LLLC
Luminaire-Level Lighting Controls

Luminaire-Level Lighting Controls Demonstration Projects Performance Report: BI Worldwide and ISD 287

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Contents

EXECUTIVE SUMMARY

Overview

As part of the Luminaire-Level Lighting Control Initiative, demonstration projects showcase the benefits of luminaire-level lighting control (LLLC) technology being used effectively in Minnesota by collecting qualitative and quantitative data. Demonstration projects also play a key role in exploring the benefits of LLLC systems, non-energy benefits, and the resulting energy savings. LLLCs are a proven technology comprising individually programmable luminaires that contain embedded sensors and compact control components, allowing each fixture to respond to occupancy and daylight, to set high-end trim, and provide a platform for future opportunities for building operators.

To better understand an LLLC system's performance and potential energy savings, the LLLC Initiative partners with local businesses by providing technical assistance, monitoring the lighting system's performance, and sharing the results via case studies and performance reports. This report summarizes the results of our analysis of LLLC systems installed as part of two retrofit projects in 2024. One of the projects was with BI WORLWIDE, a global marketing and engagement firm with its headquarters in Minneapolis, MN. The other was with Intermediate District 287, an organization that provides specialized educational services to students with diverse learning needs across its 12-member school districts in the West Metro area of Minneapolis, MN.

Prior to the retrofits, both facilities had outdated systems with no lighting controls in place, and lights were often left on too long, or left on in unoccupied spaces, resulting in wasted energy and money. To address these issues, their consultants recommended upgrading to LLLCs, tailoring the controls to address different spaces and occupancy patterns. The goal for these demonstration projects was to monitor the system performance both "out of the box" and after adjustments to demonstrate the importance of proper programming.

This report is part of the growing effort by the LLLC Initiative to promote better lighting solutions that are efficient and practical and provide additional non-energy benefits. By spotlighting these real-world examples with BI WORLDWIDE and ISD 287, the LLLC Initiative hopes to encourage building owners and facility teams to feel more confident installing LLLCs as a flexible, user-friendly system.

Objective

This study's objective is to analyze the real-world energy performance and efficiency of LLLCs in a pilot installation. By metering and recording lighting energy consumption before and after the implementation of LLLCs, this study aims to quantify the energy savings achieved through various control strategies, including high-end trim, motion sensing, and daylight harvesting. This study evaluates how these strategies contribute, both individually and collectively, to reducing energy use while maintaining appropriate lighting levels for occupant comfort and productivity.

Additionally, this study assesses system responsiveness, control effectiveness in different space types, and overall operational efficiency. The findings from this study will provide data-driven insights into the benefits and challenges of LLLC implementation, informing future lighting design and energy efficiency projects.

Approach

To monitor the LLLC system performance, power meters (eGauge Core 4015) were installed at both sites for several weeks to measure power values of several lighting circuits. Data was collected at one-minute intervals and stored locally on the meter. Each meter was connected to the internet with a cellular modem that connected with eGauge servers. The research team automatically downloaded daily power data throughout the study for data analysis. This approach allowed CEE to assess efficiency and energy consumption and is consistent with other studies conducted by CEE. Detailed monitoring and analysis approaches are described in this report's Data Collection and Analysis section.

Findings

These demonstration projects demonstrate the benefits and potential energy savings of retrofitting outdated lighting systems with LLLCs, as well as the importance of early planning and collaboration.

This study demonstrated that properly programming LLLCs is crucial to maximizing energy efficiency and ensuring optimal performance. Without well-configured settings, even advanced lighting systems may fail to deliver significant savings or could lead to occupant dissatisfaction. Programming allows for fine-tuning control strategies such as high-end trim, ensuring that luminaires operate at the necessary light levels without excessive energy use.

Lessons learned:

- Motion-sensing settings must be calibrated to align with occupancy patterns, minimizing unnecessary lighting while avoiding disruptions in occupied spaces.
- Daylight harvesting relies on precise dimming responses based on real-time ambient light conditions to reduce artificial lighting when natural light is sufficient.
- LLLCs can deliver significant energy savings when properly programmed and deployed, with observed reductions in lighting energy consumption of up to 78% at BI WORLDWIIDE and up to 76% at ISD 287 for specific circuits compared to the previous lighting systems.
- Key control strategies — high-end trim, motion sensing, and daylight harvesting — each contributed measurable savings, while their combined application offered even greater reductions.

