FUTURE FOCUS
Advanced Lighting & HVAC Controls Integration Final Report

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STUDY CONDUCTED BY:

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FUTURE FOCUS

Future Focus reviews new program ideas, measures, and delivery methods and tests new participation opportunities for future expansion and inclusion in the Focus on Energy program portfolio. The initiative supports energy efficiency and renewable energy research and reviews new and emerging energy efficient technologies.

KEY DEFINITIONS

BACnet: Building Automation and Control Networks. A communications protocol enabling interoperability between different building systems like lighting and HVAC.

BAS: Building automation system. A system monitoring and enabling control of various systems in commercial buildings including HVAC, lighting, electrical and plumbing.

NLC: Networked lighting controls. Commercial lighting systems combining sensors, network interfaces and controllers to allow for real-time adjustments to lighting output including occupancy sensing, daylight control and high-end trim.

LLLC: Luminaire level lighting controls. Sensors embedded in each luminaire in the NLC system. LLLC are a type of NLC system enabling granular occupancy sensing throughout the site.

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EXECUTIVE SUMMARY

The Focus on Energy Advanced Lighting + HVAC Controls Integration Demonstration Project evaluated the feasibility, technical challenges, and energy savings potential of integrating networked lighting controls (NLC) with HVAC systems in commercial buildings. This integration uses NLC occupancy data to optimize HVAC operations, anticipated to reduce total building energy use by 5–20%.

Two demonstration sites—Aurora Medical Group Southwest Waukesha Clinic and Fond du Lac Public Library—successfully implemented the NLC+HVAC integration. Whole-building electricity savings ranged from 11% to 41%, with HVAC system savings of 12–17%. Two school sites initially enrolled had to withdraw due to the high cost of enabling BACnet capabilities in the lighting system.

Program Recommendations

1. **Target outreach to high-opportunity markets** – Focus on large, owner-occupied, energy-intensive facilities (e.g., schools, government, healthcare, large offices) with variable occupancy patterns and compatible HVAC/BAS infrastructure.
2. **Screen sites for savings potential** – Leverage resources like the DesignLights Consortium's (DLC) NLC-HVAC Integration Decision Tree to identify high opportunity sites. Require detailed vendor cost estimates and zone mapping for both lighting and HVAC controls before enrollment to ensure feasibility.
3. **Leverage select trade allies** – Work to identify a small number of technically proficient vendors to act as "project expediters" capable of identifying high opportunity sites as well as coordinating lighting and HVAC controls work to streamline the customer's participation process.
4. **Prioritize full retrofit projects** – Combining NLC installation with HVAC integration in a single project reduces the potential for unexpected costs compared to integration of a pre-existing NLC systems.
5. **Ensure accountability for resolving issues** – Ensure the project team has identified who will perform the "integration manager" function responsible for ensuring technical challenges during implementation are promptly resolved through coordination between lighting and HVAC vendors.
6. **Verify operations; define verification requirements up front** – Use a standardized checklist to confirm correct and functional integration before incentives are paid.
7. **Provide technical assistance and education** – Offer HVAC control sequences, engineering support, and training for vendors and facility staff to build market capability and promote best practices. Use existing materials for easy program launch.
8. **Adopt a simplified custom incentive approach** – Custom incentives are recommended over a prescriptive approach given the degree of savings variability resulting from site-specific factors; consider bonuses for vendor collaboration.

9. **Streamline savings calculations** – To simplify the custom incentive process, apply the recommended TRM workpaper methodology using deemed savings factors by building type combined with a few project-specific inputs for both heating and cooling systems.

The demonstration confirmed NLC+HVAC integration is technically feasible, can yield significant energy savings, and could be advanced through targeted market engagement, streamlined processes, and focused technical and financial support.

INTRODUCTION

Focus on Energy has been providing incentives for NLC systems since 2017. By combining control capabilities with efficient LED lighting, NLC retrofits can deliver significantly more energy savings than stand-alone LED retrofits. DLC research showed NLCs can save approximately 50 percent more lighting energy than a standard LED retrofit.[1] However, the high cost of NLC systems remains a major barrier to broader adoption. To further improve NLC cost-effectiveness, DLC and other industry leaders have been advancing the strategy of integrating NLC with HVAC controls.

The most common approach to this integration involves connecting an NLC system with the building automation system (BAS) to drive HVAC savings through NLC-enabled occupancy controls. Although effective integration of NLC with HVAC does not require luminaire-level lighting controls (LLLC), LLLC products increase energy savings potential because fixture-level sensors distribute granular occupancy sensing throughout the space. By sending occupancy signals to the BAS, the NLC system enables zoned HVAC control strategies like thermostat setbacks, VAV box turndown, temperature and pressure reset, full unit shutdown, and demand control ventilation. A 2023 DLC study found occupancy sensors can save 30% of the energy used for HVAC, and HVAC represents around half of a typical commercial building's energy consumption.[2] This research found integrating lighting and HVAC controls can cost-effectively save 5-20 percent of total building energy usage.[3]

The goal of the advanced lighting + HVAC demonstration project for Focus on Energy was to assess the feasibility of developing an incentive offering to support integration of NLC systems with HVAC controls in commercial buildings. Launched in late 2022, the demonstration sought to recruit a total of five sites served by utilities participating in Focus on Energy. Recruitment prioritized sites larger than 15,000 sq. ft. in the following market segments: K-12 schools,

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[1] Wen, Y-J., Kehmeier, E., Kisch, T., Springfield, A., Luntz, B., & Frey, M. (2020). *Energy Savings from Networked Lighting Control (NLC) Systems with and without LLLC*. Prepared by Energy Solutions for the Northwest Energy Efficiency Alliance and DesignLights Consortium. Accessed June 11, 2025. Available at: https://designlights.org/resources/reports/report-energy-savings-from-networked-lighting-control-nlc-systems-with-and-without-lllc/

[2] DesignLights Consortium (2023, September 1). *Future Proofing Energy Efficiency with Networked Lighting Controls*. Accessed June 13, 2025. Available at: https://designlights.org/resources/reports/future-proofing-energy-efficiency-with-networked-lighting-controls/

[3] Halfpenny, T. (2023, September 27). *Here's How Networked Lighting Controls Can Level Up Energy Efficiency Efforts*. DesignLights Consortium. Accessed June 11, 2025. Available at: https://designlights.org/news-events/news/networked-lighting-controls-can-level-up-energy-efficiency/

higher education, government, retail, service and offices. Eligible sites were required to have an existing or planned BAS using the BACnet communications protocol, and to either have NLC already installed ("integration only" sites) or to be planning an NLC retrofit combined with HVAC integration ("full retrofit" sites).

This project had the following research objectives:

i. Assess the viability of a future NLC+HVAC program offering and issue program design recommendations
ii. Identify technical implementation challenges and opportunities relevant to program design
iii. Develop a streamlined methodology for quantifying energy savings impacts from NLC+HVAC projects

This report will describe the research methodology and approach for conducting the demonstration. The Research Findings section will identify factors relevant to program design as well as energy savings impacts. The report will conclude with an assessment of future program strategies and program design considerations.

RESEARCH METHODOLOGY

The NLC+HVAC demonstration addressed the following research questions:

- Targeting strategies:
    - What customer types and trade ally types have greater potential for pursuing and supporting NLC+HVAC projects?
    - What building types and characteristics have the greatest opportunity for achieving energy savings impacts with NLC+HVAC?
- Incentive strategies:
    - What level of incentive is needed to drive interest in NLC+HVAC?
    - Does providing direct incentives to the technicians responsible for lighting and HVAC controls programming facilitate prompt resolution of system integration challenges?
- Implementation strategies:
    - Do certain NLC systems make the system integration process easier or harder (e.g., identify brands and/or features streamlining the setup and integration process)?
    - What implementation challenges arose and what solutions overcame them?
    - What are the documentation and data collection needs to assess opportunities at candidate sites and to accurately calculate savings at installed sites?
    - How viable is the NLC+HVAC approach (market interest, economics, technical feasibility) compared to an alternative path in which a separate occupancy sensor network is installed for HVAC control?
- Energy savings impacts:
    - Quantify the energy savings impacts (electricity and natural gas) from participating demonstration sites.
    - Identify recommended changes to the Wisconsin TRM to capture the full savings impact of NLC+HVAC, including development of a TRM work paper.

These research questions were addressed through market engagement (participant recruitment and technical assistance for demonstration sites), collecting utility billing data and equipment submetering data to quantify energy savings impacts at demonstration sites, and quantifying pre- and post-integration energy usage. The methodologies for each element of the research process are described below.

Participant Engagement

The demonstration sought to recruit at least two sites characterized as “full retrofits”—replacing existing lighting with NLC and then integrating the lighting and HVAC controls—as well as two “integration only” participants—sites with previously installed NLC systems capable of simply integrating the lighting and HVAC controls. Because Focus on Energy has been offering NLC incentives for years, researching integration-only sites would help to evaluate the viability of engaging past NLC incentive recipients about a future HVAC controls integration project.

We employed a two-pronged outreach strategy to recruit demonstration sites: one focused on outreach to customers and the other targeted Focus on Energy trade allies. Energy advisors from Focus on Energy led outreach to customers. The research team shared information about this project and a marketing flyer with the implementation teams supporting, schools, government, commercial, and small-to-medium industrial customers. The energy advisors employed a targeted approach, sending the marketing flyer to customers and trade allies who had pursued NLC projects in the past as well as those with current planned NLC projects. They also targeted a number of institutional building owners and companies with aggressive sustainability goals who participate regularly in Focus on Energy. Customers were contacted via email and the research opportunity was discussed in regularly scheduled coordination calls. For the research team’s direct outreach to vendors, Focus on Energy shared a list of trade allies who had supported past NLC projects.

There were no formal surveys or interviews as part of the demonstration scope, but the Research Findings section includes information gathered from discussions with participating customers and trade allies throughout the project. Once sites were enrolled, the research team facilitated a kickoff meeting with the customer and the staff/vendors involved in programming lighting and HVAC controls. Participants were given a document with recommended HVAC controls sequences (Appendix A). Following the kickoff, the research team’s technical lead met as needed with customer staff and vendors to address technical questions and make sure the integration process remained on track. We also monitored data from each site to determine if energy savings impacts were being achieved. When one site failed to show measurable impacts to energy usage several months after the controls work was completed, we convened a team meeting to identify the issue and suggest controls changes that could be made. We conducted a results presentation for each customer at the end of the monitoring period (6+ months after completion of the controls integration).

Site Data Collection

To support a robust measurement and verification (M&V) process for the integrated controls demonstration, the project team implemented a comprehensive site data collection strategy encompassing utility billing data, monitoring equipment, and operational data from each facility.

Data was collected to enable comparison of energy consumption before and after the retrofit installation, ensuring savings from both lighting and HVAC systems could be accurately quantified and attributed.

Lighting energy data was gathered by sub-metering representative lighting circuits prior to and following the retrofit, with special care taken to document the dates and details of in-progress lighting upgrades. These measurements were supplemented by design documentation and equipment wattage data. Fixture power and runtime were collected using power monitoring equipment installed by the project team at all accessible lighting electric panels.

HVAC fan and cooling systems were sub-metered to monitor energy consumption directly. In addition, data from the BAS and NLC system were collected to support whole-system performance analysis. Key trend data points included air handling unit (AHU) fan speeds, variable air volume (VAV) damper positions, boiler modulation percentage, and occupancy signals. This data was accessed through scheduled email reports when made available by facility personnel.

Periodic site visits were conducted to verify equipment configuration, review BAS/NLC capabilities, and validate instrumentation quality. Once the monitoring equipment was verified as recording the data correctly, remote data downloads and analysis were conducted periodically to ensure the system was operating as expected. Equipment nameplate information and control sequences were collected to supplement the analysis.

Utility billing and AMI interval data were collected to model pre- and post-installation energy use and costs. Monthly utility bills provided baseline financial data, while 15-minute or shorter interval data enabled weather-normalized regression modeling. All data was timestamped with clear documentation of data sources and mapping.

Together, these methods ensured high-quality, traceable data for evaluating energy savings, disaggregating impacts by system, and validating M&V results across the study period.

Data Analysis

The project team used the collected data to quantify energy savings attributable to the integrated NLC + HVAC retrofit and to disaggregate those savings between lighting and HVAC systems. The analysis focused on comparing pre- and post-retrofit energy use patterns, adjusting for external factors such as weather and sub-annual data collection periods to isolate the retrofit's impact.

Lighting Energy Analysis

Sub-metered lighting data was used to build operating hour profiles for the lighting system. These profiles, in combination with verified fixture wattages, enabled calculated estimates of lighting energy consumption before and after the retrofit. For circuits transitioned from T8 to LED during the research baseline period, design documents and calculations were used to separate energy savings attributed to the retrofitted equipment from those attributed to the luminaire level controls updates.

HVAC Energy Analysis

HVAC fan and cooling power data collected through circuit-level sub-metering allowed the project team to directly compare HVAC energy use before and after the controls integration.

Analysis focused on identifying changes in operation associated with the NLC-integrated zone-level occupancy signals, which were used to reset VAV damper positions and fan speeds. Trends in fan power were analyzed against building schedules and occupancy to confirm the controls responded as intended and to quantify the associated energy reduction.

Whole-Building Energy Analysis
The project team used AMI interval electric data to conduct a weather-normalized regression analysis of whole-building energy use before and after the retrofit. This analysis provided a top-down estimate of total savings and served as a check on the sum of system-level savings. Interval data was modeled using a change-point analysis. The regression models were normalized to typical meteorological year (TMYx) weather data to estimate normalized annual savings.

Validation and Uncertainty
All savings estimates were validated through consistency checks across data sources (e.g., sub-metered loads, utility bills, and BAS/NLC trends). When uncertainty in the datasets or methodology were deemed significant, a conservative approach was taken which would err on the side of underrepresenting savings as opposed to overrepresenting them.

RESEARCH FINDINGS

This section details results from our engagement with customers and trade allies during the outreach, recruitment and implementation process.

Participant Engagement

Four sites initially enrolled in the demonstration (Table 1) but the two school sites had to drop out before completing the controls integration. Challenges with the school sites illustrated a barrier to the viability of “integration only” projects. The previously installed or scoped NLC systems were not capable of supporting the BACnet communications required to send occupancy signals to the BAS. Where all HVAC controls sold today are BACnet-enabled, enabling BACnet for lighting control is an upgrade with additional cost. Both integration-only sites required installation of additional gateways and a one-time BACnet license fee. Additional lighting control zones were also needed to improve controls. The cost of enabling BACnet for lighting controls ranged from $20,000 to $60,000. While the clinic was able to incur the cost of the necessary upgrades to the lighting system, both schools had to drop out in part due to higher-than-expected costs on the lighting side. Competing energy project priorities were also a contributing factor to the decision not to proceed, as both sites were also enrolled in Focus on Energy’s retrocommissioning program with work scheduled to begin on a similar timeframe.

Table 1: Sites enrolled in the NLC+HVAC demonstration

Site	Project type	NLC system
Fond du Lac Public Library (FDL)	Full retrofit	nLight AIR
Aurora Medical Group Southwest Waukesha Clinic	Integration only	nLight AIR
Glacial Drumlin School*	Full retrofit	nLight AIR
Monona Grove High School*	Integration only	nLight AIR

* Two schools in Monona Grove were originally enrolled in the pilot but later dropped out due to competing energy retrofit priorities and challenging project economics.

Trade ally engagement

During the outreach process, six Focus on Energy trade allies participated in an informational call about the demonstration: McKinstry, Energy Performance Lighting, Faith Technologies, Graybar, B&B Electric, and Genesis Energy International.

- Graybar played a critical role in enrolling the Fond du Lac library project, including serving as a de facto "owners rep," working with lighting and HVAC vendors to obtain quotes and securing the owner's commitment to participate. Graybar remained engaged and supportive throughout the two-year demonstration.
- McKinstry secured enrollment from two Monona Grove schools and was interested in enrolling additional schools, but it was not possible as we sought to enroll a diversity of building types.
- McKinstry and Graybar both reported they see business opportunities in supporting lighting and HVAC controls integration projects. Both mentioned the value of participating in the demonstration to generate energy savings data as well as potential case studies to promote with other customers.
- Faith Technologies has tested lighting and HVAC controls integration in their own facility. They expressed interest in hosting a future event in partnership with Focus on Energy to increase awareness about this strategy.

Given the technical complexity of these controls integration projects and the lack of industry proficiency with this relatively new strategy, the success of a future program offering will require strong engagement with trade allies. Instead of a broad-based opportunity that many trade allies will participate in, successful trade ally engagement will involve identifying a small number of market champions who can help customers identify the controls integration opportunity. Likely adopters include energy services companies (ESCOs) and companies that install and service HVAC controls. While Graybar played a critical role in making the Fond du Lac library project successful, many lighting distributors focus primarily on the design and supply of products and may not be well-suited for the project expediter role

Customer engagement

Energy advisors pursued a highly targeted outreach approach to recruit participants. They reported a targeted approach was needed due to the high cost of NLC systems, the uncertainty of potential savings from integration projects, and the technical complexity of the controls integration process. In addition, since the demonstration was seeking to enroll a small number of sites, a targeted approach limited the risk of over-subscription. These factors led them to focus outreach on a small subset of customers and trade allies who were more likely to be interested in this type of project.

Overall the energy advisors felt this type of project would be challenging to sell except to a narrow niche of customers due to the high cost and uncertain savings. It can be difficult to get customer attention for easy opportunities, and far more challenging for technically complex projects. For customers already considering NLC installations, the energy advisors mentioned a key motivation would be getting more value out of their NLC projects. DLC research corroborates the need for effective targeting strategies. DLC's NLC-HVAC Integration Decision Tree recommends answering the following questions to identify potential candidates:[4]

iv. Is the owner interested in innovative energy-saving ideas? Will they tolerate investments with a longer payback?
v. Does the building have a variable occupancy pattern for higher energy savings potential?
vi. Do HVAC zone boundaries align well with NLC zone boundaries? If not, could zones be realigned?
vii. Does the HVAC system support VAV for higher energy savings potential?
viii. Does the building have a BAS already in place or planned, and does the BAS use BACnet communications protocol?

Other important factors in the success of controls integration projects include ensuring facilities staff are engaged and have the capacity to support project implementation. Finding vendors who are experienced champions of controls integration may be challenging since this is still an emerging approach. At a minimum it will be important to ensure companies supporting the lighting controls programming and those supporting the HVAC controls programming are willing and able to support the work. Engaging IT staff early to ensure data security concerns do not become a barrier is another recommended best practice.

Technical Implementation

Delivering a successful lighting/HVAC controls integration project requires someone on the team be accountable for ensuring the integration process is working correctly. This "integration manager" role can include troubleshooting to identify and resolve barriers in communication between the NLC and HVAC systems, as well as verifying the controls are properly programmed to ensure energy savings. For example, the FDL project initially had long time delays on the setting defining a zone as unoccupied. This meant the setbacks for unoccupancy

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[4] DesignLights Consortium (2025, February 6). *NLC-HVAC Integration Decision Tree.* Part of the *NLC-HVAC Integration Toolkit*. Accessed July 21, 2025. Available at: https://designlights.org/resources/reports/nlc-hvac-integration-toolkit/

were rarely being triggered in the first six months after integration. The research team identified the issue, scheduled a team meeting to decide how to resolve it, and continued monitoring the site data after the change was made.

We encouraged each project team to identify an integration manager during the kickoff, but it defaulted to the research team to monitor and verify the integration process at each site. Programs should consider strategies for ensuring the controls integration is successful. One option is to define a set of requirements for verifying the integration is functioning as expected and make incentives contingent upon verification. Appendix B: Verification Checklist includes a verification checklist program staff could use to confirm the integration is functioning properly. DLC suggests programs could offer incentives "for master system integrators to review designs before installation and help solve problems afterwards."[5] Program administrators will need to balance the need for accountability with the added complexity of verification requirements.

