirements are provided in a companion spreadsheet as an engineering reference.

DATA ACQUISITION PROCESS

In the future, energy data to be reported autonomously from the NLC systems to the utilities via the internet. However, it is premature at this moment due to the lack of a standardized data model and secure reporting and transmission protocol. This guideline may serve as a starting point for developing such standards, but its main intention is to provide the framework to initiate the energy data reporting practice. An automated and more sophisticated reporting protocol and data model may be included in future versions of the guideline when all of the supporting infrastructures are in place.

SERVICE-LEVEL AGREEMENT (EXAMPLE)

The utilities shall establish a standard service-level agreement with the energy data providers, which may be the customers, trade allies, manufacturers, or a combination, substantiating that the data are strictly used in the M&V calculations or will be used in an anonymized fashion to support NLC research to ensure customer privacy and security. Publications derived from the energy data shall be free of any personally identifiable information; in this case the manufacturers or the customers. Any extended use and distribution of the data without explicit consent of the data providers shall be prohibited.

Table 8. Reporting Guidelines Data Elements – Required Only.

This table lists the 7 required data elements for the standard M&V calculations to arrive at meaningful results that can be used to support EE programs.

Data Element	Definition	Required ® / Preferred (P)*	Data Type	Unit	Minimum Requirements
Site	The building in which the NLC system is installed. An NLC installation may not cover the entire building and a building may have multiple NLC installations due to specific needs of a lighting design of different ownership/tenancy.				
NLC System Manufacturer	The manufacturer of the NLC system	**R**	Alphanumeric		
NLC System Product Name / Model	The name of model number of the NLC system	**R**	Alphanumeric		
Building / Business Type	The main business function pertaining to the portion of the building where the NLC system is installed	**R**	Alphabetic	List: Select from the Building Types	ASHRAE 90.1-2016 Table 9.5.1 (preferred)
Baseline Information* **	The energy consumption condition before the NLC system was put in place. The cluster of baseline information may be reported at site, zone or luminaire level depending on the data availability.				
Maximum Rated Power without Controls	The maximum possible power consumption of the NLC system without any control strategy in effect. If a luminaire retrofit has occurred, this value is equal to the maximum rated power of the new luminaire(s).	**R**	Numeric	W	Zone or luminaire level
Energy Consumption Data* **	The time series of energy consumption collected by the NLC system.				
Energy Data Reporting Interval	The frequency an energy measurement is reported	**R**	Alphanumeric	List: "Minutes (Please Specify)"; "Event-based"	15 minutes or less if time intervals
Energy Data Reporting Timestamp	Date and time of the energy measurement.	**R**	Float or Text		Unix time or RFC 3339 time
Energy Measurement / Calculation	The actual energy reading that is reported.	**R**	Numeric	Whr or W	Zone or luminaire level

* For data elements marked as “Preferred” or "P", it is the manufacturer’s and customer’s discretion whether to supply the data elements.
** Luminaire level information is only relevant if energy data are reported at the luminaire level.
*** Data in these categories should be reported at the level consistent with where the energy data are collected (zone or luminaire).

Table 9. Reporting Guidelines Data Elements – Required and Preferred

This table lists both required and preferred data elements. The additional preferred data made available and voluntarily supplied by the manufacturers and customers will enable the utility M&V team to perform more accurate and sophisticated savings calculations.

Data Element	Definition	Required (R)/ Preferred (P)*	Data Type	Unit	Minimum Requirements
Site	The building in which the NLC system is installed. An NLC installation may not cover the entire building and a building may have multiple NLC installations due to specific needs of a lighting design of different ownership/tenancy.				
NLC System Manufacturer	The manufacturer of the NLC system	**R**	Alphanumeric		
NLC System Product Name / Model	The name of model number of the NLC system	**R**	Alphanumeric		
Site ID	Unique identifier for a particular NLC system installation.	P	Alphanumeric		
Building / Business Type	The main business function pertaining to the portion of the building where the NLC system is installed	**R**	Alphabetic	List: Select from the Building Types	ASHRAE 90.1-2016 Table 9.5.1 (preferred)
ZIP Code	A system of 5-digit codes that identifies the individual Post Office or metropolitan area delivery station associated with an address.	P	Numeric		
Gross Floor Area	Total floor area of the NLC installation site with no deductions.	P	Numeric	Square Feet	
Nominal Business Hours	Number of hours a year the site is open for business	P	Numeric	Hours/Year	
Nominal Cleaning Crew Hours	Number of hours a year the cleaning crew works on the site	P	Numeric	Hours/Year	
Space	An enclosed area, not necessarily enclosed by physical walls, within a building that is designated to a specific function and usage.				
Space Type	The main usage of an enclosed area, not necessarily by physical walls, within a building.	P	Alphabetic	List: Select from the Space Type	ASHRAE 90.1-2016 Table 9.5.1 (preferred)
Gross Floor Area	Total floor area of the space with no deductions.	P	Numeric	Square Feet	
Zone	Typically a logical area defined in the NLC system to correspond a group of luminaires, sensors and user interfaces to a physical space. A zone may represent an entire space or a subdivision of a space depending on the commissioning and configuration needs.				
Zone ID / Name	Unique identifier for a zone.	P	Alphanumeric		
Number of Luminaires	The number of luminaires within a zone.	P	Numeric		
Luminaire**	The luminaire level data is only relevant for systems with individually addressable/controllable luminaires.				
Luminaire ID	Unique identifier of a luminaire.	P	Alphanumeric		