INTRODUCTION

The LLLC Initiative, part of the Minnesota Efficient Technology Accelerator (ETA) program administered by Center of Energy and Environment (CEE), strives to advance the adoption of

LLLCs to bring lasting change to the Minnesota lighting market and ultimately make these systems standard for commercial buildings. The initiative builds demand for LLLCs by addressing adoption barriers through local engagement, education, and partnerships. It supports buildings owners, designers, and installers with training, technical expertise, and resources to simplify decision-making, incentive opportunities, and installation.

LLLCs represent an advanced approach to lighting efficiency by integrating sensors and individual luminaire control capabilities. Unlike traditional centralized lighting control systems, LLLCs enable granular, fixture-level adjustments, allowing for greater flexibility in managing energy use. The key benefits of LLLCs include significant energy savings through control strategies such as high-end trim, motion sensing, and daylight harvesting, which collectively reduce unnecessary energy consumption. Additionally, LLLCs enhance occupant comfort by providing consistent and adaptive lighting levels while allowing for customizable settings. For both demonstration projects, each luminaire is equipped with occupancy sensors, daylight sensors, and wireless communication, providing the capability to respond dynamically to real-time environmental conditions, delivering light when and where necessary. The following is an overview of each of the lighting strategies analyzed.

- **High-end trim** is a lighting control strategy that limits the maximum output of a luminaire to a level below its full capacity, reducing energy consumption while maintaining sufficient illumination for the space. Instead of allowing fixtures to operate at 100% brightness, high-end trim sets a lower maximum level based on the lighting needs of an area, task requirements, and occupant preferences. This adjustment not only results in immediate energy savings but also extends the lifespan of the lighting system by reducing overall wear on components. High-end trim is particularly effective in over-lit spaces, where reducing output has minimal impact on visual comfort while significantly improving efficiency.

- **Motion sensing** is a lighting control strategy that uses occupancy sensors to detect movement in a space and automatically adjusts lighting levels based on occupancy status. When motion is detected, the system activates or increases the lighting to a predefined level, ensuring adequate illumination for occupants. If no movement is sensed for a specified period, the lights either dim or turn off completely to conserve energy. Motion sensing is particularly effective in areas with intermittent occupancy, such as offices, conference rooms, restrooms, and hallways, where lights would otherwise unnecessarily remain on.

- **Daylight harvesting** is a lighting control strategy that reduces artificial lighting based on the availability of natural daylight in a space. Using integrated light sensors, the system continuously monitors ambient light levels and automatically dims or turns off luminaires when sufficient daylight is present. This adaptive approach ensures that artificial lighting is only used when necessary, saving a significant amount of energy while maintaining appropriate illumination levels for occupants. Daylight harvesting particularly benefits spaces with ample windows or skylights, such as offices, classrooms, and lobbies, where natural light varies throughout the day. By dynamically adjusting lighting output, this strategy not only improves energy efficiency but also enhances occupant comfort, reduces glare, and supports a more sustainable building design.

SITE OVERVIEWS

For these demonstration projects, the LLLC team sought out retrofit projects to support in realizing the benefits of LLLC systems. The recommended project types were with schools, offices, warehouses, parking garages, community centers, or government-owned facilities. We also sought projects that involved common fixture types and layouts and space usage, so the general findings from these could be applicable to similar sites. Some additional criteria included:

- The project site must complete a detailed lighting audit
- The project site must have natural daylight available and variable occupancy schedules
- Open to temporary reconfiguration of system programming for energy analysis and temporary installation of meters for energy analysis
- Standalone operation (integration with other systems/controls or internet connections not required)
- LLLCs must be listed on the Design Light Consortiums Qualified Product List (QPL)
- The system must be capable of self-serve startup (factory support not required for configuration of controls)
- Once programmed, the lights must dim and/or turn off in response to natural daylight or when they detect vacancy, and be configured to balance occupant comfort while maximizing energy savings

Based on these requirements the following two sites were selected.