Both participants noted the value of education and technical assistance when we did the final results presentation for each site. Educational strategies for trade allies will increase awareness of the controls integration opportunity and build technical capacity for delivering successful projects. This is important given controls integration is still a relatively new strategy for industry. DLC concurs: "Supporting NLC systems and integrations effectively will also require custom and turnkey incentive programs coupled with technical assistance and trade ally and customer education."[6] Our own experience with these sites showed the importance of regular check ins with the project team to determine if they were running into any hurdles. Focus on Energy energy advisors could potentially perform this function, checking in with the integration manager or project lead by phone or email to determine if any issues are impeding completion of the controls integration and if technical assistance from the program team could help resolve the issue.

Another technical finding is many NLC systems are being sold and installed without enabling BACnet capabilities. It is an added cost for hardware and licensing can be skipped if integration is not planned as part of the initial project scope. (See challenges with integration-only sites described as described in the Participant Engagement section above). Graybar mentioned they strongly encourage customers to include this functionality to preserve future options for how the controls systems can be used. They believe BACnet capabilities should be standard for all NLC systems as it is for BAS. Other vendors we engaged with on this project, including McKinstry, were not including this functionality unless specified up front by the customer. The DLC is supporting standardization in this area, with detailed interoperability information now incorporated into their NLC qualified products list (QPL):

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[5] DesignLights Consortium (2023, September 1). *Future Proofing Energy Efficiency with Networked Lighting Controls*. Accessed June 13, 2025. Available at: https://designlights.org/resources/reports/future-proofing-energy-efficiency-with-networked-lighting-controls/

[6] DesignLights Consortium (2023, September 1). *Future Proofing Energy Efficiency with Networked Lighting Controls*. Accessed June 13, 2025. Available at: https://designlights.org/resources/reports/future-proofing-energy-efficiency-with-networked-lighting-controls/

The DLC maintains a list of NLC systems that qualify for energy efficiency rebates and incentives across the USA and Canada. As of January 2025, 90 systems are listed. The list is searchable by manufacturer, brand and various capabilities. Under "Advanced Capabilities" on the left, you can filter for systems that support integration with BACNet Systems. To see more about a particular NLC system's support for external system integration, select the NLC system, then in the Summary menu select "External Systems Integration". This will open the "Interoperability" menu. Scroll down to the External Systems Integration section. For even more details, close the pop-up menu for that system, then in the main QPL view, select "Add All results to My List" in the upper right corner, then "Download My List" in the upper left corner, then "Download to Excel". In the downloaded file, columns DC:DL provide more data about parameters that are available.[7]

To ensure wider adoption programs should strive to make the incentive process as streamlined as possible. While building-specific savings variability makes it challenging to develop a fully prescriptive incentive approach, there are ways to simplify the savings calculation method without compromising too much on rigor. The calculation methodology referenced in the TRM work paper (Appendix C: TRM work paper) combines a few accessible project-specific inputs with deemed savings factors by building typology for both the heating and cooling systems. These deemed savings factors were established through literature review of case studies published by DLC as well as the results of this research. This methodology is streamlined to enable program administrators and evaluators to quantify savings confidently without undue analytical burden. It reflects real-world system interactions, accommodates variation in building usage, and remains accessible for implementation at scale, making it both technically credible and cost-effective for program implementation.

One of the research questions for this project is to compare viability of the NLC+HVAC approach with an alternative path targeting installation of separate occupancy sensors for HVAC control. The technical complexity of a controls integration project is greater, but providing support for controls integration projects reduces the potential for a lost savings opportunity on the HVAC side when the customer is interested in an NLC project. Incorporating controls integration into the scope also improves the economics of the NLC investment, which is significant when choosing between NLC and a standard LED alternative. Ideally a program would have offerings supporting both strategies. Another option is using CO_2 sensors (or another type of sensor aimed at improving indoor air quality) to control HVAC. However such devices only control outside air and thus do not address most of the energy-saving measures implemented in this demonstration.

Project Costs

Both demonstration sites made cost-tracking difficult for different reasons. At the clinic, much of the controls integration work was handled in house, particularly on the HVAC side. It was

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[7] DesignLights Consortium (2025, February 6). *NLC-HVAC Integration Toolkit*. Accessed July 21, 2025. Available at: https://designlights.org/resources/reports/nlc-hvac-integration-toolkit/

not possible to get an estimate of labor costs or total hours spent on the project.[8] At the library, Graybar worked with the lighting and mechanical vendors to match the cost of the controls integration scope to the amount of the Focus on Energy incentives for the demonstration project ($26,000). As the customer had no remaining budget after implementing the NLC retrofit, this approach allowed the team to implement the controls integration scope at no additional cost to the customer.

A study completed by Lawrence Berkeley National Lab (LBNL) for Xcel Energy provides useful project cost estimates.[9] Based on a literature review and building simulation modeling for Xcel's Minnesota and Colorado territories, LBNL analyzed both an early replacement scenario (total project cost basis) and replace on burnout scenario (incremental cost basis). Cost inputs included data from RSMeans (an industry cost estimation database), "market intelligence from industry experts, and discussions with lighting and HVAC manufacturers and suppliers." LBNL's cost estimates for the Minnesota territory were:

ix. Early replacement (full cost): $4.28/sq. ft.
x. Replace on burnout (incremental cost): $1.22/sq. ft

LBNL estimated 80-94% of the cost was from the lighting side and the remainder was from the HVAC side. Our Minnesota demonstration (2018-2021) saw a full retrofit plus integration cost of $5.00/sq.ft. The cost of HVAC controls integration was $0.57/sq.ft.

As shown in Table 2, we applied the LBNL cost factors to the building square footage from the two demonstration sites to estimate the full project cost (full system replacement) versus incremental cost. We do not know how close these estimated values are to the actual project cost at each site.

Table 2: Project cost using LBNL cost factors

Site	**Building area**	**Full cost (est)**	**Incremental cost (est)**	Note: This table contains estimated cost values based on building area and the data does not reflect actual project costs
FDL Library	61,000 sq ft	$261,000	$74,420	
AAH Waukesha Clinic	15,000 sq ft	$64,200	$18,300	

[8] This scenario has occurred in other NLC+HVAC pilots the research team has worked on, and it actually presents a customer targeting opportunity. In other words, facilities (like healthcare) having in house staff with HVAC controls expertise present an opportunity for achieving controls integrations projects with lower capital investment by the customer.

[9] LBNL (December 2022). *LEDs with Advanced Lighting Controls and Occupancy Sensor-Based Demand Control Ventilation*. System Program Manual produced by LBNL for Xcel Energy. Accessed July 2, 2025. Available at: https://buildings.lbl.gov/sites/default/files/2023-10/BW_Phase_2_Program_Manual.pdf

Energy Impacts

Pilot results confirmed integrating HVAC zone-level control with networked lighting control (NLC) occupancy sensors can deliver measurable energy savings. At both sites, the control strategy reduced both HVAC and lighting power and runtime in unoccupied zones without compromising comfort. Savings potential varies by site, influenced by occupancy patterns, the number and granularity of HVAC and lighting control zones, and the extent to which systems can be set back during unoccupied periods. Table 3 and Table 4 summarize the whole-building energy savings observed at the pilot sites.

Table 3: Whole-Building Electricity Savings Results

Site	Annual Electricity Savings (kWh/year)	Annual Electricity Savings (kWh/sqft/year)	Annual Electricity Savings (%)
Aurora Health Center	18,335	1.22	11%
Fond du Lac Library	221,000	3.62	41%

Table 4: Whole-Building Natural Gas Savings Results

Site	Annual Gas Savings (Therms/year)	Annual Gas Savings (Therms/sqft/year)	Annual Gas Savings (%)
Aurora Health Center	0 to 1,600	0 to 0.11	0 to 17%
Fond du Lac Library	1,900	0.03	17%

As shown in Table 4, we were not able to quantify natural gas savings based on available data. We saw no significant difference in natural gas consumption between the pre and post-integration monitoring periods during the heating season. Gas savings from the integrated controls likely occurred but could not be reliably quantified. One possible explanation for the lack of change in usage is the domestic hot water (DHW) load was negligible during the pre-installation period due to lack of occupancy. In the post-installation period, although natural gas savings likely occurred due to implementation of occupancy-based HVAC controls, increased DHW demand may have offset those savings resulting in minimal change in natural gas usage. Since we could not estimate a gas savings value from the available data, we estimated a range of possible values using observed electricity savings as a proxy. The calculations showed a 17% reduction in electricity use for the HVAC system, attributed to both fan and mechanical cooling savings. Natural gas savings, by contrast, are expected to come solely from heating reductions, primarily reheat savings on the hot water loop. While exact values cannot be calculated, it is reasonable to assume gas savings are greater than zero but less than the 17% system-wide electricity savings observed. See Aurora site report in Appendix D for additional information about available data.

While whole-building results help illustrate the overall impact of the technology, system-level savings offer a clearer view of its effect on individual HVAC and lighting systems. These results are summarized in Table 5 below, where annual percentage savings are expressed as a percentage of the system's energy use, rather than the whole building. Natural gas use was not broken out by system, as HVAC was the primary end use of natural gas in both sites.

Table 5: System-Level Electricity Savings Results

Site	System	Annual Electricity Savings (kWh/year)	Annual Electricity Savings (kWh/sqft/year)	Annual Electricity Savings (%)
Aurora Health Center	HVAC	11,400	0.76	17%
Aurora Health Center	Lighting	6,935	0.46	35%
Fond du Lac Library	HVAC	29,150	0.48	12%
Fond du Lac Library	Lighting (Including LED retrofit)	191,850	3.15	41%
Fond du Lac Library	Lighting (controls only)	56,170	0.92	12%

Across both sites, the integrated controls produced significant reductions in both HVAC and lighting energy use. Whole-building electricity savings ranged from 11% to 41%, with the highest relative gains in spaces where lighting control upgrades included both LED retrofits and advanced occupancy-based scheduling. HVAC savings were most pronounced where the controls enabled deeper setbacks during unoccupied periods. These results demonstrate HVAC+NLC integration is a cost-effective, scalable strategy for reducing commercial building energy use, with savings potential strongly influenced by occupancy patterns and control zone granularity.

CONCLUSIONS AND RECOMMENDATIONS

The NLC +HVAC demonstration projects achieved significant HVAC savings (12-17% system savings) by leveraging the NLC systems' occupancy-sensing capabilities to improve HVAC control. Expanding the potential for NLC systems to capture additional savings is critical to advancing adoption of this high-cost measure. At the same time, controls integration projects are technically complex to implement. As we saw with the attrition of two enrolled school sites, there is significant variability between buildings on the feasibility of implementing this strategy.

If Focus on Energy decides to develop a new offering to increase adoption of this strategy, the section below summarizes program design recommendations.

Program Recommendations

xi. **Target outreach on high opportunity market segments**: Adoption of controls integration opportunities is more likely among institutional market segments like schools and government as buildings are owner-occupied and customers may have sustainability goals making them more likely to pursue innovative strategies. DLC reports "the most potential value in large offices, retail, healthcare, and other high energy use buildings."[10] The Focus on Energy demonstration saw a lot of interest from an ESCO working with schools and we had to cap school participation at two sites to ensure a diversity of building types. Energy-intensive building types with variable occupancy schedules (education, government operations buildings like public works/safety, and outpatient healthcare are all good examples) also have more potential to benefit from this strategy. The DLC has published a decision tree detailing other factors leading to better savings potential like HVAC systems supporting VAV and existing or planned BAS.[11]

xii. **Screen candidate sites to ensure viable projects**: The initial screening process we used to vet potential sites was not as in depth as it needed to be for determining lighting system capabilities. To ensure project viability, it would be preferable to require submission of fully scoped lighting and HVAC integration costs from the vendors and ideally mapping of lighting and HVAC control zones.

xiii. **Leverage select trade allies to identify projects**: Both the owner-focused and trade ally-focused outreach pathways recruited projects for the demonstration, but we saw more traction from the trade allies. Due to the technical complexity of controls integration process, a small number of technically sophisticated vendors could potentially play a "project expediter" role to bring NLC+HVAC projects into the program. They would ideally have existing partnerships with lighting and HVAC subcontractors, acting as an owner's rep and providing a more streamlined pathway for customer participation.

xiv. **Prioritize full retrofit opportunities:** Doing a controls integration project with a previously installed NLC system involves greater than anticipated technical challenges and lighting system upgrade requirements. Focusing on a project scope including both NLC retrofit and HVAC controls integration appears to be the more viable long-term

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[10] DesignLights Consortium (2023, September 1). *Future Proofing Energy Efficiency with Networked Lighting Controls*. Accessed June 13, 2025. Available at: https://designlights.org/resources/reports/future-proofing-energy-efficiency-with-networked-lighting-controls/

[11] DesignLights Consortium (2025, February 6). *NLC-HVAC Integration Decision Tree.* Part of the *NLC-HVAC Integration Toolkit*. Accessed July 21, 2025. Available at: https://designlights.org/resources/reports/nlc-hvac-integration-toolkit/

program opportunity. This approach enables the owner and vendors to plan for all project requirements from the outset and has less potential for unexpected costs

xv. **Ensure accountability for resolving issues**: Encourage the project team to designate an "integration manager" responsible for trouble shooting if communications between lighting and HVAC system are not working properly.

xvi. **Ensure a clear process for verifying controls integration is complete**: Define expectations up front for participating vendors. Establish a clear process for verifying the integration is working correctly at the end of the project. Appendix B includes a verification checklist.

xvii. **Offer technical assistance and education to support market development**: These types of controls integration projects are not yet widely implemented. Dedicated technical assistance to customers and their vendors would help advance market understanding of best practices. During the demonstration, the research team's engineers provided HVAC control sequences (Appendix A) to guide the implementation effort and maximize savings. An engineer was available to answer questions and discuss the approach. In addition, informational resources and webinars could help build awareness of this strategy. One trade ally we engaged with, Faith Technologies, has implemented this type of controls integration at their own facility and expressed interest in hosting an informational event in partnership with Focus on Energy. Vendor capabilities range widely and a relatively small number of vendors will be capable of providing the necessary level of project support. Identify trade ally champions who can lead the way while supporting capacity-building activities like training and technical assistance. Market successful case studies to build interest in the approach.[12]

xviii. **Offer custom incentives:** Given the high degree of savings variability between different sites and building types, a custom incentive approach is more feasible than a prescriptive rebate. In addition, custom incentives calculated on the basis of energy savings are a more effective way of motivating controls sequences maximizing energy savings potential. While performance-based incentives also motivate the maximization of controls-driven savings strategies, they can also lead to longer timelines for incentive payment and greater programmatic complexity. The demonstration also offered an incentive of $5,000 to motivate the lighting and HVAC controls programmers to work collaboratively to address implementation challenges. This incentive was part of the total package making it feasible for the FDL project to proceed at no cost to the customer. With the clinic, the HVAC controls programming was done in-house by facility staff so the vendor collaboration scenario was not applicable. The customer still earned the incentive, however, making it part of the incentive package made it feasible to implement the needed updates to the NLC system to enable BACnet communication.

xix. **Streamline savings calculations**: DLC recommends incentive programs be as turnkey as possible.[13] The TRM workpaper (Appendix C) recommends a custom calculation

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[12] A project implementation guide and multiple case studies can be found at: https://slipstreaminc.org/tags/controls/integrated-controls. DLC's Integration Toolkit can be found at: https://designlights.org/lighting-hvac-integration/

[13] DesignLights Consortium (2023, September 1). *Future Proofing Energy Efficiency with Networked Lighting Controls*. Accessed June 13, 2025. Available at: https://designlights.org/resources/reports/future-proofing-energy-efficiency-with-networked-lighting-controls/

methodology combining a few accessible project-specific inputs with deemed savings factors by building typology for both the heating and cooling systems. This streamlined approach enables program administrators and evaluators to quantify savings confidently while reducing analytical burden.

Lessons Learned

The project team conducted a debrief and results presentation with each customer at the end of the project. Both customers were very pleased with the projects and the process. They would like to see a program offering benefitting future projects. We also engaged with several Focus on Energy trade allies interested in this approach, as discussed above.

Challenges and lessons learned include:

- The demonstration fell short of its recruitment target due to the disenrollment of two school sites. Recruiting some backup sites may have helped, but due to the long timeframes involved in project recruitment this was not something we were able to pursue.

xx. Other challenges with the disenrolled school sites were that the research team had no direct communication with the customer, only their energy services vendor. This made it challenging to obtain clear commitments about the level of expected effort from the customer and their vendor, as well as firm timelines. The vendor was juggling many projects and it seemed difficult to obtain focused attention on the research project.

- This demonstration tested the viability of doing the controls integration at sites which previously installed NLC systems. We determined this was likely not a viable program strategy because enabling BACnet capabilities is not a default option for most NLC projects. Planning for the controls integration at the outset of the NLC project is necessary.
- Thorough implementation and verification are important. Careful execution of the sequence of operations, along with proper commissioning, helps ensure the full energy savings potential of this or other controls-based measures can be achieved.
- Energy savings potential varies widely by site. While both pilot sites implemented the measure as proposed, their savings as a percentage of system energy use were on the lower end of the observed range. This variability underscores the importance of site characteristics in determining outcomes. Factors tending to produce higher savings include:
    - Long hours of operation
    - Significant variation in occupancy patterns throughout the day
    - A high number of enclosed spaces or HVAC control zones able to be independently set back during unoccupied periods

  Integration can still yield meaningful results even in buildings with lower variability in occupancy. Although the demonstration sites did not have all of the characteristics leading to high savings potential, both still demonstrated measurable savings without negatively affecting occupant comfort, indicating this strategy can be beneficial across a wide range of building types.

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APPENDIX A: HVAC CONTROL SEQUENCES

Target: AHU systems with single-duct variable-air volume (VAV) systems and VAV terminal units with hot water reheat.

Summary of proposed controls

- VAV Terminal Units with Hot Water Reheat
  - Occupancy control
  - Zone minimum primary airflow, and heating/cooling airflow
  - Cooling requests
  - Pressure requests
  - Heating requests for VAV with DAT Sensor
  - Heating requests for VAV without DAT Sensor or a Zone Radiant Heating Valve
  - Occupancy requests
- Multiple Zone VAV Air Handling Unit
  - AHU static pressure reset
  - AHU cooling SAT reset
  - AHU Zero Occupancy Control
- Hot Water Supply Temperature Reset

VAV Terminal Units with Hot Water Reheat

1.1 Setpoints and control modes

Thermostat control ("standby mode"). For VAV zones integrated to an occupancy point coming from a NLC system zone, it is required:

a. When the occupancy sensor indicates the space has been unpopulated for 5 minutes during the Occupied Mode, the active heating and cooling setpoints shall be decreased (setback) by 3° F (adj).
b. When the sensor indicates the space has been occupied for 30 seconds continuously, the active heating and cooling setpoints shall be restored to their previous values.
c. This occupancy control should not be employed during morning warm-up or for 15 minutes after.

1.2 Zone primary airflow. The airflow from the air handling unit to the ventilation zone, including outdoor air and recirculated air.