Data Element	Definition	Required (R)/ Preferred (P)*	Data Type	Unit	Minimum Requirements
Baseline Information***	The energy consumption condition before the NLC system was put in place. The cluster of baseline information may be reported at site, zone or luminaire level depending on the data availability.				
Pre-retrofit Control Strategies	The mechanisms that allow manipulation of the light output before the NLC system is put in place.	P	Alphabetic	List: "Personal Control", "Daylighting", "Occupancy Sensing"	
Maximum Rated Power without Controls	The maximum possible power consumption of the NLC system without any control strategy in effective.	**R**	Numeric	W	Zone or luminaire level
Energy Consumption Data***	The time series of energy consumption collected by the NLC system.				
Energy Data Type	The type of energy measurement that is reported.	P	Alphabetic	List: "Average Power"; "Instantaneous Power"; "Interval Energy"; "Cumulative Energy"; "Other (Please Specify)"	
Energy Data Origin	The location where the reported energy measurement is generated	P	Alphanumeric	List: "Zone ID"; "Luminaire ID"	
Nominal Accuracy	The accuracy of the reported energy measurement	P	Numeric	%	
Energy Data Reporting Interval	The frequency an energy measurement is reported	**R**	Alphanumeric	List: "Minutes (Please Specify)"; "Event-based"	15 minutes or less
Energy Data Reporting Timestamp	Date and time of the energy measurement.	**R**	Float or Text	Unix time or RFC 3339 time	
Energy Measurement / Calculation	The actual energy reading that is reported.	**R**	Numeric	Whr or W	Zone or luminaire level

* For data elements marked as "Preferred" or "P", it is the manufacturer's and customer's discretion whether to supply the data elements.
** Luminaire level information is only relevant if energy data are reported at the luminaire level.
*** Data in these categories should be reported at the level consistent with where the energy data are collected (zone or luminaire).

APPENDIX B: DATA SHARING AGREEMENT

All information in this section is for educational purposes and should not be used directly in a formal contract without consulting with an attorney.

This document provides a high-level overview and justification for the use of a data sharing agreement between project stakeholders of Networked Lighting Control systems (NLC) installations.

THE DATA SHARING AGREEMENT

A Data Sharing Agreement specifies the conditions under which a party that has useful data agrees to share its data with a party seeking data. In the case of the NLC system energy data reporting, this could be the customers or the manufacturers agreeing to share the energy data with utilities for evaluating the savings and cost-effectiveness an energy efficiency program.

DATA MANAGEMENT PLAN

Each data sharing agreement should be part of a broader Data Management Plan. There are comprehensive resources and tools available online, including checklists and templates, to help guide the development of the Data Management Plan.[24]

DATA SHARING BEST PRACTICES

Data sharing best practices guide the development of Data Sharing Agreements, and are broadly available on the internet.[25] The following data sharing best practices were summarized from a broad data sharing agreement review and are shown below in **Table 10.**

[24] Example of online resources. 1) DMPonline by the Digital Curation Centre (DCC): http://www.dcc.ac.uk/dmponline. 2) Data management planning by the UK Data Service: https://www.ukdataservice.ac.uk/manage-data/plan. 3) Guidelines for Effective Data Management Plans by the Inter-university Consortium for Political and Social Research (ICPSR): http://www.icpsr.umich.edu/icpsrweb/content/datamanagement/dmp

[25] A sample of Data Sharing Agreement can be found on Contract Standards website at https://www.contractstandards.com/contracts/data-sharing-agreement. Another good template is the Model Data Sharing Agreement available from the Inter-university Consortium for Political and Social Research (ICPSR) at https://deepblue.lib.umich.edu/handle/2027.42/136146. These samples should not be used 'as is' for any legally binding contract.