Intermediate School District 287

Intermediate District 287 (ISD 287) serves 12-member school districts across Minnesota, providing innovative, specialized services to help each district meet the unique learning needs of its students. So, when ISD 287 looked to modernize the lighting system it sought to improve the quality of the lighting for its employees, save energy, and incorporate more control and flexibility into the system. This pilot project took place in a 60-year-old, three-story, 66,763 square foot facility in Plymouth, MN, that is mostly office space with a small portion of the building used as warehouse space.

The ISD 287 lighting vendor conducted a thorough assessment of the facility identifying occupancy patterns, areas with strong daylight, and spaces with poor lighting. Before the retrofit, the building had outdated yellow lighting, consisting of linear fluorescent, compact fluorescent lamps, and HID fixtures, with no controls in place. Lights were often left on too long or in unoccupied spaces, wasting energy and money. Based on the assessment and interviews, the team recommended upgrading to LLLCs to achieve greater energy savings and take advantage of the added flexibility LLLCs offer compared to a standard LED upgrade.

System Characteristics

The team selected MaxLite's c-Max Lighting Controls system, a user-friendly LLLC system well suited to the building's mix of open offices, cubicles, and warehouse space. The system enables LLLC and non-LLLC luminaires to be controlled together using wireless controls. The system's control features, like occupancy sensing and timeclock adjustments, gave ISD 287 the flexibility to fine-tune settings without relying on external support.

In total, 819 fixtures were retrofitted or replaced across the building, and 586 of them feature MaxLite's c-Max system. All luminaires were retrofitted with LLLC lighting fixtures, where possible. LLLCs were not available in the downlight category, and were retrofitted with LEDs integrated into the control system.

Programmed Settings

High-end trim: Throughout the building, a high-end trim of 20% was utilized to limit energy consumption through maximum output adjustment of the drivers. Because the luminaires installed provided more lighting than was required for the illumination of the space, the lighting was able to be dimmed by 50% without sacrificing the needs of the occupants. This reduction in output cannot be overrode by the wall switches, so 50% becomes the new 100% when using the dimmer. Stated in another way, dimming lights to 50% via a wall switch really means that 25% of the luminaire's maximum potential output is being reached.

Daylight harvesting: Light sensors integrated into the luminaires trigger a dimming response to natural light available, enabling luminaires adjacent to windows to reduce the luminaire light output and lower energy use.

Automatic off (motion control): When occupancy sensors detect that spaces are vacant, lights are dimmed to 20% after 15 minutes to warn anyone in the space that if motion is not detected for 5 additional minutes, lights will turn completely off. In open office areas, where large quantities of luminaires are located, occupancy zones do not exceed 600 sq. ft.

Manual on: Instead of motion sensors turning lights on automatically when some areas become occupied, occupants must turn the lights on by using the switches on the wall, ensuring that lights don't turn on when they are not needed.

Dimming control: When lights are turned on, whether by motion sensor in areas where manual on is not enabled, or by turning lights on using the wall switches, lights turn on to 75% instead of 100%. Occupants can use the wall switches to ramp up lighting levels to 100% when desired.

BI WORLDWIDE

BI WORLDWIDE, a Minnesota-based marketing and engagement firm, set out to reduce energy consumption at their Minneapolis headquarters located in Edina, MN, as part of their corporate sustainability efforts. This pilot project took place in a 72,300 sq. ft. single-story building with a mezzanine, containing a mixture of warehouse and office space. The warehouse space contains aisles lined with shelves of goods, as well as some tables near entryways. The office space is primarily an open office setting, with some conference rooms, small phone rooms, a lunchroom, and a few private offices.

A consultant from CEE's One-Stop Efficiency Shop assessed the existing lighting system, which consisted of outdated fluorescent fixtures lacking controls and causing harsh glare in some areas. To address these issues and achieve greater energy efficiency, the consultant recommended upgrading to an LLLC system, tailoring the controls to meet the needs of the different spaces and occupancy patterns.