Zone minimum primary airflow

a. Select Vmin (VAV cooling MIN) to be the existing design zone minimum outdoor airflow rate, for use when space is occupied.
b. The minimum occupied airflow (Vmin) should match existing design unless the zone's occupancy sensor detects an unoccupied condition and the space temperature setpoint

is satisfied, in which case Vmin should be set to 0. In other words, the VAV box's airflow setpoint or damper command can be set to 0 in unoccupied conditions.

c. Use existing design values for cooling airflow setpoint (Vcool-max) and heating airflow setpoint (Vheat-min).
d. Active maximum and minimum heating and cooling airflow setpoints shall vary depending on the Mode of the zone (Table 6):

Table 6: Set points as a function of zone group mode

Setpoint	Occupied	Standby or Unoccupied
Cooling maximum	Vcool-max	0
Cooling minimum	Vmin	0
Heating minimum	Vmin	0
Heating maximum	Vheat-max	0

e. In larger spaces such as fitness centers or open offices, adjust the VAV minimum setpoint dynamically between 0 and Vmin based on the percentage of space occupied by lighting fixtures in the HVAC zone registering occupancy.

1.3 System Resets for Zone-Level Input in Digital VAV Boxes: A suppression period, adjustable to a value like 1 minute, can be implemented. This period allows for accommodating rapid changes in the thermostat slider setpoint, ensuring the output does not impact the AHU (Air Handling Unit) system-level setpoint adjustments until after the suppression period has elapsed.

i. Cooling Requests:

a. If the zone temperature exceeds the zone's cooling setpoint by 5° F for 2 minutes and after suppression period due to setpoint change, send 3 requests.
b. Else if the zone temperature exceeds the zone's cooling setpoint by 3° F for 2 minutes and after suppression period due to setpoint change, send 2 requests.
c. Else if the Cooling Loop is greater than 95%, send 1 request until the Cooling Loop is less than 85%.
d. Else if the Cooling Loop is less than 95%, send 0 requests.

xxi. Pressure Requests:

a. If the measured airflow is less than 50% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 3 requests.
b. Else if the measured airflow is less than 70% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 2 requests.
c. Else if the damper position is greater than 95%, send 1 request until the damper position is less than 85%.
d. Else if the zone temperature is satisfied send 0 cooling Requests.

xxii. **Heating Requests:** If there is a VAV with DAT sensor and Hot-Water Coil, Hot-Water Reset Requests

a. If the DAT is 30° F less than setpoint for 5 minutes, send 3 requests.
b. Else if the DAT is 15° F less than setpoint for 5 minutes, send 2 requests.
c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.
d. Else if the HW valve position is less than 95%, send 0 requests.

xxiii. **Heating Requests:** If there is a VAV without DAT sensor and Hot-Water Coil or Zone Radiant Hot-Water Coil, Hot-Water Reset Requests

a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.
b. Else if the HW valve position is less than 95%, send 0 requests.

xxiv. **Occupancy Requests**: This refers to the occupancy point integrated from the NLC system indicating the zone is populated.

Multiple Zone VAV Air Handling Unit

AHU Static Pressure. Reset static pressure with Trim & Respond logic using the parameters shown in Table 7:

Table 7: Supply air pressure trim & respond variables.

Variable	Value
Device	Supply Fan

Variable	Value
SP_0	120 Pa. (0.5 inches)
SP_{min}	25 Pa. (0.1 inches)
SP_{max}	Maximum Design Static Pressure
T_d	10 minutes
T	2 minutes
I	2
R	Zone Static Pressure Reset Requests (see section 1.5.ii)
SP_{trim}	-12 Pa (-0.05 inches)
SP_{res}	15 Pa (+0.06 inches)
$SP_{res-max}$	32 Pa (+0.13 inches)

1. **Device**: AHU variable supply fan.
2. **SP0**: This value represents an initial setpoint value for duct static pressure. It's the starting point for the control loop associated with the supply fan.
3. **SPmin**: This value represents the minimum allowed duct static pressure setpoint. The control system will not allow the pressure to go below this value.
4. **SPmax**: This value is not provided directly in the table but is referred to as "Max_DSP," or existing duct static pressure setpoint. It represents the maximum allowed duct static pressure setpoint. The control system will not allow the pressure to exceed this value.
5. **Td**: This value represents a time constant or time delay for some aspect of the control loop or response time associated with duct static pressure.
6. **T**: This value represents another time constant or time delay for a different aspect of the control loop or response time associated with duct static pressure.
7. **I**: This is the number of ignored requests.
8. **R**: This represents a variable related to the number of zone pressure requests.
9. **SPtrim**: This value represents an adjustment able to be made to the duct static pressure setpoint.
10. **SPres**: This value represents another adjustment to the duct static pressure setpoint.
11. **SPres-max**: This value represents a maximum allowable adjustment to the duct static pressure setpoint under certain conditions.

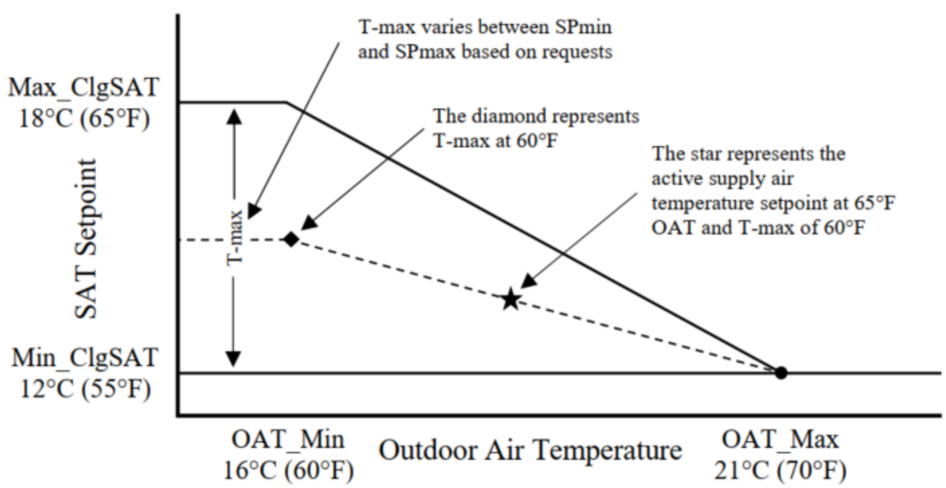
AHU SAT.

Reset Discharge Air Temperature with Trim & Respond logic using the parameters shown in Table 3.

a. During Occupied Mode and Setup Mode, setpoint shall be reset from Min_ClgSAT when the outdoor air temperature is OAT_Max and above, proportionally up to T-max when the outdoor air temperature is OAT_Min and below.
b. T-max shall be reset using linear reset between Min_ClgSAT and Max_ClgSAT. The parameters shown in Table 3 are suggested as a starting place, but they will require adjustment during the commissioning/tuning of the system.
c. During Cooldown Mode, the setpoint shall be Min_ClgSAT.
d. During Warmup Mode and Setback Mode, the setpoint shall be 95° F.

Table 8: Supply air temperature trim & respond variables.

Variable	**Value**
Device	Supply Fan
SP_0	SPmax
SP_{min}	Min_ClgSAT
SP_{max}	Max_ClgSAT
T_d	10 minutes
T	2 minutes
I	2
R	Zone cooling SAT requests
SPtrim	+0.2°F
SPres	-0.3°F
SPres-max	-1.0°F



1. **Device**: AHU variable supply fan.
2. **SP0**: This represents an initial setpoint value for the control loop associated with the supply fan.
3. **SPmin**: This represents the minimum allowed Supply Air Temperature (SAT) setpoint, which is associated with "Min_ClgSAT" (Minimum Cooling SAT).

4. **SPmax**: This represents the maximum allowed SAT setpoint, which is associated with "Max_ClgSAT" (Maximum Cooling SAT).
5. **Td**: This value represents a time constant or time delay for some aspect of the control loop or response time.
6. **T**: This value represents another time constant or time delay for a different aspect of the control loop or response time.
7. **I**: This is the number of ignored requests.
8. **R**: This represents a variable related to the number of zone temperature cooling requests.
9. **SPtrim**: This value represents an adjustment able to be made to the SAT setpoint, for fine-tuning or control optimization.
10. **SPres**: This value represents another adjustment to the SAT setpoint, which may be related to response or reset logic.
11. **SPres-max**: This value represents a maximum allowable adjustment to the SAT setpoint under certain conditions.

Outside Airflow Setpoint Control: The Air Handling Unit (AHU) outside air flow setpoint is to be continuously recalculated when the building is in occupied mode.

1. **Determining Zone Occupancy**:
    - Occupancy status for a particular zone *for the purposes of calculating outdoor airflow* is determined by either:
        - Occupancy status from the network lighting control (NLC) system associated with the VAV box in the NLC-designated zone, or
        - If present, zone level CO2 measurements.
2. **Partial Occupancy**:
    - Each zone becoming occupied will start a minimum timer of 15 minutes (adjustable). The zone's occupancy status should not revert to unoccupied until this timer expires, even if the zone indicates it is unoccupied during this period.
    - For each Variable Air Volume (VAV) system zone occupied (indicates true occupancy), increase the AHU outside air flow setpoint by the amount of the zone's existing designed Cooling CFM Minimum air flow setpoint.
    - AHU outside air flow should never exceed the pre-established design outside air flow setpoint (for full occupancy).

AHU Zero Occupancy Control

The section above for VAV **Zone minimum primary airflow** states VAV's go to zero air flow only if the building is occupied and the zone setpoint is satisfied. On the event if zone setpoints are satisfied and the NLC integration to VAV box zones indicates zero occupancy for the AHU system serving those VAV boxes during normal occupied hours as determined by the BAS schedules:

- Index the AHU to off if all VAV box dampers are commanded to zero percent.
- Turn associated exhaust systems (e.g., toilets exhaust) off.

During normal occupied hours, if the AHU is off due to zero occupancy, allow the AHU to remain off until two requests for occupancy are received by the VAV system:

- Adjust to one request for small VAV AHU systems of 10 boxes or less.
- Adjust up to three required occupancy requests for large VAV systems serving 20 to 30 VAV boxes, or tune as necessary.

Hot Water Distribution System

Hot Water Supply Temperature Reset. Reset static pressure with Trim & Respond logic using the parameters shown in Table 9:

Table 9: Boiler hot water plant temperature setpoint trim & respond variables.

Variable	Value
Device	Hot Water Plant Setpoint
SP_0	110 °F *
SP_{min}	110 °F *
SP_{max}	160 °F
T_d	10 minutes
T	2 minutes
I	2
R	Zone Hot Water Requests
SP_{trim}	-2 °F
SP_{res}	+2 °F
$SP_{res-max}$	+6 °F

1. **Device**: Boiler hot water temperature setpoint.
2. **SP0**: This represents an initial setpoint value for the control loop associated with the hot water plant temperature setpoint.
3. **SPmin**: This represents the minimum allowed Boiler Plant Hot Water Temperature Setpoint. * For non-condensing boilers, it is recommended to use a minimum setpoint temperature of 140 °F to ensure proper operation.
4. **SPmax**: This parameter represents the maximum allowable Boiler Plant Hot Water Temperature Setpoint, measured in degrees Fahrenheit (°F). It is essential to cross-reference this value with the HVAC design schedules to ensure compatibility with the coil specifications in the hot water system. * Typically, a setpoint temperature of 160 °F is considered safe to use, even if the coils were originally designed for a higher temperature of 180 °F. However, in newer buildings, the hot water system may have been designed for a lower temperature, such as 140 °F. Therefore, always verify the design schedules to determine the appropriate SPmax for your specific system.
5. **Td**: This value represents a time constant or time delay for some aspect of the control loop or response time.
6. **T**: This value represents another time constant or time delay for a different aspect of the control loop or response time.

7. **I**: This value is the number of ignored requests.
8. **R**: This represents a variable related to the number of zone temperature cooling requests.
9. **SPtrim**: This value represents an adjustment able to be made to the SAT setpoint, for fine-tuning or control optimization.
10. **SPres**: This value represents another adjustment to the SAT setpoint, which may be related to response or reset logic.
11. **SPres-max**: This value represents a maximum allowable adjustment to the SAT setpoint under certain conditions.

APPENDIX B: VERIFICATION CHECKLIST

The nature of this measure – controls integration with no clear visible change – requires some amount of verification to ensure success. Two options are provided. A minimum verification is an option where programs are more scaled and markets are more mature, and there is some confidence in integrators to execute these projects. A full verification is also provided, where the program is newer, the market has less experience with this approach, or there is simply more time for verification.

Minimum verification

If possible, at least a week prior to retrofit set up data trends on SAT, static pressure, and zone airflow in the largest 10% of zones. These would make verification easier after retrofit.

Function	Documentation	Complete
Commissioning HVAC Controls: Confirm commissioning checks have been completed to verify occupancy-based zone temperature and airflow setpoints are changing appropriately to both occupied and unoccupied states.	Commissioning checklist, BAS screenshots, or data trend charts. Need evidence of some (not all) key zones showing some are responding; 10% may be adequate. If zone airflows are allowed to modulate to zero, simply verify they are fully shut at times. If the minimum is non-zero, compare zone airflow to either occupancy data or pre-retrofit minimum setpoints. Also check thermostat setpoints are changing even throughout the regularly scheduled operation of the HVAC system.	☐
AHU-Level Controls Commissioning: Review and document the final settings of the AHU reset programming (e.g. trim and respond), confirming adjustments in setpoints related to duct static pressure and AHU leaving air temperature dynamically change.	Commissioning checklist, BAS screenshots, or data trend charts verifying HVAC responds to lighting occupancy signals as expected. Screenshots need to document permanent setting of tuned T&R setpoints. Ideally compare SAT and duct static with pre-retrofit levels; otherwise, further analysis may be needed based on number of zones occupied.	☐

Full verification

Complete everything from basic verification, plus as much of the following as possible:

Function	Documentation	Complete
BACnet Integration Confirmation: Verify the BACnet protocol is properly configured in the HVAC building automation system (BAS)	BACnet device configuration screenshots (online/offline status and points) of the NLC devices documenting the successful connection and communication between lighting and HVAC control systems.	☐
Occupancy Data Visualization: Ensure occupancy data captured from NLC is visibly integrated and displayed on BAS graphics for each HVAC variable air volume (VAV) zone and/or table view of entire NLC system on the HVAC BAS, enabling real-time monitoring by building operators.	BAS Screenshots of user interface GUI for HVAC zones.	☐
HVAC Timeout Settings Verification: Validate the tuning of occupancy timeout settings for each HVAC zone to ensure efficient operation and energy savings, with documentation of settings for permanent records.	Commissioning checklist, BAS screenshots, or data trend log charts verifying HVAC responds to lighting occupancy signals as expected.	☐
Documentation and Record Keeping: Ensure all commissioning data, including AHU Trim and Respond (T&R) settings, BAS configurations, system settings, and operational data are thoroughly documented and integrated into the client's permanent record-keeping system. This integration facilitates easy access for maintenance, future upgrades, and ensures consistent reference for all building systems and operational efficiencies.	PDF submittal records typical to HVAC industry mechanical contracting where owner has been provided documentation for record-keeping purposes to document how the building is operating. If the BAS supports PDF uploads, relevant documentation should be uploaded. Critical setpoints or sequences may also be added as comments within the appropriate GUI screens.	☐
Troubleshooting and System Adjustment: Training has been conducted for building operators for troubleshooting.	Training checklist signed by BAS controls vendor	☐

APPENDIX C: TRM WORK PAPER

HVAC Integration to Network Lighting Controls

	Measure Details
Measure Master ID	
Workpaper ID	
Measure Unit	
Measure Type	Hybrid
Measure Group	HVAC
Measure Category	Controls
Sector(s)	Commercial, Schools & Government
Annual Energy Savings (kWh)	Varies by principal building activity
Summer Peak Demand Reduction (kW)	0
Winter Peak Demand Reduction (kW)	0
Annual Therm Savings (Therms)	Varies by principal building activity
Lifecycle Energy Savings (kWh)	Varies by principal building activity
Lifecycle Therm Savings (Therms)	Varies by principal building activity
Water Savings (gal/year)	0
Effective Useful Life (years)	12[1]
Incremental Cost ($/unit)	

Measure Description

HVAC integration to networked lighting controls (NLC) generates HVAC savings by using the luminaire level lighting control sensors to control HVAC setpoints. When the lighting fixture sensors detect unoccupancy in each HVAC control zone, the airflow and temperature setpoints can be adjusted to decrease ventilation, heating, and cooling energy.

Description of Baseline Condition

The baseline condition is an interior lighting system that does not include connected controls strategies. Additionally, the baseline condition for the measure requires an HVAC system in which *individual zones* can be effectively turned down or off via temperature setpoints or ventilation control with input from the occupancy sensors. Some traditional examples include packaged, split, or built-up air handlers, VAV systems, rooftop units, radiant and chilled beam systems, and distributed heat pump systems.

Description of Efficient Condition

The efficient condition includes a networked lighting control system listed on the DLC NLC QPL (Technical Requirements Table v4.0 or higher) that is integrated with the HVAC control sequences. The HVAC system is programmed to respond to occupancy signals from the lighting sensors by reducing ventilation, heating, and cooling setpoints during unoccupied periods. HVAC control sequences should include:

- Thermostat setback
- VAV terminal airflow reduction
- VAV resets based on occupancy (can include some combination of vent reset, demand control ventilation, static pressure, and supply air temperature resets)

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The HVAC system must be capable of zone-level control, with one controller/thermostat per room or per every few rooms (e.g. VAV, distributed heat pumps, small rooftop units, chilled beams, etc.). HVAC systems with a single AHU serving a large area with many rooms (e.g. a single zone RTU serving an entire small office, or 10 or more rooms in a building, etc.) are not applicable.

Annual Energy-Savings Algorithm

$$kWh_{SAVED} = (Area * EEI_{COOL}) * SF_{COOL} * \frac{HOU}{HOU_{TYPICAL}}$$

$$Therm_{SAVED} = (Area * GEI_{HEAT}) * SF_{HEAT} * \frac{HOU}{HOU_{TYPICAL}}$$

Annual Energy and Coincident Peak Demand Savings Variables

Variable	Description	Units	Value
Area	Total gross area of building	sqft	User defined input
$\mathrm{EEI_{COOL}}$	Electricity energy intensity of cooling system	kWh/sqft	Varies by principal building activity, see table below
$\mathrm{SF_{COOL}}$ [2,3,4,5,6,7,8,9,10]	Deemed cooling savings factor	%	Varies by principal building activity; see table below; 30% default
HOU	Hours of operation per day	Hours/day	User defined input
$\mathrm{HOU_{TYPICAL}}$	Typical hours of operation per day	Hours/day	Varies by principal building activity, see table below
GEI_{HEAT}	Gas energy intensity of heating system	Therms/sqft	Varies by principal building activity; see table below
$\mathrm{SF_{HEAT}}$ [2,3,4,5,6,7,8,9,10]	Deemed heating savings factor	%	Varies by principal building activity, see table below; 28% default

Energy End Use Intensities and Hours of Use by Principal Building Activity

Principal building activity	EEI_{COOL} [11]	GEI_{HEAT} [5]	HOU [12]	SF_{COOL}	SF_{HEAT}
Education	4.8	27.4	8.50	25%	25%
Food sales	9.6	41.1	15.19		
Food service	16	37	12.28		
Health care	11.3	46.6	10.07		
Inpatient	13.5	58.3	10.07		
Outpatient	8.3	28.1	10.07	17%	9%
Lodging	6.8	16.5	9.19	60%	60%
Mercantile	6.9	21.4	11.58	31%	28%
Retail (other than mall)	6.8	19	11.58	45%	45%
Enclosed and strip malls	6.8	22.9	11.58		
Office	6.8	22.7	9.66	31%	28%
Public assembly	8.6	41.1	7.48	12%	12%
Public order and safety	6.5	28.5	9.38	31%	28%
Religious worship	2.8	19.6	7.48	31%	28%

Principal building activity	EEI_{COOL} [11]	GEI_{HEAT} [5]	HOU [12]	SF_{COOL}	SF_{HEAT}
Service	4.1	41	7.48	31%	28%
Warehouse and storage	2.5	19.1	9.49	30%	30%
Other	7.7	31.9	10.06		
Vacant	3	20.1	0.00		

Coincident Peak Demand Savings Algorithms

There are no peak savings associated with this measure.