Table 10. Key Elements of Data Sharing Agreements

Key Elements of Data Sharing Agreements
General introduction **Parties involved**: the organizations and agencies involved in the agreement. **Purpose of agreement**: the reason for the agreement and the allowed uses of the data.
Data transmission and content **Data transmission**: the file format (ex: comma-delimited text file, SAS database); approved methods for transmission, such as secure file uploads, encrypted email; and the timing of the data delivery (one time, annually, etc.) **Data description**: listing of fields to be included; what the level of observation will be (address, census tract, etc.); and the time period the data represents. **Agency disclaimers**: legal language releasing the agency from any liability from incorrect data or how the data is used.
Handling and release of data and analysis **Data security requirements**: specifications of security measures (staff confidentiality pledges, encrypted digital data storage); and, if appropriate, a date by which the data should be returned or destroyed. **Conditions for release of data to third parties**: provisions (if any) for release of the file to third parties with explicit permission from the agency; could also prohibit commercial re-selling of the data. **Conditions for release of data analysis**: the minimum time required for agency review of any analysis to be released (ideally not allowing the agency to stop the release); suppression rules to avoid identification of any individuals (such as any geography with less than 10 cases will not be reported.) **Source requirements**: proper citation of the data source or any disclaimer required on reports.
Procedural, contractual issues **Renewal schedule**: The time period the agreement is in force and how often it must be renewed (such as annually). **Amendment process**: the process for amendments to the agreement. **Termination causes**: the reasons for which either organization can end the agreement.
This best practice is adopted from the National Neighborhood Indicators Partnership (NNIP) online guides webpage for Key Elements of Data Sharing Agreements.

DATA SHARING AGREEMENT GUIDELINES SPECIFIC TO NETWORKED LIGHTING CONTROLS

In order to ensure that a data sharing agreement covers all necessary data, it is recommended that, at minimum, data sharing agreements include specific mention of the following:

- Duration of data collection for each reporting period
- Frequency of data collection requests (one-time or yearly)
- Discussion of anonmyzation and removal of any PII
- Sharing of anonymized data with third party organizations such as DLC for research purposes to further advance industry understanding and utility NLC programs

APPENDIX C: SENSITIVITY ANALYSIS OF INFERRED BASELINE APPROACH

The inferred baseline approach attributes savings only when a zone is "occupied", which is defined as power draw above a specific power threshold. The original calculation defined the occupancy threshold as 10% of maximum measured power. However, modifying that threshold affects energy savings claims: a lower threshold will classify more hours as occupied and will increase savings, while a higher threshold will reduce inferred occupied hours and estimated savings. A sensitivity analysis was conducted using 5% and 15% power thresholds to estimate their impact on overall savings. The results indicated that neither the 5% or 15% had an appreciable impact on overall savings (less than a 5% impact either way on control factor), as shown in **Figure 20**.