System Characteristics

An nLight Air system by Acuity Brands was used to illuminate and control the lighting in this building. This system provides both illumination and advanced controls throughout the building, enabling LLLCs and non-LLLCs to be controlled together using a hybrid wireless and wired approach. Non-LLLCs are controlled using dimmers and sensors installed throughout the space and communicate with LLLCs to provide a seamless experience for the building occupants. The project consisted primarily of six fixture types, with 403 of the 544 luminaires installed being LLLCs, covering the entire warehouse area and most of the office space. The lunchroom and corridors were largely non-LLLCs, due to their form factors — downlights and pendants largely rely on external, non-integrated control components due to limited real estate in their housings.

Programmed Settings

Throughout the building, high-end trim of 20% was used to reduce unnecessary energy consumption without sacrificing occupants' needs. Motion control was enabled with a default 10-minute timeout, later adjusted to 30 minutes during start up, and ultimately reduced to a 20-minute timeout. While the LLLC system included daylight sensors, the site elected not to implement daylight harvesting at this building at the time of our field work.

METHODOLOGY AND ANALYSIS

The following describes the methods used to monitor and verify performance and energy use for each site.

3.1 ISD 287

Methodology

Power meters were installed to measure lighting power on two of the building's three floors, the second and third floors. Power meters were installed inside breaker panels that contained lighting circuits, and current transformers were installed to separately meter individual circuits on each floor. Power measurements were taken at one-minute intervals, and the data was continuously uploaded to the eGauge server using a cellular modem connected to each meter. Both instantaneous power and total energy consumption were used for data analysis.

Space and Metering Overview

ISD 287 is a three-level office building that includes a mix of space types. The building contains open-office areas with cubicles, enclosed offices, various sized conference rooms with varying occupancy, break areas, and warehouse space. The second floor primarily consists of an open-plan office area with cubicle workstations, as well as small offices and two conference rooms at the north and south ends. The third floor contains various sized conference rooms that are used sporadically throughout the day. Table 1 provides an overview of the second and third floor and the number of metered circuits and luminaires. The first floor was not included as part of the metered study.

Table 1. Building overview of the metered locations

Site	Meter Location	Number of Metered Lighting Circuits	Metered Space Types	Number of Metered Luminaires
ISD 287	Second floor	6	Open office, cubicle, conference room	95
ISD 287	Third floor	7	Small and large conference rooms	199

The blue shading in Figure 1represents the portion of the building served by the metered lighting included in this study. The metered areas captured most of the occupied areas of the second and third floors, including spaces that best represented the building and the varying occupancy and use patterns for lighting in the building.

Figure 1. ISD 287 Floor plans showing metered areas shaded in blue

Power meters were installed on July 3, 2024, and data collection started on July 4, 2024, for both floors. The initial metering included baseline measurements of the existing lighting system and ended on July 18 and August 1 for the second and third floors, respectively. Table 2 summarizes the dates of the metering period.

Table 2. Dates of the metering period

Floor	Installation Date	Baseline Metering Duration	LLLC Metering Duration
Second	7/4/2024	7/4/24–7/18/24	7/20/24–11/19/24
Third	7/4/2024	7/4/24–8/1/24	8/3/24–11/19/24

Analysis

Data analysis was completed to compare energy consumption of baseline lighting operation to post-retrofit LLLC lighting. Power data was used to calculate energy savings due to LLLC lighting and control strategies of daylight harvesting, motion sensing, and high-end trim. Overall energy savings from the lighting upgrade were calculated, and specific examples were drawn to highlight the impact of motion sensing and daylight harvesting.

Power Consumption by Floor

Power data for each floor was summed to calculate total energy consumption for each day of the monitoring period in kilowatt hours (kWh) as shown in Figure 2. To calculate total energy consumption by floor, all metered circuits were added together to represent total energy consumed across all metered lighting circuits. Each floor shows high baseline energy consumption before August, and a sharp decrease due to the replacement of fluorescent lighting with LLLCs implementing daylight harvesting, motion controls, and high-end trim. The third floor shows more savings than the second floor, and a much sharper decline in overall energy use as it mainly consists of sporadically used conference rooms that greatly benefited from motion controls. Lighting on the second floor was more consistent as the space was generally occupied during working hours. Overall, both floors show a significant reduction in overall energy use.