Assumptions

The baseline HVAC system's electric and natural gas usages are estimated using CBECS data. If actual baseline values are available, they should replace the portion of the equation enclosed in parentheses.

The deemed savings factors are based on a compilation of results from several studies complied by DLC. There was a total number of 21 sites, the results of which were averaged by principal building activity.

To account for sites with abnormally large or small hours of operation, they are scaled by typical annual hours by principal building activity.

The CBECS Survey Data documents several electricity end uses. For the measure calculations, electric space heating, ventilation, and cooling were all summed to get Electricity energy intensity of cooling system.

The CBECS Survey Data presents gas energy intensity in cubic feet of gas per square feet. This was converted to Therms using EIA's 2024 reported heat content of natural gas for Wisconsin of 1,045 Btu per cubic foot.[13]

Revision History

Version Number	Date	Description of Change
00	10/2025	DRAFT II

[1] DesignLights Consortium. Economic Potential of Networked Lighting Controls in Commercial Buildings. August 2023.

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[3] Better Buildings, U.S. Department of Energy, "Field Validation of Lighting Retrofit with HVAC Integration and Plug Load Controls at CentraCare in Becker, Minnesota," 2021, https://integratedlightingcampaign.energy.gov/sites/default/files/2023-07/EED_2282_FLYER_CentraCare-FieldVal_FINAL2.pdf.

[4] PNNL, U.S. Department of Energy, "Lighting System Integration with HVAC and Plug Loads: Tinker Air Force Base," 2021, https://integratedlightingcampaign.energy.gov/sites/default/files/2021-02/EED_1063_BROCH_ESTCPbrand.pdf.

[5] Whipple, Jason, IBIS, "Occupancy Enabled HVAC Optimization Case Study," 2022, https://www.ibismsi.com/occupancy-enabled-hvac-optimization-case-study/.

[6] New Building Institute, California Energy Commission, "California State University Dominguez Hills—James L. Welch Hall," 2021, https://filesnewbuilding.s3.amazonaws.com/wp-content/uploads/2021/05/Retrofit-Tech-Case-Study_CSU_FINALv5.pdf.

[7] Enlightened, Building Robotics Inc., " Menlo Business Park Case Study," "California State University, Long Beach Case Study," 2022, https://www.enlightedinc.com/wp-content/uploads/2022/09/Enlighted_Casestudy_Menlo-Rev01.pdf.

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[9] Pellegrino, et al., IEEE, "Lighting Control and Monitoring for Energy Efficiency: A Case Study Focused on the Interoperability of Building Management Systems," June 2015, https://www.researchgate.net/publication/277751115_Lighting_Control_and_Monitoring_for_Energy_Efficiency_A_Case_Study_Focused_on_the_Interoperability_of_Building_Management_Systems.

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[11] U.S. Energy Information Administration. 2018 CBECS Survey Data. Tables E6:Electricity consumption intensities and E8: Natural gas consumption and intensities.

[12] PA Consulting Group Inc. State of Wisconsin Public Service Commission of Wisconsin Focus on Energy Evaluation Business

Programs: Deemed Savings Manual V1.0. Table 3-5 Hours of Use Values. March 22, 2010.

[13] U.S. Energy Information Administration. Heat Content of Natural Gas Consumed. https://www.eia.gov/dnav/ng/ng_cons_heat_a_epg0_vgth_btucf_a.htm.

APPENDIX D: AURORA HEALTH CENTER ANALYSIS

This Appendix summarizes key characteristics about the Aurora Health demonstration site and details its lighting and HVAC systems. Additionally, it summarizes the steps taken to collect and analyze building data, quantifying the energy impacts resulting from the integration of NLC and HVAC controls.

Site Details

Building Information and Profile

The facility located at 1005 Spring City Drive in Waukesha, WI, is an active outpatient clinic with a building area of approximately 15,000 gross square feet. Figure 1 below shows an aerial view of the site where the top of the image is facing north.

Figure 1: Aerial image of site taken from Google Earth

HVAC Design

The building is served by two 7,500 CFM air handling units, each with an economizer section, supply fan, exhaust fan, gas fired preheat burner, and 20-Ton DX cooling coil. AHU-1 primarily serves the northern portion of the building, with AHU-2 serving the southern portion. Each unit serves several variable air volume terminal air boxes with hot water reheat. The hot water loop is served by two 500 MBH gas-fired condensing hot water boilers.

Lighting Design

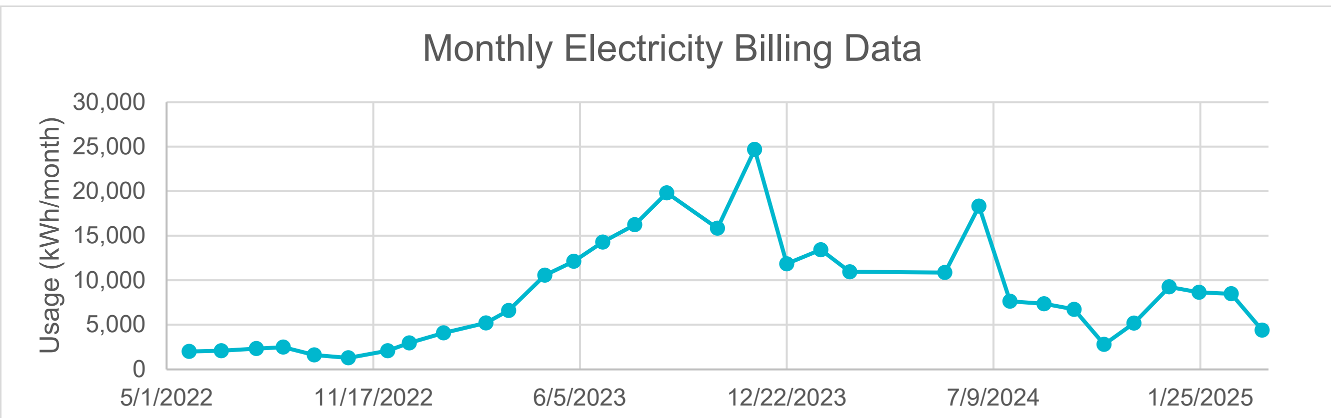
The pre-implementation lighting system consisted mainly of 2'x2' and 2'x4' LED fixtures with a mix of manual switching, vacancy sensing, and occupancy sensing controls. Some areas included dimmable fixtures with wall-mounted controls. The post-implementation system retained the same fixtures but integrated the lighting controls and sensors into the HVAC control system using the nLight platform. Because the fixtures remained unchanged, all lighting system savings are attributed to the updated controls. (This was referred to in the main report as the “integration-only” scenario.)

Baseline Energy Information

The project team obtained historical energy usage data from the utility, on-site PV generation data, and whole building monitored data. The following sections describe our findings for each dataset.

Monthly Utility Data

The site purchases electricity and natural gas through We Energies. The project team obtained electricity and natural gas cost and usage data spanning May 2022 to March 2025 as well as a single bill for the month of September 2023. The billing usage data is summarized in Figure 2 below.



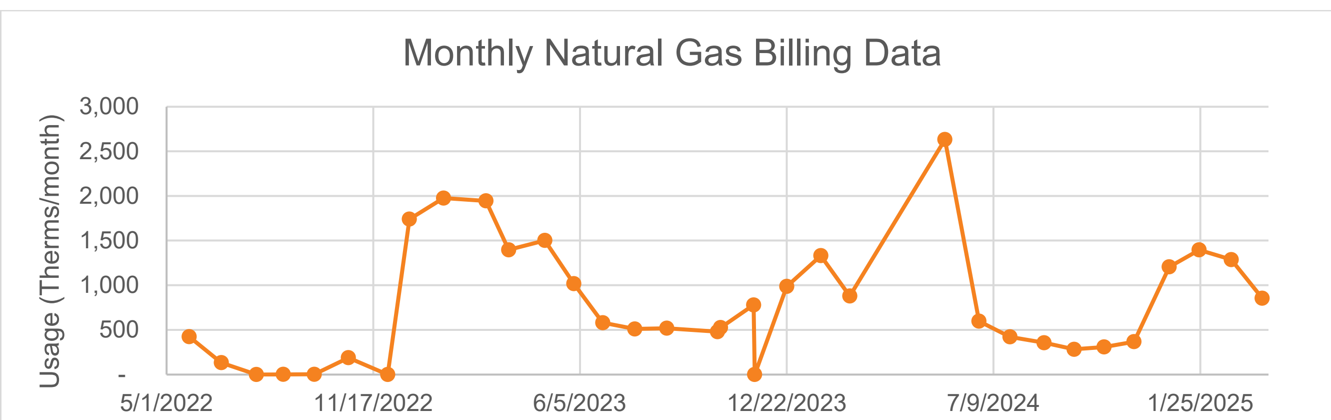


Figure 2: Monthly Utility Usage Data for Electricity (top) and Natural Gas (bottom)

The electricity and natural gas trends do not follow a typical monthly profile due to several factors. The dataset begins in May 2022 but a major renovation took place in 2023, and the building was not fully occupied until fall 2024. Outliers and missing data, often caused by billing true ups, are also present. Additionally, on-site solar PV was installed, which, depending on whether it is front of or behind the meter, can cause summer electricity usage to underrepresent the building’s actual load.

The missing data was filled using averages of adjacent months to estimate baseline year usages spanning September 2023 to August 2024, resulting in annual electricity and natural gas usages of around 160,500 kWh and 9,500 therms respectively. The total annual cost was estimated to be $24,300 and $5,500 for electricity and natural gas, respectively, or $29,800 total. This results in blended rates of $0.15 per kWh for electricity and $0.58 per therm for natural gas.

Table 10: Baseline Year (Sep 2023 to Aug 2024) Utility Billing Data Summary

	Annual Use (kWh or Therms/year)	Annual Cost ($/year)	Blended Rate ($/kWh or Therms)	EUI (kBTU/sqft)
Electricity (kWh)	160,500	$24,300	$0.15	36.5
Natural Gas (Therms)	9,500	$5,500	$0.58	63.3
Total		**$29,800**		**99.8**

According to ENERGY STAR Portfolio Manager,[14] the national median site EUI for clinics is 64.5 kBTU/sqft. The site's baseline EUI was 55% higher than this median, placing it in a less efficient category before the NLC integration was installed.

Monitored Building Electricity Data

Because interval meter data was not available from the utility, the project team monitored the electricity use at the main panels to validate the baseline energy calculations and savings estimates. The analysis mirrored the HVAC savings calculations but because this is just a validation step, we provide only a brief summary of the results. The monitored baseline data spans from 4/26/2024 to 8/26/2024. The results of this validation step calculate an annualized usage of 165,900 kWh, which supports the baseline usage estimated from utility bills.

Solar Photovoltaic Interval Data

The site had rooftop solar PV panels installed during the data collection period. The project team obtained hourly interval data of the array’s production, in watts, across two inverters. The data ranges from 3/12/2024 to 11/13/2024. It was aggregated to monthly kWh to estimate annual production. Because data for March and November were incomplete, the partial data was assumed to be representative and scaled appropriately. For January, February, and December, which had no data, an average of March and November’s production was used to estimate these months. The results suggest an annual solar production of approximately 84,000 kWh per year. These results are shown in Figure 3 below. The project team used NREL’s PVWatts Calculator[15] to substantiate this dataset. Typical assumptions produced a similar estimate, reinforcing the validity of the dataset.

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[14] https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf

[15] https://pvwatts.nrel.gov/index.php

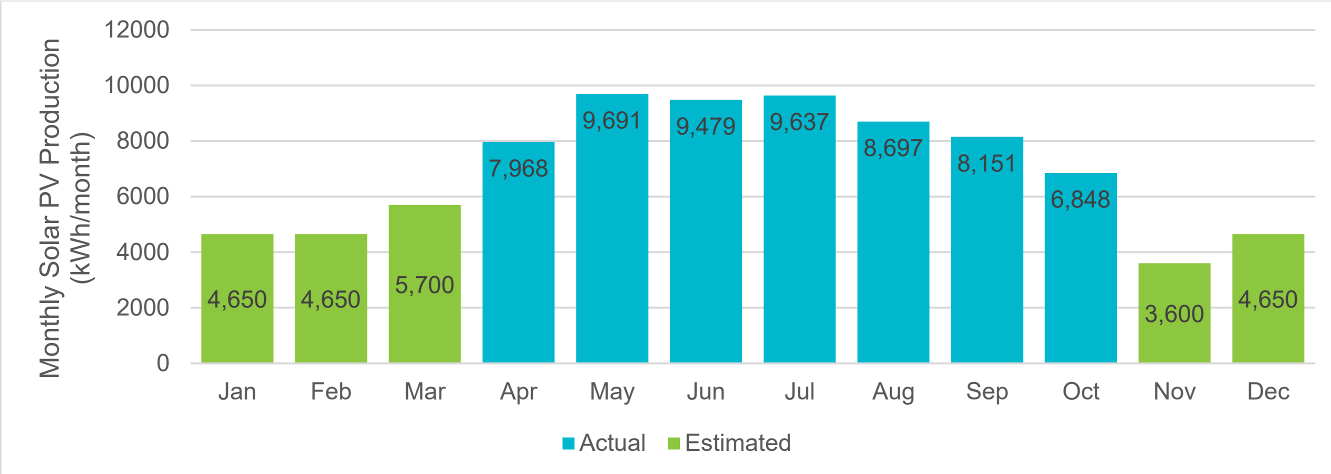


Figure 3: Monthly Solar PV Production

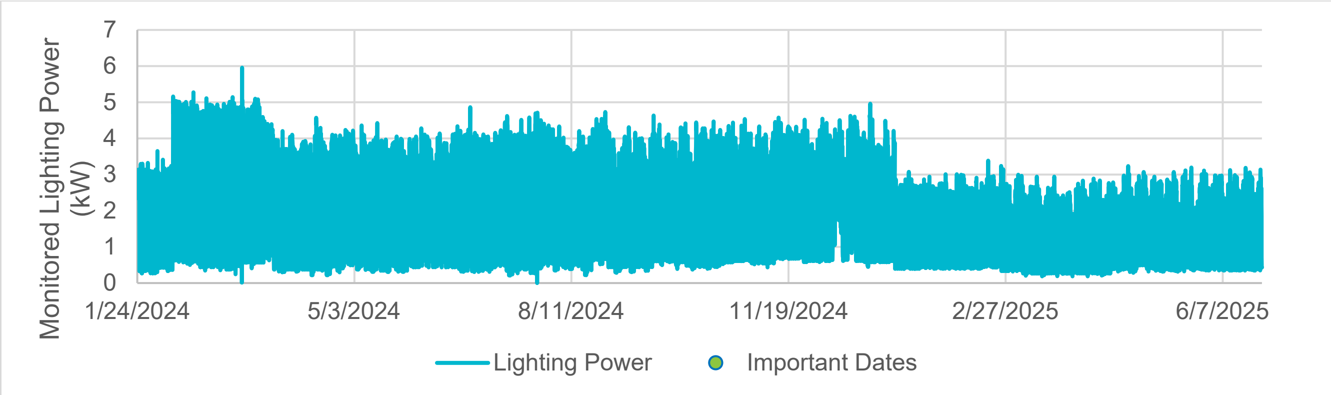
Lighting System Energy Savings Calculations

Lighting System Data Collection

The project team used eGauge monitoring equipment to collect baseline lighting system data and calculate savings. True power sensors were installed on individual lighting circuits in the electrical panels, measuring power (watts) at one-minute intervals. All lighting panels were captured, enabling accurate calculation of total system savings.

Lighting System Data Analysis

The lighting system was monitored from 1/24/2024 to 6/24/2025. One-minute interval data was aggregated to hourly for analysis, as summarized in Figure 4 below.



Date	Notes
1/24/2024	Start of eGauge data collection
4/26/2024	Issues in eGauge setup solved
8/26/2024	New system installed, integrating sequences
11/12/2024	Preliminary analysis shows no lighting savings, results shared with team
1/14/2025	Follow up with building team, integration complete
6/25/2025	End of eGauge data collection

Figure 4: Hourly Monitored Lighting System Power with Important Dates Highlighted

Data collection began on 1/24/2024 but was impacted by setup issues which were resolved by 4/26/2024. As such, the pre-installation period is defined as 4/26/2024 to 8/26/2024, when upgrades were completed, and network lighting control sequences were enabled. A preliminary analysis conducted with data through 11/12/2024 showed no significant savings. This finding was shared with the building team, and control sequence corrections were implemented by 1/14/2025. The period from 8/26/2024 to 1/14/2025 is considered a transition phase and excluded from analysis. Post-installation data collection continued through 6/25/2025, with the post-installation period defined as 1/14/2025 to 6/25/2025.

The network lighting controls reduced both peak power and overall energy use by turning off lights during unoccupied periods. Since the building's operating hours remained roughly the same, all calculated savings can be attributed to the network lighting controls. Manual and time-based controls had already been optimized in the pre-installation period. To show a typical daily pattern, power data was averaged by hour across both the pre- and post-implementation periods. The results are shown in Figure 5 below.

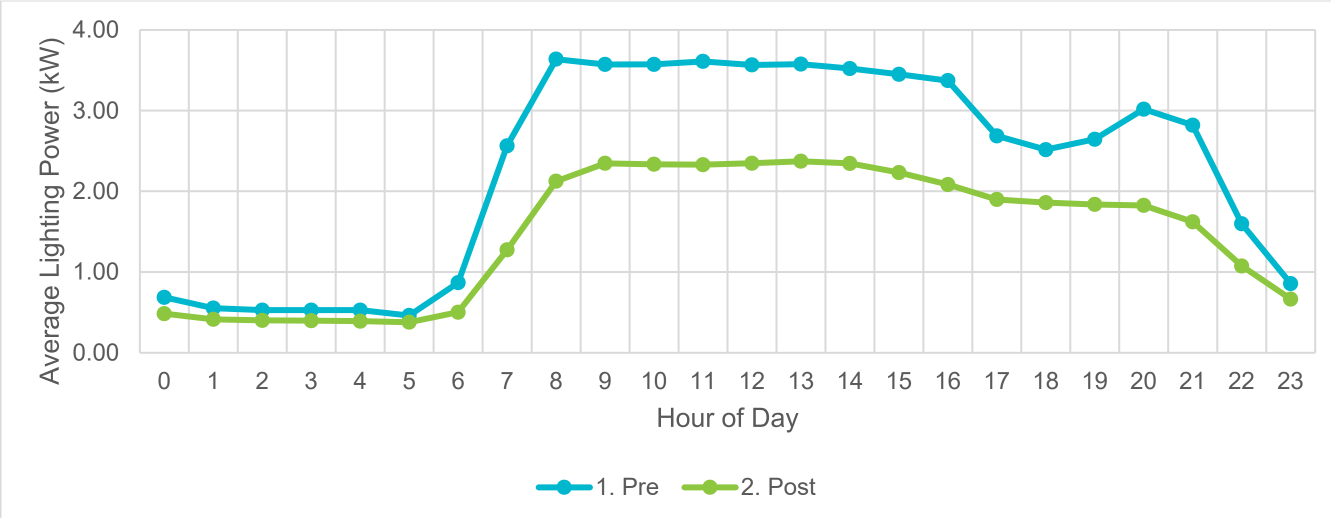


Figure 5: Typical Daily Lighting Power Profile Pre versus Post

Lighting System Savings Results

Table 11: Lighting Savings Summary

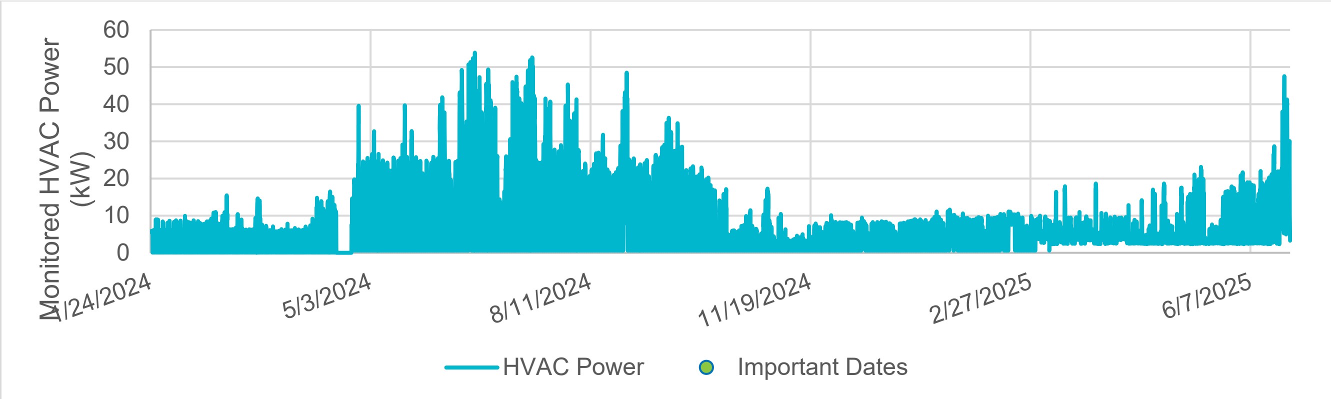
	Average Daily Electricity Use (kWh/day)	Average Daily Peak Power (kW)	Annual Electricity Use (kWh/year)	Annual Electric Bill Cost ($/year)
Pre-Installation	55	4.9	20,075	$3,000
Post-Installation	36	3.4	13,140	$2,000
Savings	**19**	**1.5**	**6,935**	**$1,000**
Savings (%)	**35%**	**30%**	**35%**	**33%**

HVAC System Electricity Savings Calculations

HVAC System Electric Data Collection

The project team used eGauge monitoring equipment to collect baseline HVAC system data and calculate savings. True power sensors were installed on the two AHU's main electrical panels, measuring power (Watts) at one-minute intervals of both fan and compressor power. All HVAC panels were captured, enabling accurate calculation of total system savings.