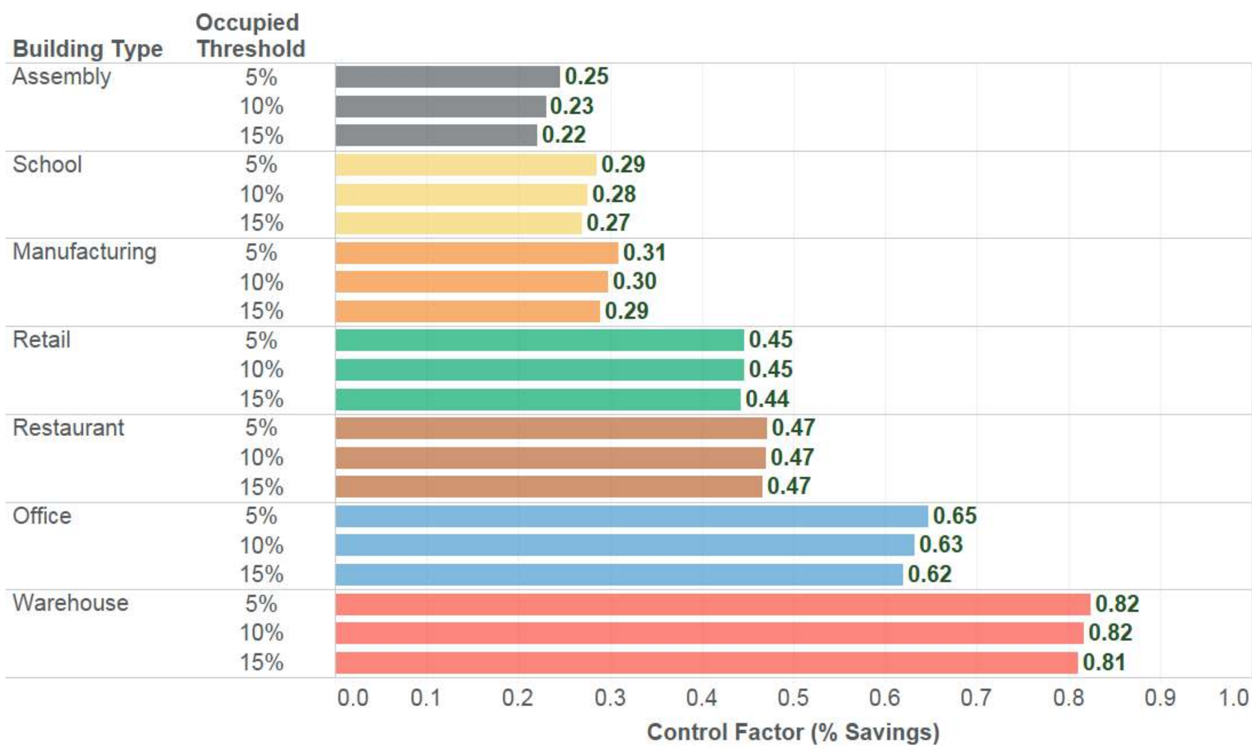

Figure 20. Energy savings sensitivity analysis results.

Similarly, the sensitivity analysis found that varying these thresholds had very little impact on overall results for operating hours. This conclusion was confirmed through visual analysis of load profiles, which shows that in many cases power ramps up and down very sharply on an hourly basis, with a clear boundary between occupied and unoccupied. This suggests that the method for delineating between "occupied" and "unoccupied" is valid.

APPENDIX D: METHOD FOR ESTIMATING RATED POWER WHEN NOT PROVIDED

One data contributor was not able to provide the rated power of the existing luminaires, only the pre-retrofit power prior to an LED upgrade. Therefore, the following procedure was used to estimate rated power for each LED luminaire:

- Discard all the time series data where *power used* and/or *dimming level* are 0. (These values are not helpful for estimating the rated power of each fixture.)
- For each fixture, in each time interval, divide *power used* by the accompanying *dimming level* to calculate a series of *rated power estimate* values for each fixture. In doing so, a linear power-dimming curve is implicitly assumed.
- For each fixture, calculate the mean and standard deviation of all *rated power estimate* values.
- For each fixture, discard all *rated power estimate* values that are less than or greater than three standard deviations from the mean *rated power estimate*. (This attenuates the effect of unreliable outlier estimates that exist due to measurement error and/or non-linearity of the power-dimming curve.)
- For each fixture, calculate the *average rated power estimate* as the average of the *rated power estimate* values without outliers.
- For each fixture, the *final rated power estimate* is either the *average rated power estimate* or the maximum observed value of *power used*. This step is necessary to ensure that the estimated rated power of a fixture does not exceed its measured power.

APPENDIX E: SAMPLE BUILDING AND SPACE TYPE MAPPING

Although some projects did not have space type information, those that did typically had customer-centric zone names, such as “Night restocking” or “Boxing - Unlabeled Cir. 4.” In ambiguous cases, and situations where a space did not map to the standardized categories, zones were assigned to a “Whole Building” category to be included in just the building-level analysis. Examples of building and space type mappings are provided in **Table 11.**

Table 11. Comparison of sample building and space type designations mapping.

Contributor Provided		DEER		BEDES	
Building Type	**Space Type**	**Building Type**	**Space Type**	**Building Type**	**Space Type**
Big box retail	Lunch Room	Retail - Large (Big Box)	Break	Retail	Kitchenette
Auditorium	N/A	Assembly	Whole building	Assembly Convention Center	N/A
Small office	Hallway	Office - small	Hall	Office	Corridor
Warehouse	N/A	Unconditioned warehouse	N/A	Warehouse unrefrigerated	N/A