Figure 2. Total energy consumption for each day during monitoring period

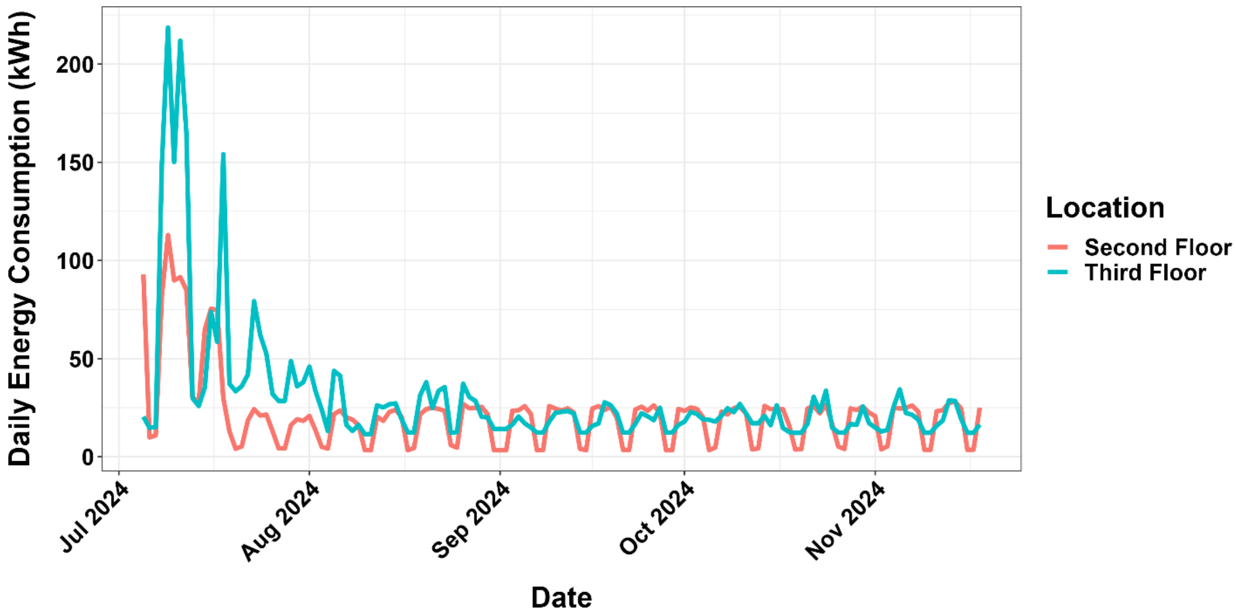
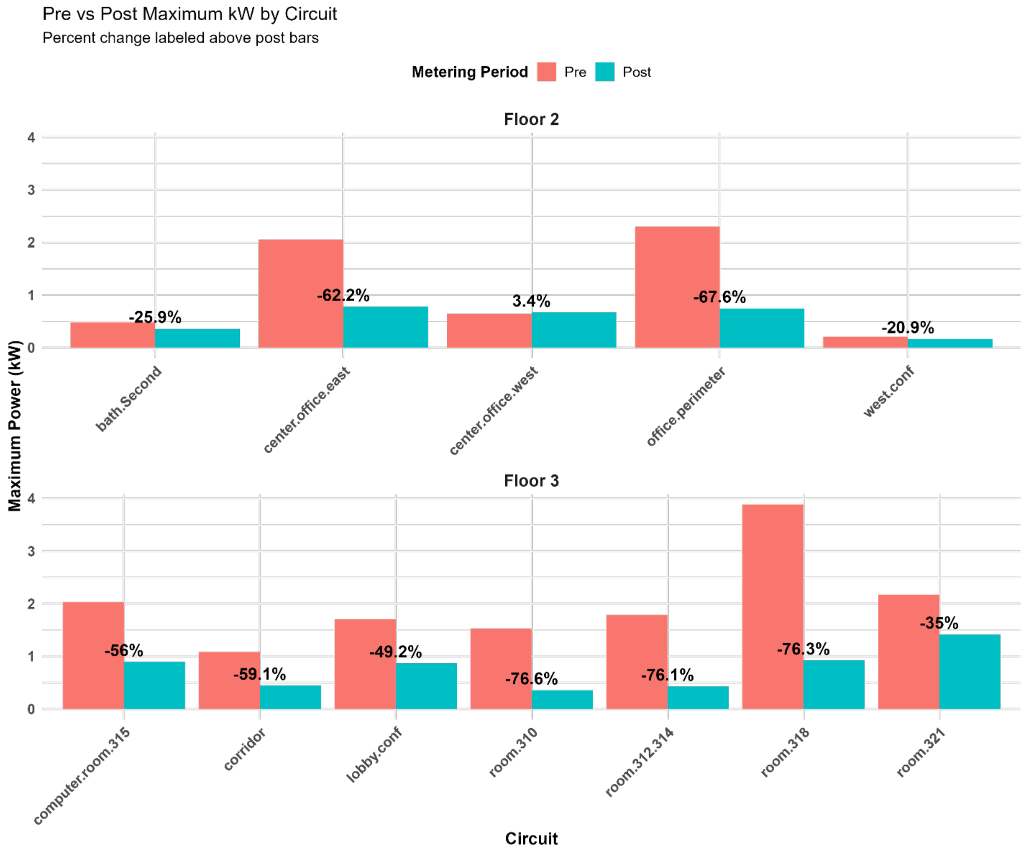