The HVAC system was monitored from 1/24/2024 to 6/24/2025. One-minute interval data was aggregated to hourly for analysis, as summarized in Figure 6 below.



Date	Notes
1/24/2024	Start of eGauge data collection
4/26/2024	Issues in eGauge setup solved
9/26/2024	Installation begins with updated sequences to AHU2
10/10/2024	Installation completed with updated sequences to AHU1
6/25/2025	End of eGauge data collection

Figure 6: Hourly Monitored HVAC System Power with Important Dates Highlighted

Data collection began on 1/24/2024 but was impacted by setup issues, which were resolved by 4/26/2024. As such, the pre-installation period is defined as 4/26/2024 to 9/26/2024, when upgrades began, and AHU-2 control sequences were enabled. Control sequences for AHU-1 were implemented by 10/10/2025. The period from 9/26/2024 to 10/10/2025 is considered a transition phase and excluded from analysis. Post-installation data collection continued through 6/25/2025, with the post-installation period defined as 10/10/2025 to 6/25/2025.

A summary of the daily HVAC electric use versus outdoor air temperature is depicted in Figure 7 below.

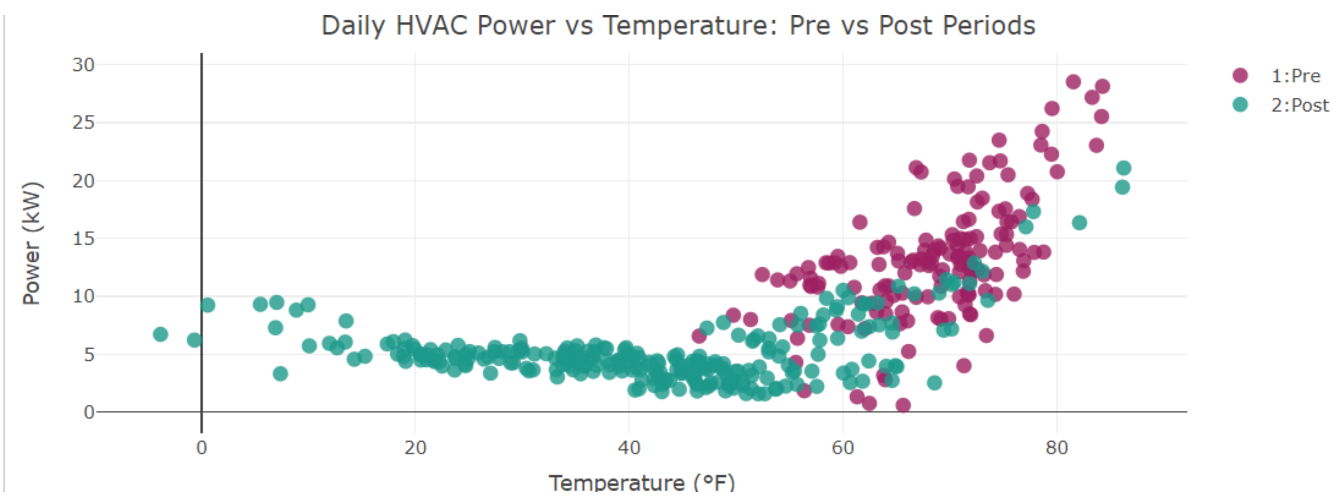


Figure 7: Daily HVAC Electric Use versus Outdoor Air Temperature – Pre vs Post

From the data, there is evidence of a drop in daily electricity use between the two monitoring periods in the cooling season. This data was used to normalize electric use versus outdoor air temperature, annualize electricity use, and calculate savings.

HVAC System Electric Data Analysis

To account for differing weather conditions between the two monitoring periods, the project team normalized daily electricity consumption (kWh/day) by regressing it against average daily outdoor air dry-bulb temperature (°F). Actual meteorological year (AMY) weather data was sourced from Milwaukee Mitchell International Airport.[16] Separate regressions were developed for the pre- and post-installation periods.

The project team evaluated three types of change-point models to capture weather-sensitive energy use, including both heating and cooling loads: 5-paremeter (5P), 3-parameter cooling (3PC), and 3-parameter heating (3PH) models.[17] More specifically, the segmented package[18] in R-software was used to generate the models.

The results of these regressions, including R² values, are summarized in Figure 8 below.

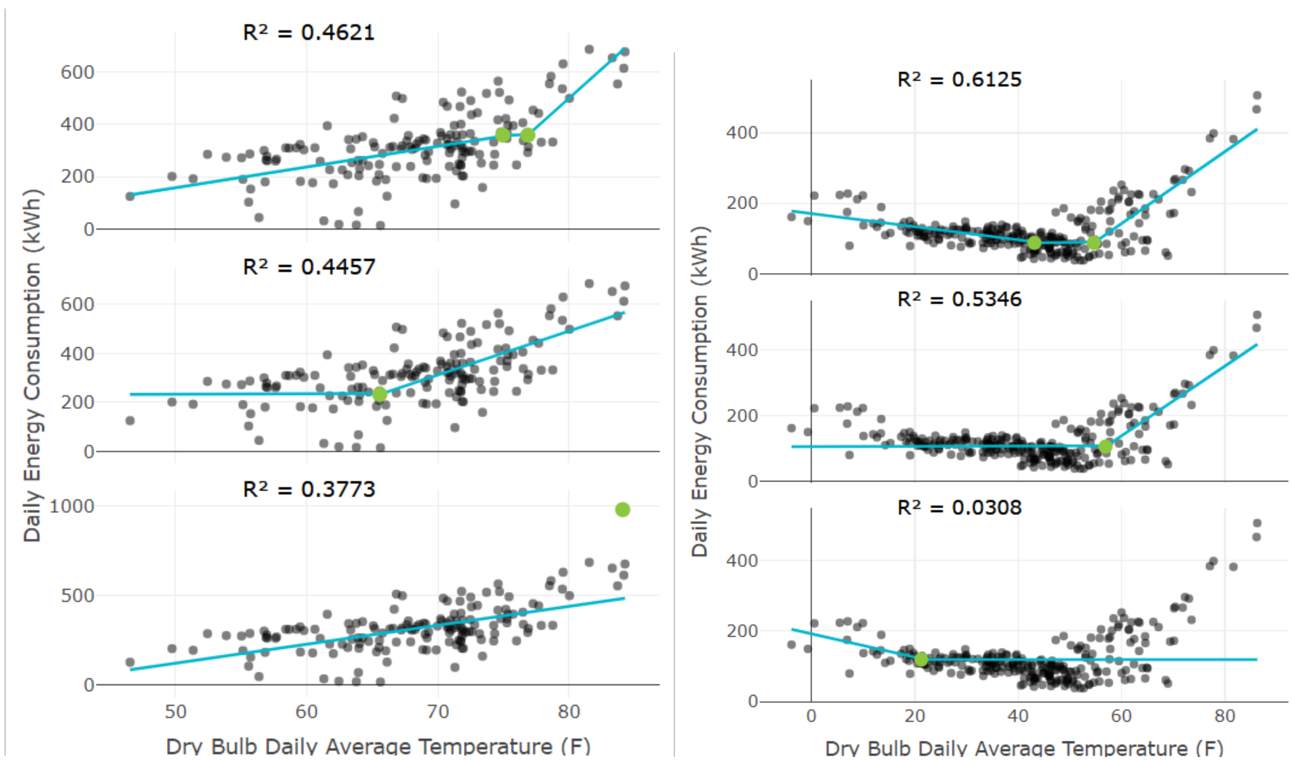


Figure 8: Daily Electricity Regression Models – Pre (left) vs Post (right); 5P (top), 3PC (middle), and 3PH (bottom)

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[16] [Local Climatological Data (LCD) | Data Tools | Climate Data Online (CDO) | National Climatic Data Center (NCDC) (noaa.gov)]

[17] ASHRAE Guideline 14-2014. Table 5-1: Sample Models for Whole-Building Approach

[18] https://cran.r-project.org/web/packages/segmented/index.html

After reviewing model performance, the 3PC model was selected as the most appropriate for normalizing pre-installation electricity usage, while a 5P model was selected for the post-installation scenario. Unfortunately, due to issues with the initial eGauge setup, the project team was unable to monitor pre-installation electricity use at temperatures below 55°F. Although a 5P model might have more accurately represented building operation with full data, the 3PC model better fits the available data and is likely to underpredict pre-installation energy use, slightly reducing calculated savings and making the analysis more conservative. In addition to selecting the 3PC model, pre-installation energy use below 55°F will be set equal to the post-installation model to eliminate savings where monitoring data is unavailable.

Additionally, this decision was based on multiple evaluation metrics including R^2, CV(RMSE), residual standard error (RSE), interpretation of the changepoint values, and the overall energy signature shape.

Table 12 summarizes the modeling metrics and parameters for each scenario. A larger R^2 value means the model explains a greater proportion of the variance, which generally indicates a better fit. A lower CV(RMSE) value means the model predictions have smaller errors, also indicating a better fit. While many factors must be considered in modeling, a common rule of thumb for a passing daily weather normalization model is an R^2 above 0.5 and a CV(RMSE) below 30%. The pre-installation scenario model performed just below these metrics, but as explained above, it is the best model available with the existing data, and the model was chosen to remain more conservative with savings calculations.

Table 12: Summary of HVAC Modeling Metrics

Scenario	Model	Change-Point Temperature(s)	RSE	R^2	Adj R^2	CV(RMSE)
Pre	5P	74.9, 76.9	94.7	0.46	0.45	29.6%
Pre	3PC	65.6	95.5	0.45	0.44	30.0%
Pre	3PH	84.1	101.2	0.38	0.37	31.8%
Post	5P	43.1, 54.6	41.6	0.61	0.61	33.7%
Post	3PC	56.9	45.5	0.53	0.53	36.9%
Post	3PH	21.3	65.6	0.03	0.02	53.3%

Whole-building electricity usage was annualized using typical meteorological year (TMYx) weather data.[19] The change-point regression models were applied using daily TMYx

[19] https://climate.onebuilding.org/

temperature data to normalize for weather variability and extrapolate the sub-annual data to a full year.

Annual savings were calculated by comparing the annualized electricity use models between the pre- and post-installation periods. The annualization models used the following equation structure which comes from ASHRAE Guideline 14.

$$E = C + B_1(B_3 - T)^+ + B_2(T - B_4)^+ \quad (1)$$

Where:

- E = daily energy use
- C = constant energy use, baseload
- B_1 = heating slope, at temperatures below the change-point
- B_3 = heating change-point temperature
- B_2 = cooling slope, at temperatures above the change point
- B_4 = cooling change-point temperature
- T = daily TMYx temperature
- $(\,)^+$ = only positive values inside parentheses

The coefficients used in the models are summarized in Table 13 below.

Table 13: Summary of Electric Interval Model Coefficients

Scenario	Model	C	B_1	B_2	B_3	B_4
Pre	3PC	232.5	-	17.9	-	65.6
Post	5P	87.9	-1.92	10.2	43.1	54.6

HVAC System Electric Savings Results

The normalized results of the models are shown in Figure 9 below.

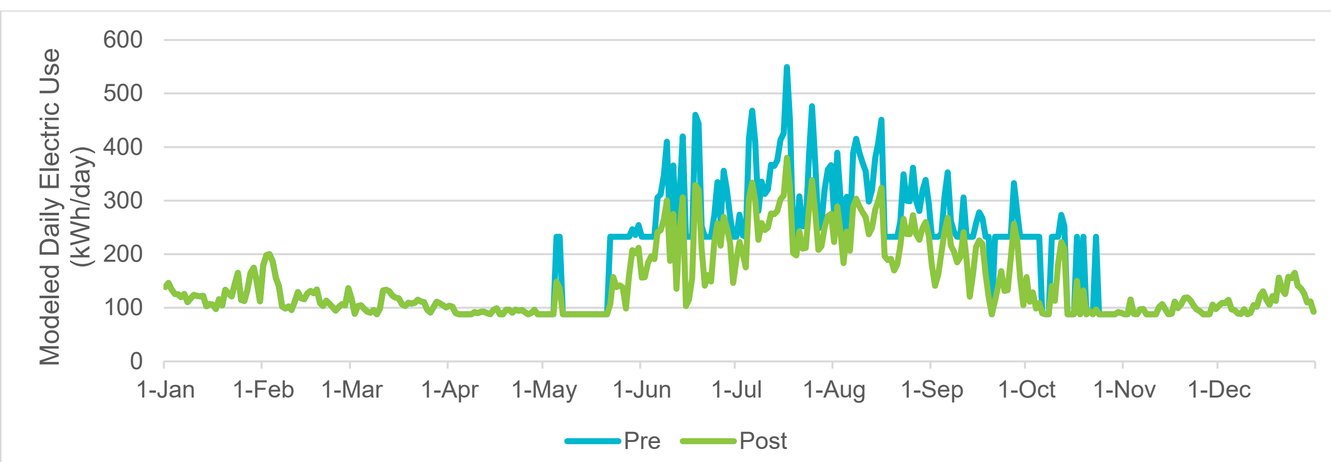


Figure 9: Electric Interval Modeling Results

Annual electricity usage was calculated by summing the daily modeled usage over 365 days for both the pre- and post-installation periods. The difference between these totals represents the normalized annual energy savings. Using the utility rates from the baseline, the annual electricity cost savings were then determined. Note, the utility bill data obtained by the project team did not include a demand component, so the cost savings are estimated from the blended rate alone.

To estimate demand savings, the peak daily energy usage for each season was identified and divided by 24 hours/day to approximate average peak demand. This process yielded a demand savings value for each month. The twelve-monthly values were then averaged to determine an approximate annual demand savings.

These results are summarized in Table 14 below.

Table 14: Normalized HVAC Electricity Savings Results

Scenario	Modeled Annual Energy Use (kWh/year)	Modeled Monthly Peak Demand (kW)	Annual Total Electricity Bill Cost ($/year)
Pre	65,700	11.2	$9,900
Post	54,300	9.1	$8,100
Savings	11,400	2.1	$1,800
Savings (%)	17%	19%	18%

HVAC System Natural Gas Savings Calculations

HVAC System Gas Data Collection

In the absence of natural gas interval meter data, the project team made attempts to gather boiler modulation data to estimate savings. Unfortunately, we were only able to obtain post-implementation data which is insufficient to estimate savings. This left the project team with only utility billing data to use in savings calculations. Even this dataset presents challenges, as the building was not fully occupied until the post-implementation period began, which could result in an increase in DHW load and obscure savings results.

HVAC System Gas Data Analysis

The monthly billing data for December, January, and February were summarized for the pre- and post-implementation periods. Monthly usage was divided by billing days to calculate daily use for each datapoint. This was then plotted versus outside air temperature to see if there was a significant drop in weather normalized use between the two monitoring periods. The results of this analysis are shown in Figure 10 below.

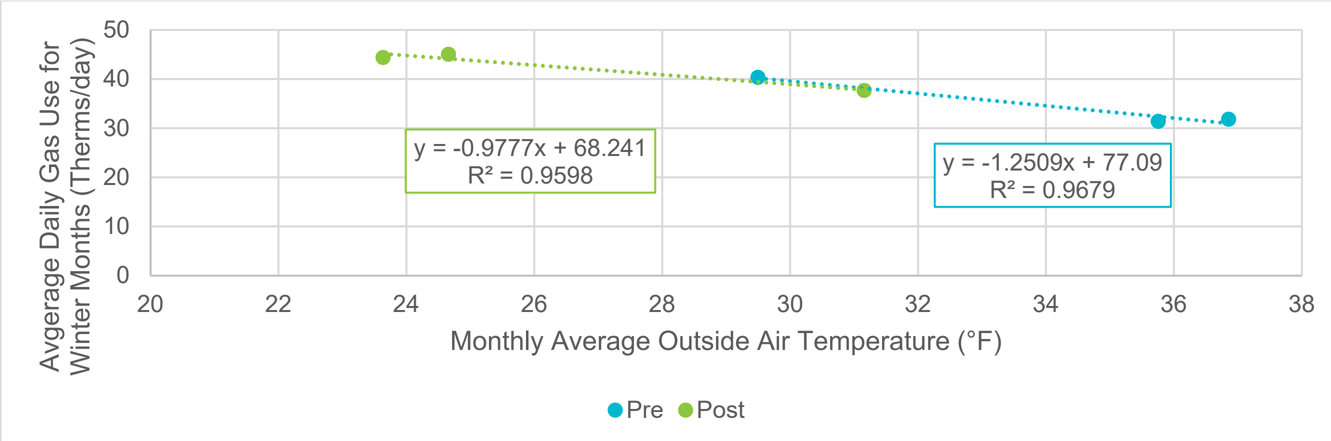


Figure 10: Monthly Natural Gas Billing Data – Daily Use vs. Average Monthly Outside Air Temperature

From the data, there is no significant difference between the two monitoring periods for the heating season. Gas savings from the integrated controls are likely but cannot be reliably quantified with the available data. One possible explanation is the domestic hot water (DHW) load was negligible during the pre-installation period due to lack of occupancy. In the post-installation period, although savings were likely achieved through integrated controls, increased DHW demand may have offset those savings, resulting in minimal change in the billing data.

In the absence of more detailed data, a rough range of natural gas savings can be estimated using observed electricity savings as a proxy. The calculations showed a 17% reduction in electricity use for the HVAC system, attributed to both fan and mechanical cooling savings. Natural gas savings, by contrast, are expected to come solely from heating reductions, primarily reheat savings on the hot water loop. While exact values cannot be calculated, it is reasonable to assume gas savings are greater than zero but less than the 17% system-wide electricity savings observed.