Figure 3 compares the maximum lighting power measured before and after the retrofit from fluorescent fixtures to LLLCs. Each bar represents the peak measured power for each metered circuit during each period, before and after retrofit, showing significant reductions across most building areas. This data illustrates when all lighting fixtures on a specific circuit are on to isolate power reduction by replacing fluorescent fixtures with higher-efficiency LLLCs, removing the influence of control strategies such as daylight harvesting or motion sensing.

Figure 3. Comparison of maximum lighting power before and after retrofit

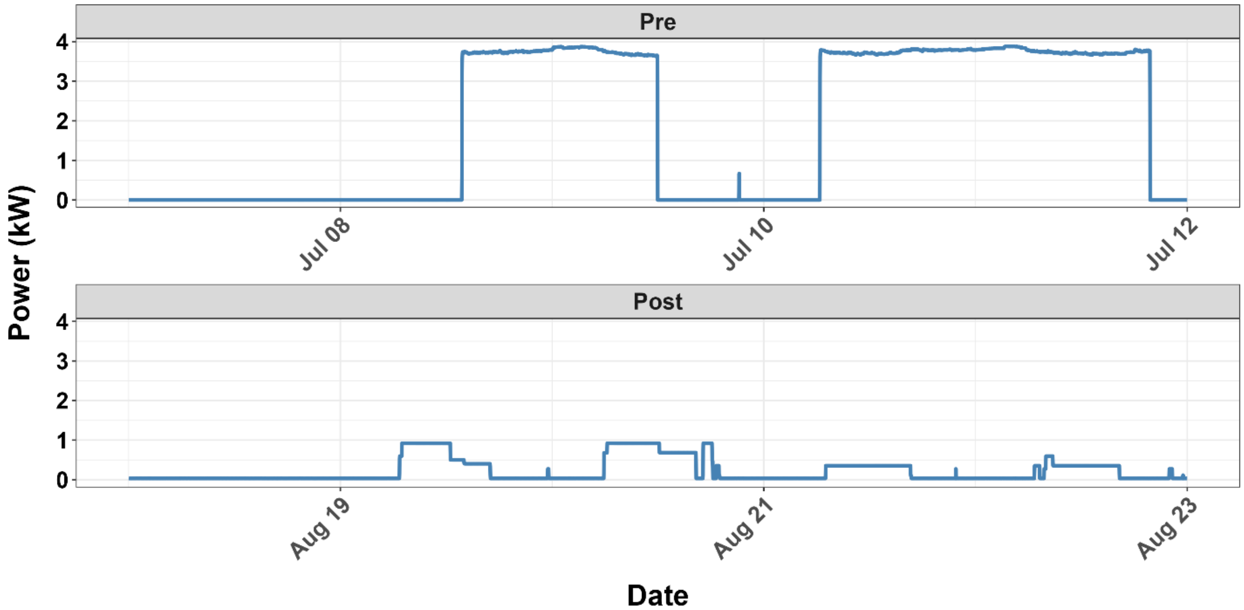


Motion Controls

LLLC lighting with motion control offers significant energy savings compared to standard lighting controlled by a basic switch. Certain building and space types provide greater opportunity for energy savings from motion control, such as conference rooms, warehouse areas, and intermittently occupied spaces that are often left lit when not in use.