HVAC System Gas Data Results

Table 15: HVAC Gas Savings Results

Scenario	Annual Gas Use Minimum Estimated Savings (Therms/year)	Annual Gas Use Maximum Estimated Savings (Therms/year)	Annual Total Gas Bill Cost ($/year)
Pre	9,500	9,500	$5,500
Post	9,500	7,900	$4,600 to $5,500
Savings	-	1,600	$0 to $900
Savings (%)	0%	17%	0 to 16%

APPENDIX E: FOND DU LAC PUBLIC LIBRARY ANALYSIS

This Appendix summarizes key characteristics about the Fond du Lac Public Library demonstration site and details its lighting and HVAC systems. Additionally, it summarizes the steps taken to collect and analyze building data, quantifying the energy impacts resulting from the integration of NLC and HVAC controls.

Site Details

Building Information and Profile

The facility located at 32 Sheboygan Street in Fond du Lac, WI, is a public library with a building area of approximately 61,000 gross square feet across three levels: lower, first, and second floors. Figure 11 below shows an aerial view of the site where the top of the image faces north.

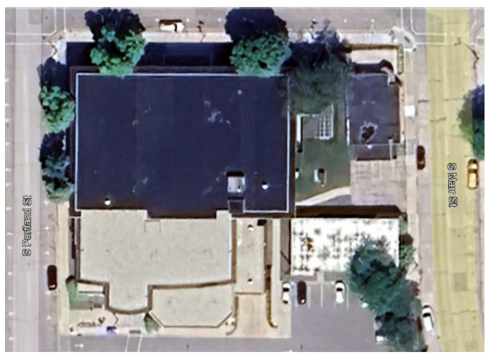


Figure 11: Aerial image of site taken from Google Earth

HVAC Design

The building is served by three air handling units, each with an economizer section, supply fan, return fan, hot water heating coil, and chilled water cooling coil. Each unit serves a specific floor and includes hot water reheat with VAV air terminal units for the respective zones. The hot water loop is served by three gas fired hot water boilers, and the chilled water loop is served by an air-cooled chiller.

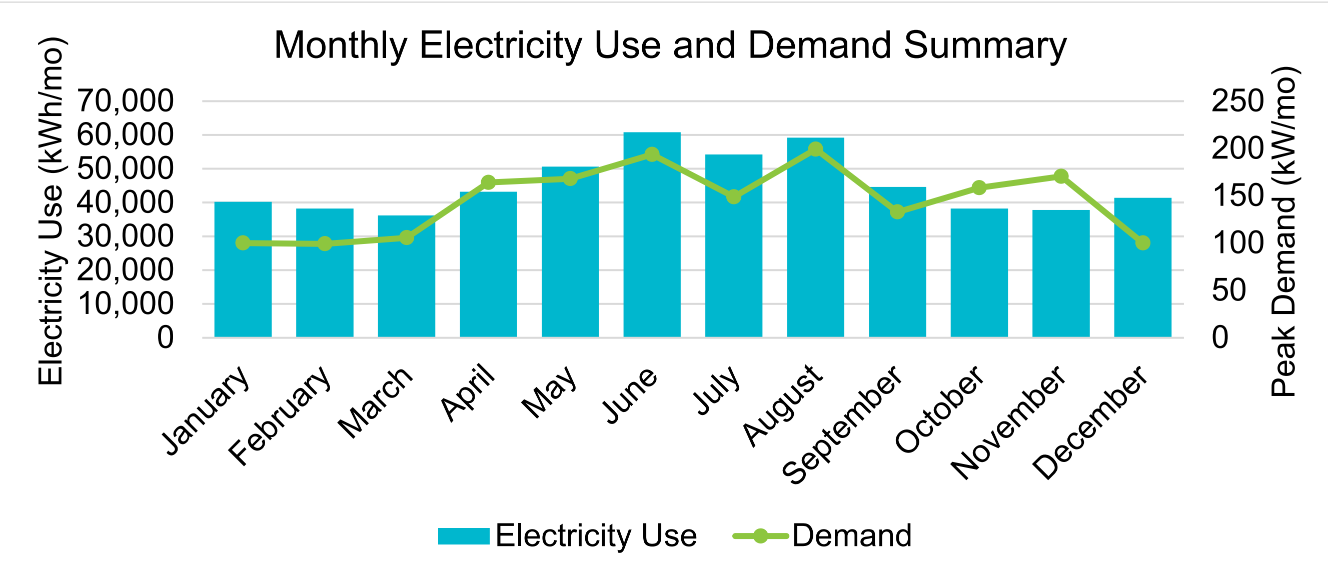
Lighting Design[20]

The pre-implementation lighting system comprised primarily four-foot T8 linear fluorescent fixtures, four-pin compact fluorescent fixtures, and a few incandescent and compact fluorescent bulbs. The pre-installation lighting power density (LPD) was approximately 0.8 W/sqft. The post-implementation lighting system replaced these fixtures with primarily two-foot by two-foot LED fixtures with integrated smart occupancy sensors communicating using the nLight platform. The post-implementation LPD is approximately 0.2 W/sqft.

[20] Lighting system descriptions and power densities came from the Comprehensive Lighting Solution Application workbook

Baseline Utility Information

The site purchases electricity and natural gas through Alliant Energy. The project team obtained electricity and natural gas cost and usage data spanning June 2021 to November 2024 as well as a single bill for the month of May 2023. This information was used to establish baseline utility information. The baseline billing period spans 11/8/2022 to 11/7/2023 for both electric and natural gas usage. The electric and natural gas utility billing data is summarized below in Figure 12 and Figure 13, respectively.



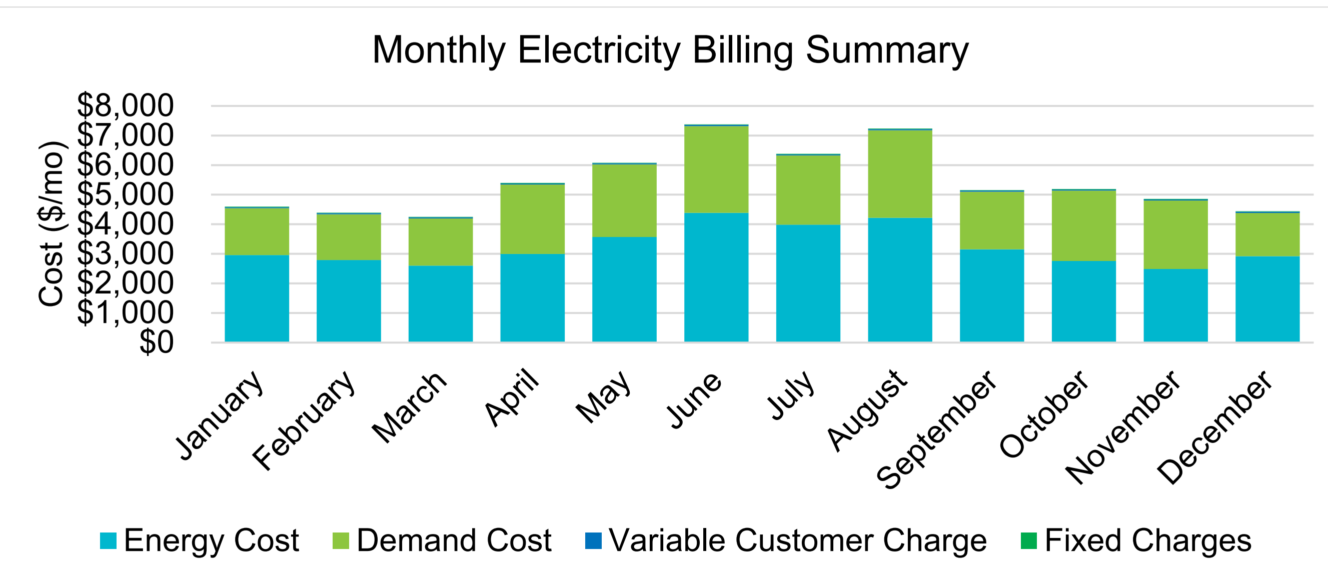


Figure 12: Baseline (Nov 2022 to Nov 2023) Electric Utility Billing Data[21]

[21] *The project team had a billing component breakdown only for May 2023, which was used to estimate breakdowns for other months. However, total monthly costs reflect actual values.*

In the baseline year, the site used a total of 544,600 kWh with a maximum peak demand of 199 kW occurring in August 2023. The total annual cost was $65,356, with an estimated 59% of the bill attributed to energy costs, 40% to demand costs, and 1% to other charges. The average blended rate was $0.120/kWh. Based on the May 2023 bill, the energy rate is $0.0705/kWh and the demand rate is $14.62/kW. These values will be used when estimating utility cost savings.

At 60,930 gross square feet, the building had an electric EUI of 30.5 kBtu/sqft.

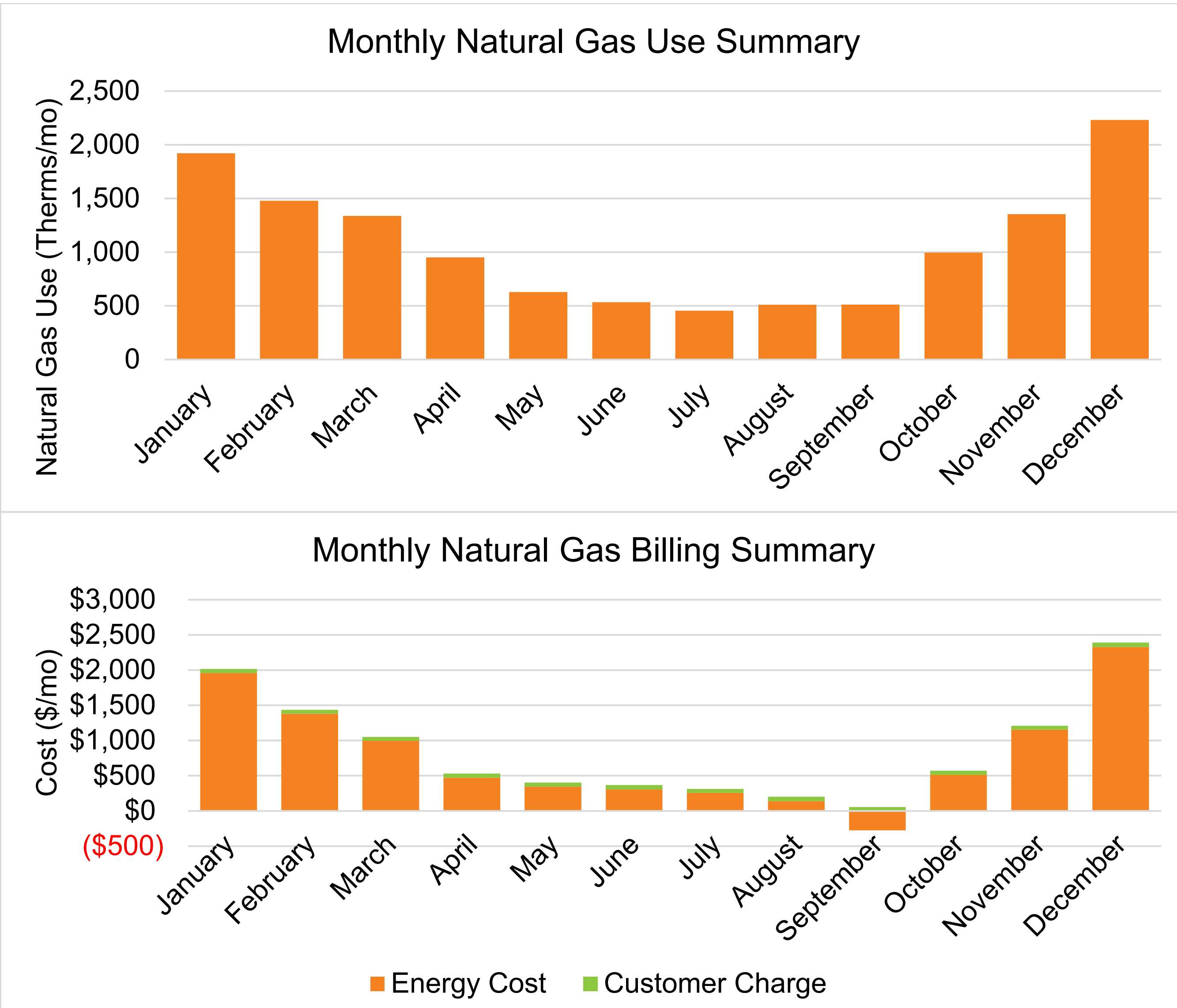


Figure 13: Natural Gas Utility Billing Data

In the baseline year, the site used a total of 12,907 Therms with a peak monthly usage of 2,231 Therms occurring in December 2022. The total annual cost was $10,264, with an estimated 93% of the bill attributed to energy costs and 7% to other charges. The average blended rate was $0.795/Therm. At 60,930 gross square feet, the building had a natural gas EUI of 21.18 kBtu/sqft. There was a negative charge in September 2023. While there was no information provided, this is generally due to a true up on meter reads or other billing overpayments.

A summary of both the electricity and natural gas utility data is summarized in Table 16Table 10 below.

Table 16: Baseline Year (Nov 2022 to Nov 2023) Utility Summary

	Annual Use (kWh or Therms/year)	Annual Cost ($/year)	Blended Rate ($/kWh or Therms)	EUI (kBTU/sqft)
Electricity (kWh)	544,600	$65,356	$0.120	30.50
Natural Gas (Therms)	12,907	$10,264	$0.795	21.18
Total		**$75,620**		**51.68**

According to ENERGY STAR Portfolio Manager,[22] the national median site EUI for libraries is 71.6 kBTU/sqft. The site's baseline EUI was 28% lower than this median, placing it in a more efficient category even before the NLC integration was installed.

Lighting System Energy Savings Calculations

Lighting System Data Collection

The project team used eGauge monitoring equipment to collect baseline lighting system data and calculate savings. True power sensors were installed on individual lighting circuits in electrical panels, measuring power consumption (Watts) at one-minute intervals. However, due to space constraints within the panels and the site's status as an active public space, monitoring was limited. Exposed wires posed tripping and tampering risks, restricting installation to panels in secured equipment rooms. As a result, only two of the site's nine lighting panels were monitored, representing 18% of the gross square footage of the site. Figure 14 shows the site’s floorplan highlighting the monitored lighting areas in blue.

[22] https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf

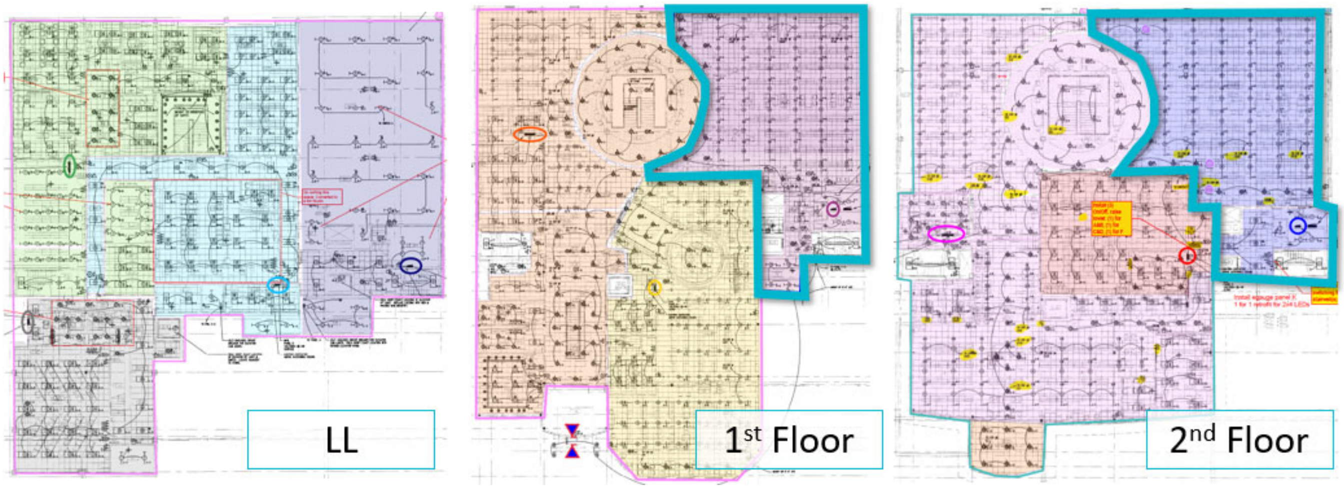


Figure 14: Site Floorplan with Monitored Lighting Highlighted in Blue

To estimate lighting usage for the entire building, the monitored data was assumed to be representative of the whole. The results were scaled by dividing by 18%. Since whole-building interval data was used to accurately determine total site savings, and these lighting calculations served only to approximate the portion attributed to lighting versus HVAC, this methodology was considered acceptable.

The project team also analyzed peak monitored power and compared it to whole-building design values to validate the 18% assumption. In both pre- and post-installation scenarios, monitored peak power was in the 20 to 25% range of design values, aligning closely with the 18% scaling factor used for whole-building calculations. The results of this verification step are summarized in the table below.

Table 17: Monitored versus Whole-Building Design Peak Lighting Power

Scenario	Design Peak Power (kW)	Monitored Peak Power (kW)	Monitored / Design Peak (%)
Pre-Installation	49.5	11.0	22%
Post-Installation	14.2	3.4	24%

Lighting System Data Analysis

The lighting system was monitored from 7/28/2023 to 3/25/2025. One-minute interval data was aggregated to hourly for analysis, as summarized in Figure 15 below.

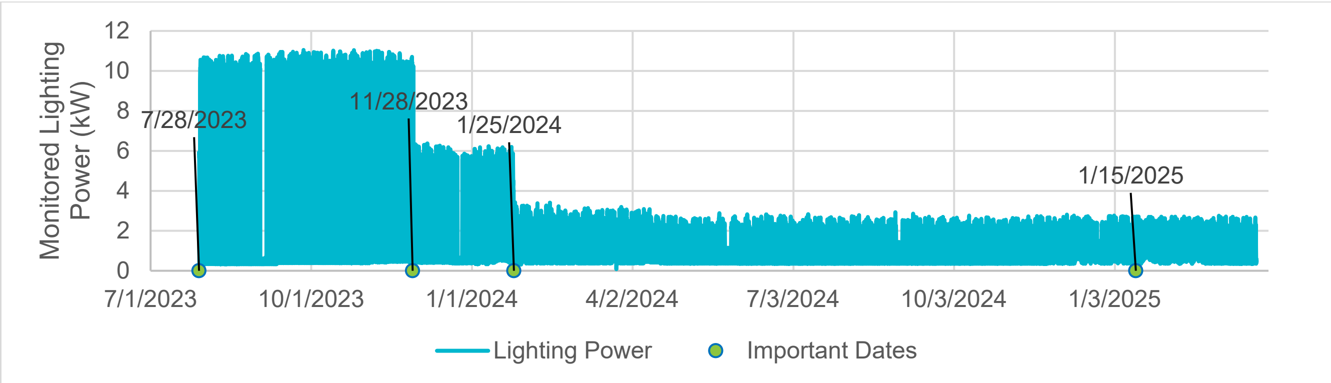


Figure 15: Hourly Monitored Lighting System Power

The raw data reveals three distinct operating modes based on average peak power and a fourth based on a known control sequence adjustment. From 7/28/2023 to 11/28/2023, peak lighting power averaged 10 kW. Between 11/28/2023 and 1/25/2024, it dropped to 5.4 kW, then to 2.4 kW from 1/25/2024 to 1/15/2025. On 1/15/2025, the lighting sequence delay was reduced from 20 to 10 minutes to enhance savings. However, this change had little to no effect on average or peak power compared to the previous mode and was not considered a distinct operating condition for system savings calculations.

The first mode represents the pre-installation phase, where the building was primarily lit by T8 linear fluorescent fixtures. The second mode marks a transition period when some, but not all, fixtures were upgraded to LEDs. This phase was excluded from savings calculations. The third and fourth modes represent the post-implementation scenario, with all lighting fixtures replaced and the system fully upgraded.

The transition to LEDs not only reduced peak power but also lowered overall operating hours due to integrated occupancy sensors, which turned off lights in unoccupied areas. To illustrate a typical daily profile, power data was averaged for each hour of the day across the pre- and post-implementation operating modes and plotted. This summary is presented in Figure 16 below.

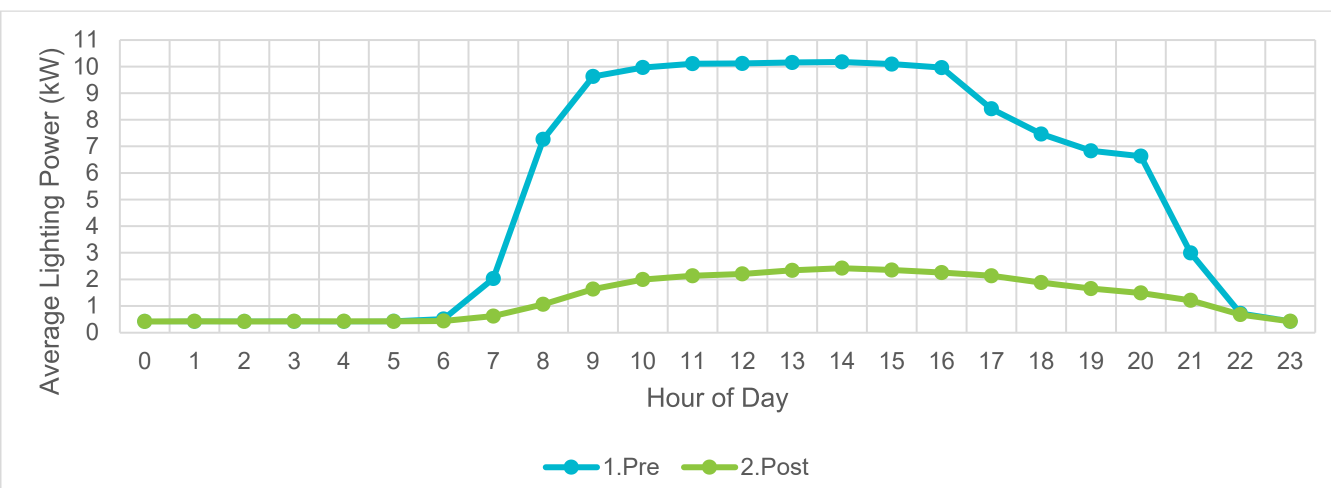


Figure 16: Typical Daily Lighting Power Profile Pre versus Post

During the pre-implementation period, the lighting system ramped up at 7:00 AM, reached peak power by 9:00 AM, and maintained it until 4:00 PM. During the post-implementation period, ramp-up began at 8:00 AM with a slower increase, peaking around 2:00 PM. In both periods, power returned to minimum levels by 10:00 PM and remained low until the next day's ramp-up.

Lighting System Savings Results

To calculate annual electricity use for the pre- and post-implementation lighting system, the average daily profiles in Figure 16 were used to represent a typical day for each period. Hourly power profiles were summed to determine daily electricity use (kWh/day), then multiplied by 365 to obtain annual energy use. The result was then divided by 18% to extrapolate from the monitored lighting circuits to the entire building. The results are shown in Table 18 and Table 19 below.

Table 18: Monitored Lighting Circuits Savings Summary

	Average Daily Electricity Use (kWh/day)	Average Daily Peak Power (kW)	Annual Electricity Use (kWh/year)
Pre-Installation	126.0	10.2	45,990
Post-Installation	31.4	2.4	11,461
Savings	**94.6**	**7.8**	**34,529**

Table 19: Entire Building Lighting Savings Summary

	Average Daily Electricity Use (kWh/day)	Average Daily Peak Power (kW)	Annual Electricity Use (kWh/year)
Pre-Installation	700.0	56.7	255,500
Post-Installation	174.4	13.3	63,656
Savings	**525.6**	**43.4**	**191,844**

It was challenging to precisely separate the energy savings from the LED retrofit into two distinct categories: (1) savings from fixture replacement and (2) savings from controls. This was because individual fixtures could not be monitored; instead, the project team monitored entire lighting circuits. As a result, observed drops in power consumption could have been caused by lights being turned off or by lower fixture wattage after the retrofit. Additionally, reductions in full-load kW could result from either the fixture replacement or high-end trim settings, which are attributable to controls.

To estimate the savings attributed to fixture efficiency improvements, the project team used the calculations provided in the Comprehensive Lighting Solution Application estimating an annual electricity savings of 169,599 kWh/year and peak power savings of 22.9 kW/month. The workbook listed annual operating hours of the lighting system as 4,707 hours. Based on the monitored data, this closely aligns with the more precise figure of 4,590 hours, a difference of only 2.5%, which substantiates the workbook calculations. Additionally, after a conversation with site personnel, a portion of these savings calculations was attributed to high-end trim settings made possible by the integrated controls. The project team was told approximately 20% of these calculated savings could be attributed to high end-trim.

Any additional savings beyond those calculations were assumed to result from reduced operating hours. The annual electricity savings, broken out by estimated categories, are shown in Table 20 below.

Table 20: Entire Building Lighting Savings Summary by Savings Category

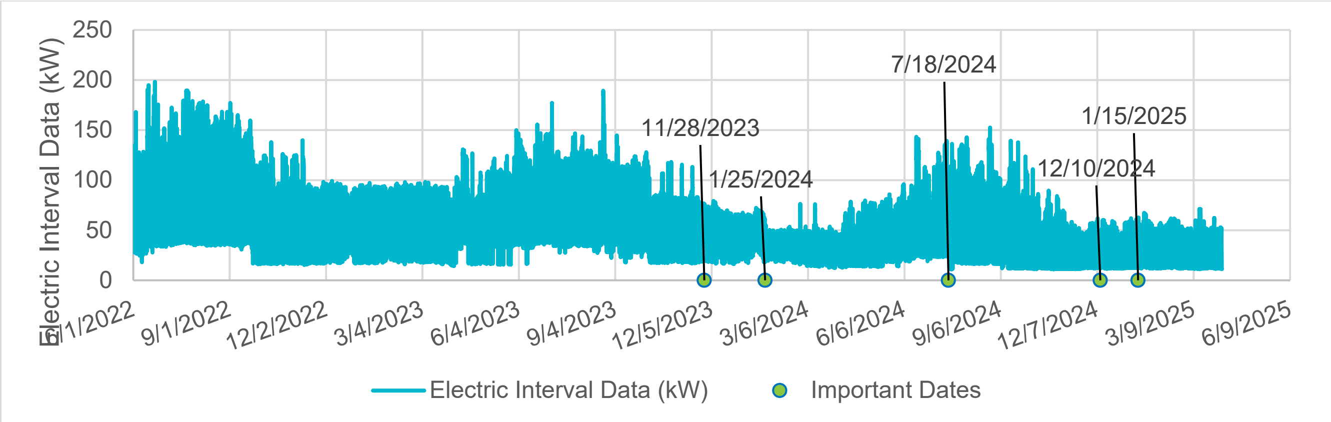
Savings Category	Annual Electricity Use Savings (kWh/year)	Percent of Total	Peak Power Savings (kW/month)	Percent of Total
LED fixture replacement	135,680	70%	18.3	42%
Controls: High-end trim	33,920	18%	4.6	11%
Controls: Reduced operating hours	22,250	12%	20.5	47%
Total	**191,844**		**43.4**	

Entire Building Energy Savings Calculations

Electricity

Data Collection

The project team collected 15-minute interval electricity usage data from 6/1/2022 to 4/8/2025. Because this dataset captures whole-building electricity use, it reflects energy consumption from both the lighting and HVAC systems. For the purpose of analysis, the 15-minute data was aggregated to hourly intervals. Figure 17 below summarizes the hourly data and highlights key dates used in the analysis.



Date	System Affected	Notes
6/1/2022	Entire building	Start of electric interval data
11/28/2023	Lighting	A portion of the lighting system was converted to LED
1/25/2024	Lighting	The remaining lighting system was converted to LED
7/18/2024	HVAC	New HVAC sequences fully integrated
12/10/2024	HVAC	5-minute delay removed from HVAC sequences
1/15/2025	Lighting	20-minute delay reduced to 10 minutes in lighting sequences

Figure 17: Hourly Electric Interval Data with Important Dates Highlighted

Upgrades began on 11/28/2023, so all data prior to this date, spanning 6/1/2022 to 11/28/2023, is considered the pre-installation period. Following this, a transition period occurred as various lighting and HVAC elements were updated. This continued until 7/18/2024, when the HVAC control sequences were fully updated and integrated with the network lighting control occupancy sensor system. The post-installation period begins on this date, and all transition data is excluded from the analysis. Although minor adjustments to delay setpoints were made on 12/10/2024 and 1/15/2025, these changes were not substantial enough to redefine the post-installation period, which spans from 7/18/2024 to 4/8/2025.

A summary of the daily whole building electric use versus outdoor air temperature is depicted in Figure 18 below.

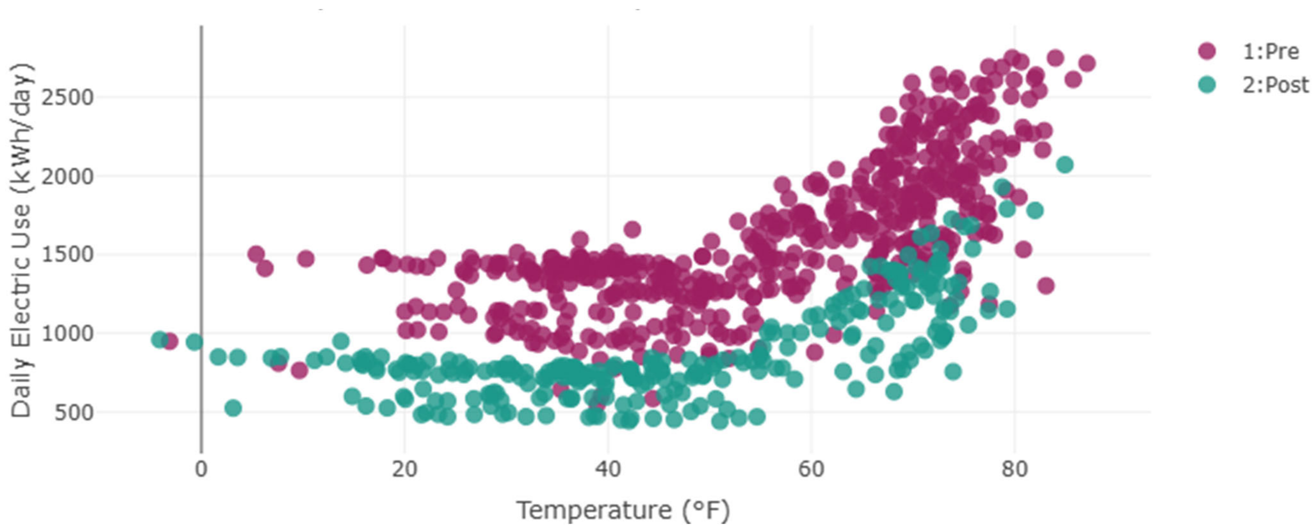


Figure 18: Daily Electric Use versus Outdoor Air Temperature – Pre vs Post

From the data, it is clear there was a significant drop in daily electricity use between the two monitoring periods. In the **Data Analysis** section below, this data will be used to normalize electric use versus outdoor air temperature, annualize electricity use, and calculate savings.

Data Analysis

To account for differing weather conditions between the two monitoring periods, the project team normalized daily electricity consumption (kWh/day) by regressing it against average daily outdoor air dry-bulb temperature (°F). Actual meteorological year (AMY) weather data was sourced from Milwaukee Mitchell International Airport.[23] Separate regressions were developed for the pre- and post-installation periods.

The project team evaluated three types of change-point models to capture weather-sensitive energy use, including both heating and cooling loads: 5-paremeter (5P), 3-parameter cooling (3PC), and 3-parameter heating (3PH) models.[24] More specifically, the segmented package[25] in R-software was used to generate the models.

The results of these regressions, including R^2 values, are summarized in Figure 19 below.

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[23] [Local Climatological Data (LCD) | Data Tools | Climate Data Online (CDO) | National Climatic Data Center (NCDC) (noaa.gov)]

[24] ASHRAE Guideline 14-2014. Table 5-1: Sample Models for Whole-Building Approach

[25] https://cran.r-project.org/web/packages/segmented/index.html

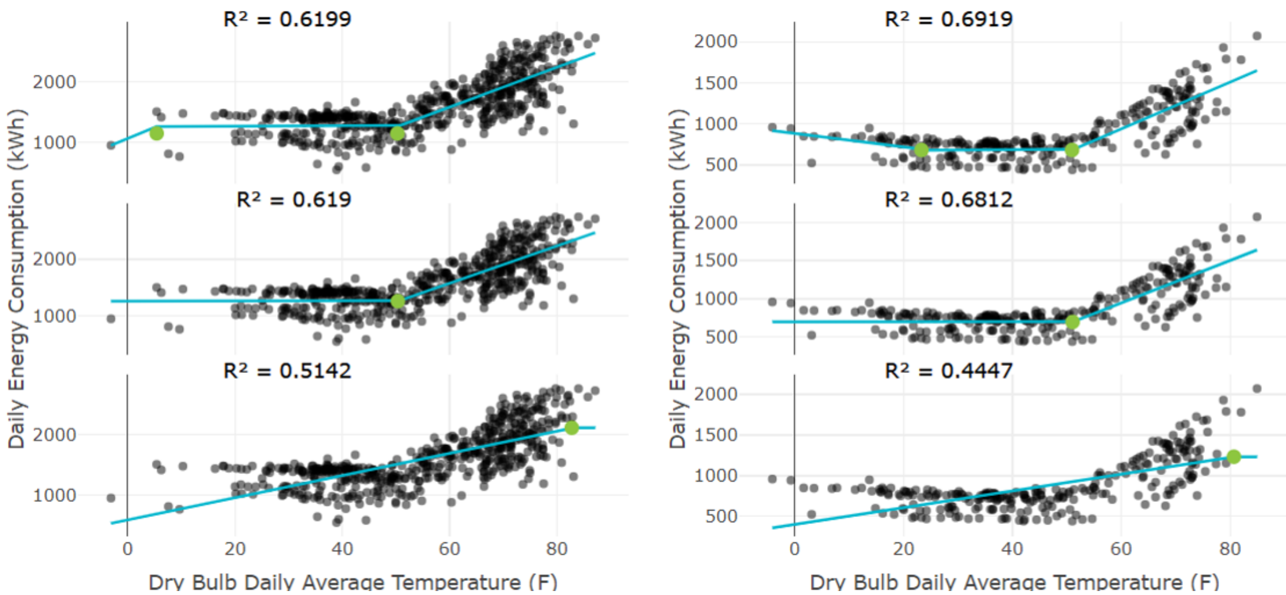


Figure 19: Daily Electricity Regression Models – Pre (left) vs Post (right); 5P (top), 3PC (middle), and 3PH (bottom)

After reviewing model performance, the 3PC model was selected as the most appropriate for normalizing electricity usage. This decision was based on multiple evaluation metrics including R^2, CV(RMSE), residual standard error (RSE), interpretation of the changepoint values, and the overall energy signature shape.

Although the post-implementation 5P model produced an R^2 1.6% higher than the 3PC model, the marginal gain did not outweigh the other considerations favored the 3PC model.

Table 21 summarizes the modeling metrics and parameters for each scenario. A larger R^2 value means the model explains a greater proportion of the variance, which generally indicates a better fit. A lower CV(RMSE) value means the model predictions have smaller errors, also indicating a better fit. While many factors must be considered in modeling, a common rule of thumb for a passing daily weather normalization model is an R^2 above 0.5 and a CV(RMSE) below 30%.

Table 21: Summary of Electric Interval Modeling Metrics

Scenario	Model	Change-Point Temperature(s)	RSE	R^2	Adj R^2	CV(RMSE)
Pre	5P	5.4, 50.3	274.9	0.62	0.62	17.0%
Pre	3PC	50.3	274.7	0.62	0.62	17.1%
Pre	3PH	82.8	310.2	0.51	0.51	19.3%
Post	5P	23.3, 50.96	173.7	0.69	0.69	19.5%
Post	3PC	51.1	176.0	0.68	0.68	19.9%
Post	3PH	80.7	232.3	0.44	0.44	26.2%

Whole-building electricity usage was annualized using typical meteorological year (TMYx) weather data.[26] The change-point regression models were applied using daily TMYx temperature data to normalize for weather variability and extrapolate the sub-annual data to a full year.

Annual savings were calculated by comparing the annualized electricity use models between the pre- and post-installation periods. The annualization models used the following equation structure which comes from ASHRAE Guideline 14.

$$E = C + B_1(B_3 - T)^+ + B_2(T - B_4)^+ \quad (1)$$

Where:

- E = daily energy use
- C = constant energy use, baseload
- B_1 = heating slope, at temperatures below the change-point
- B_3 = heating change-point temperature
- B_2 = cooling slope, at temperatures above the change point
- B_4 = cooling change-point temperature
- T = daily TMYx temperature
- $()^+$ = only positive values inside parentheses

The coefficients used in the models are summarized in Table 22 below.

Table 22: Summary of Electric Interval Model Coefficients

Scenario	Model	C	B_1	B_2	B_3	B_4
Pre	3PC	1,260	-	32.9	-	50.3
Post	3PC	697	-	27.8	-	51.1

Results

The normalized results of the models are shown in Figure 20 below.

[26] https://climate.onebuilding.org/

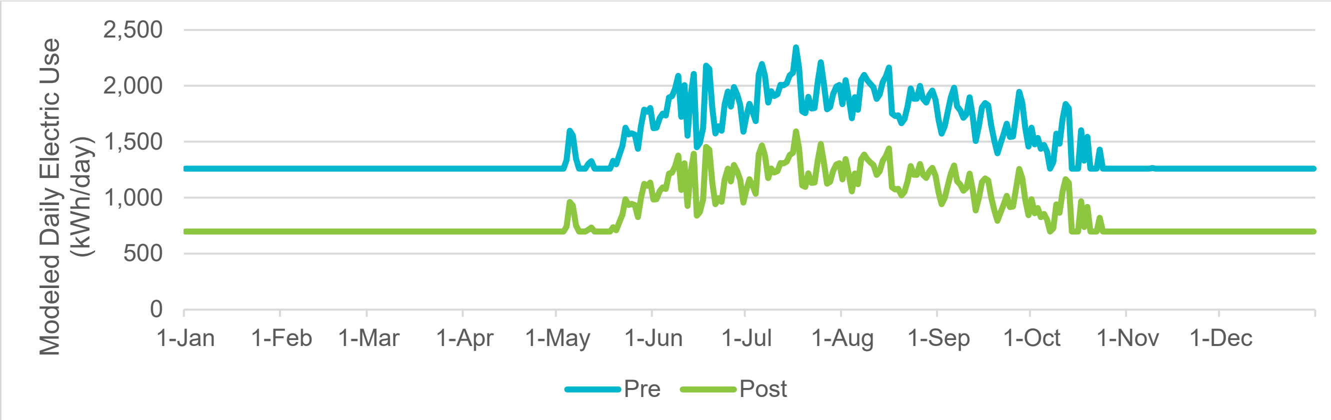


Figure 20: Electric Interval Modeling Results

Annual electricity usage was calculated by summing the daily modeled usage over 365 days for both the pre- and post-installation periods. The difference between these totals represents the normalized annual energy savings. Using the utility rates from the baseline, the annual electricity cost savings were then determined.

To estimate demand savings, the peak daily energy usage for each month was identified and divided by 24 hours/day to approximate average peak demand. This process yielded a demand savings value for each month. The twelve-monthly values were then averaged to determine an approximate annual demand savings. Note, the total bill costs include fixed costs as well as energy and demand costs, which is why they are slightly higher than just the summation of energy and demand components.

These results are summarized in Table 23 below.

Table 23: Normalized Whole-Building Electricity Savings Results

Scenario	Modeled Annual Energy Use (kWh/year)	Modeled Monthly Peak Demand (kW)	Annual Energy Cost ($/year)	Annual Demand Cost ($/year)	Annual Total Electricity Bill Cost ($/year)
Pre	539,869	69.0	$38,100	$12,100	$50,900
Post	318,878	42.6	$22,500	$7,500	$30,700
Savings	220,991	26.4	$15,600	$4,600	$20,200
Savings (%)	41%	38%	41%	38%	40%

Using the results from the **Lighting System Savings Results** section, the lighting savings were subtracted from the whole building savings in order to estimate the HVAC system savings. These results are shown in Table 24 below.

Table 24: Entire Building Savings Summary by Savings Category

Savings Category	System	Annual Electricity Use Savings (kWh/year)	Percent of Whole Building	Peak Power Savings (kW/month)	Percent of Whole Building
LED fixture replacement	Lighting	135,679	25%	18.3	13%
Controls: High-end trim	Lighting	33,920	6%	4.6	3%
Controls: Reduced operating hours	Lighting	22,245	4%	20.5	14%
HVAC occupancy controls	HVAC	29,147	5%	0	0%
Total		**220,991**	**41%**	**26.4**	**30%**

Finally, while the monitored HVAC fan data was not sufficient to calculate total HVAC savings, as explained in previous sections, the monitored fan power data does indicate unoccupied nighttime airflows were significantly reduced as a direct result of the updated controls.

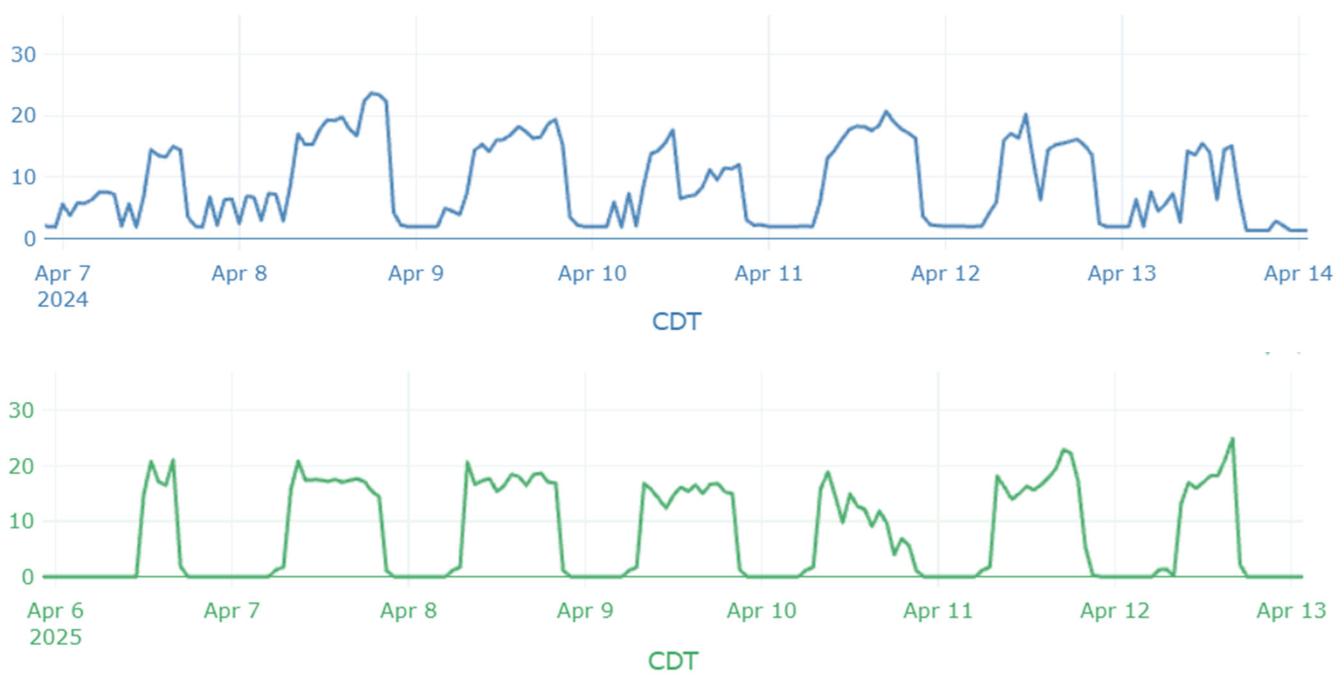


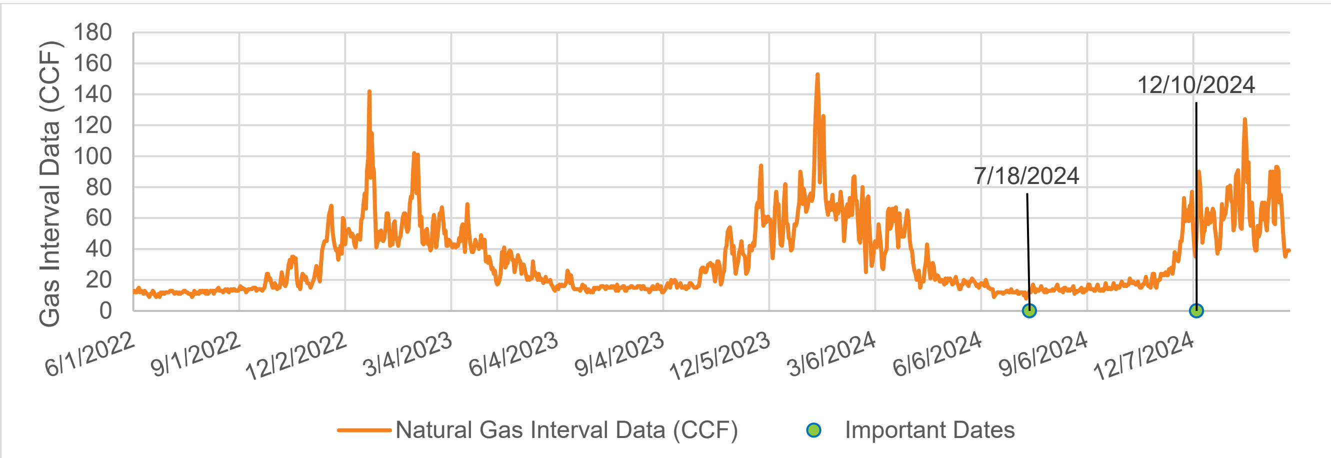
Figure 21: Fan Power Data Showing Reduced Airflow at Night for Typical Shoulder Season Week (Top: Pre, Bottom: Post)

Note the fan power drops to a minimum of approximately 2 kW at night in the pre-installation period, while it goes all the way to zero in the post-installation period.

Natural Gas

Data Collection

The project team collected hourly interval natural gas usage data from 6/1/2022 to 2/28/2025. This dataset captures whole-building natural gas use, in CCF, reflecting energy consumption from the HVAC heating systems. For the purpose of analysis, the hourly data was aggregated to daily intervals. Figure 22 below summarizes the daily data and highlights key dates used in the analysis.



Date	System Affected	Notes
6/1/2022	Entire building	Start of natural gas interval data
7/18/2024	HVAC	New HVAC sequences fully integrated
12/10/2024	HVAC	5-minute delay removed from HVAC sequences
2/28/2025	Entire building	End of natural gas interval data

Figure 22: Daily Natural Gas Interval Data with Important Dates Highlighted

Upgrades affecting natural gas use began and were completed by 7/18/2024, so all data prior to this date, spanning 6/1/2022 to 7/17/2024, is considered the pre-installation period. The post-installation period begins after this date, with no transition data requiring filtering. Although minor adjustments to delay setpoints were made on 12/10/2024, these changes were not substantial enough to redefine the post-installation period, which spans from 7/18/2024 to 2/28/2025.

A summary of the daily whole building natural gas use versus outdoor air temperature is depicted in Figure 23 below.

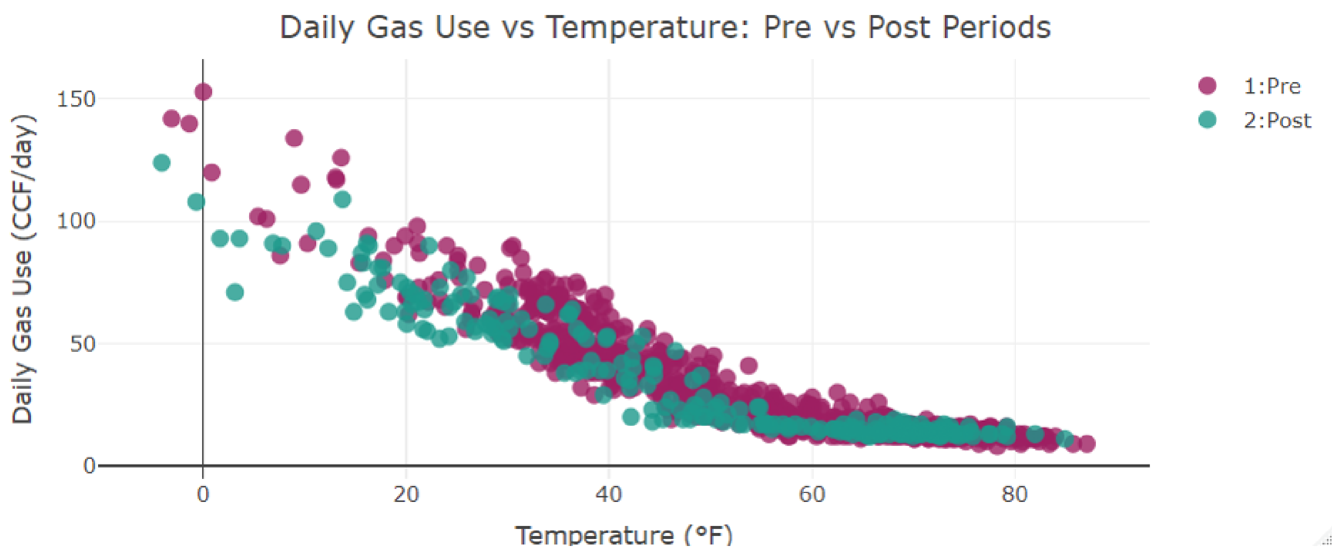


Figure 23: Daily Gas Use versus Outdoor Air Temperature – Pre vs Post

From the data, it is not clear there was a significant drop in daily natural gas use between the two monitoring periods. Because there were minimal electric HVAC savings, this is not unexpected. In the section below, this data will be used to normalize natural gas use versus outdoor air temperature, annualize natural gas use, and calculate savings.

Data Analysis

To account for differing weather conditions between the two monitoring periods, the project team normalized daily natural gas consumption (CCF/day) by regressing it against average daily outdoor air dry-bulb temperature (°F). For more details on the overall approach, refer to the electricity section above.

The results of these regressions, including R^2 values, are summarized in Figure 24 below.

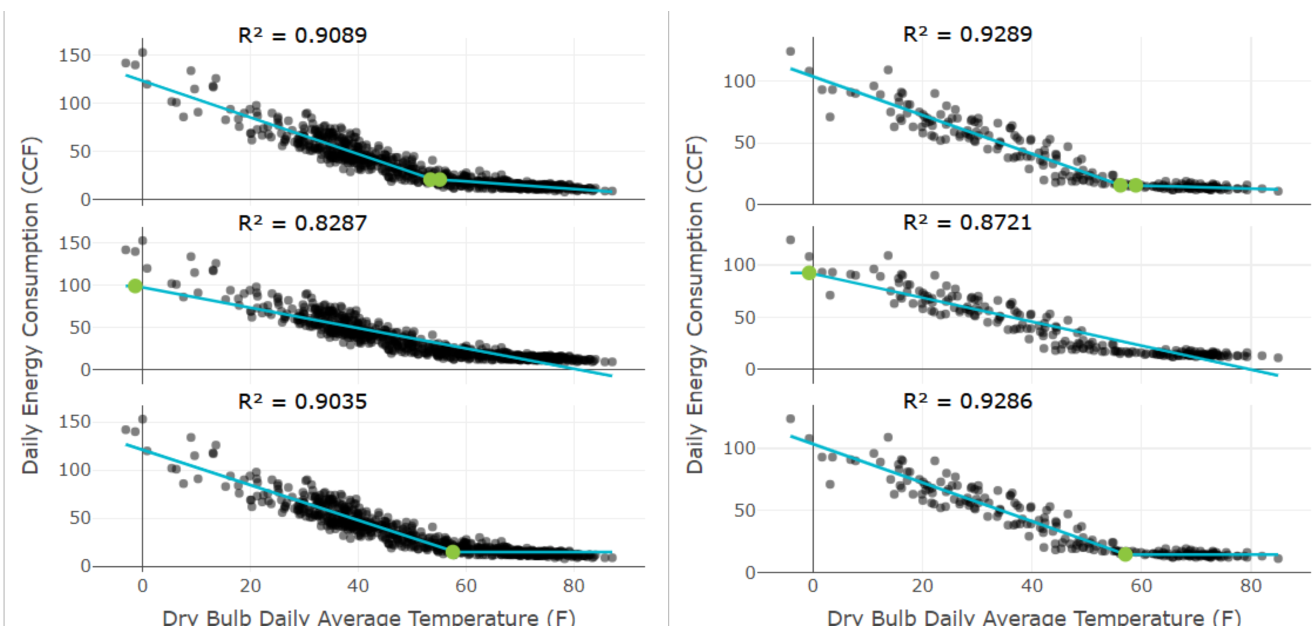


Figure 24: Daily Gas Regression Models – Pre (left) vs Post (right); 5P (top), 3PC (middle), and 3PH (bottom)

After reviewing model performance, the 3PH model was selected as the most appropriate for normalizing natural gas usage. This decision was based on multiple evaluation metrics including R^2, CV(RMSE), residual standard error (RSE), interpretation of the changepoint values, and the overall energy signature shape.

It is also worth noting, except in rare cases where justified, it is considered best practice to use the same type of model for both the pre- and post-implementation periods. Although the 5P models produced marginally higher R^2 values than the 3PH models, the negligible gain did not outweigh the other considerations favored the 3PH models.

Table 25 summarizes the modeling metrics and parameters for each scenario. A larger R^2 value means the model explains a greater proportion of the variance, which generally indicates a better fit. A lower CV(RMSE) value means the model predictions have smaller errors, also indicating a better fit. While many factors must be considered in modeling, a common rule of thumb for a passing daily weather normalization model is an R^2 above 0.5 and a CV(RMSE) below 30%.

Table 25: Summary of Natural Gas Interval Modeling Metrics

Scenario	Model	Change-Point Temperature(s)	RSE	R^2	Adj R^2	CV(RMSE)
Pre	5P	53.4, 55.1	7.1	0.91	0.91	21.3%
Pre	3PC	-1.4	9.7	0.83	0.83	29.2%
Pre	3PH	57.5	7.2	0.90	0.90	21.9%
Post	5P	56.1, 58.9	7.0	0.93	0.93	19.1%
Post	3PC	-0.7	9.4	0.87	0.87	25.6%
Post	3PH	57.1	7.0	0.93	0.93	19.1%

Whole-building natural gas usage was annualized using Typical Meteorological Year (TMYx) weather data.[27] The change-point regression models were applied using daily TMYx temperature data to normalize for weather variability and extrapolate the sub-annual data to a full year.

Annual savings were calculated by comparing the annualized natural gas use models between the pre- and post-installation periods. The annualization models used the following equation structure which comes from ASHRAE Guideline 14.

$$E = C + B_1(B_3 - T)^+ + B_2(T - B_4)^+ \quad (1)$$

Where:

[27] https://climate.onebuilding.org/

- E = daily energy use
- C = constant energy use, baseload
- B_1 = heating slope, at temperatures below the change-point
- B_3 = heating change-point temperature
- B_2 = cooling slope, at temperatures above the change point
- B_4 = cooling change-point temperature
- T = daily TMYx temperature
- $(\,)^+$ = only positive values inside parentheses

The coefficients used in the models are summarized in Table 26 below.

Table 26: Summary of Natural Gas Interval Model Coefficients

Scenario	Model	C	B_1	B_2	B_3	B_4
Pre	3PH	14.96	-1.84	-	57.5	-
Post	3PH	14.35	-1.56	-	57.1	-

Results

The normalized results of the models are shown in Figure 25 below.

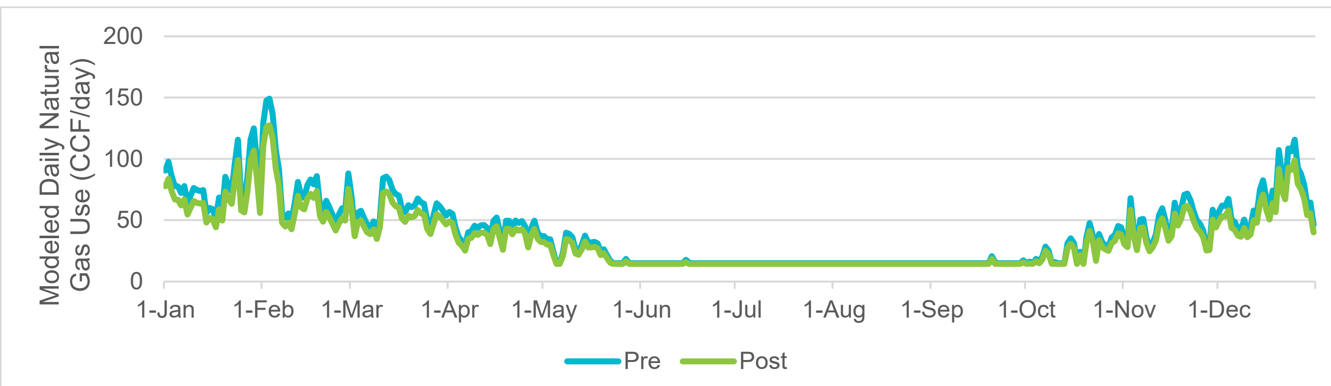


Figure 25: Natural Gas Interval Modeling Results

Annual natural gas usage was calculated by summing the daily modeled usage over 365 days for both the pre- and post-installation periods. The difference between these totals represents the normalized annual energy savings. Using the utility rates from the baseline, the corresponding cost savings were calculated. Since natural gas billing does not include a demand charge, the blended rate of $0.795 per Therm was used to estimate total annual costs based on modeled Therms. While the interval data was reported in CCF, the billing data used a conversion factor of 1.035 Therms per CCF. The project team applied the same factor to convert savings into Therms for cost calculations.

These results are summarized in Table 27 below.

Table 27: Normalized Whole-Building Natural Gas Savings Results

Scenario	Modeled Annual Energy Use (Therms/year)	Annual Energy Cost ($/year)
Pre	15,300	$12,200
Post	13,400	$10,700
Savings	**1,900**	**$1,500**
Savings (%)	**12%**	**12%**