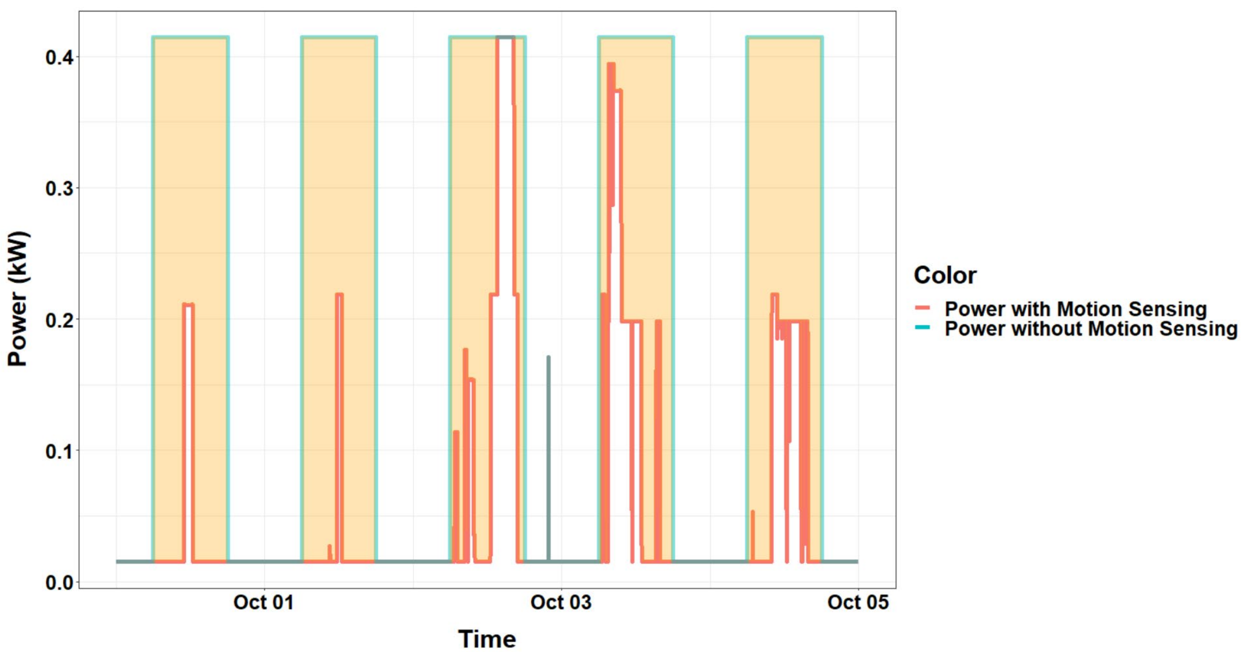
Figure 4 presents two representative weeks from the pre- and post-retrofit periods to illustrate the impact of motion sensing controls of room 318, which is a large, occasionally used conference room where lights may remain on between times of use. Prior to the retrofit, lights were left on at full power for two consecutive nights without occupancy in the conference room — after the retrofit, lights were only activated when the room was in use. The data also displays multiple distinct power levels, reflecting different groups of fixtures turning on and off as occupants move throughout the room.

Figure 4. Plot-Room 318 before and after motion sensing example



To demonstrate energy savings from motion sensing, a typical work week of measured power data was compared against a simulated schedule in which the lights operated from 6:00 a.m. to 6:00 p.m. In Figure 5, the green line represents the maximum measured power draw during the week, while the pink line shows the raw metered power data. The yellow shaded area indicates the energy savings, equaling a 75.1% reduction in this example.

Figure 5. Maximum measured power drawn during the week



Daylight Harvesting

Daylight harvesting was implemented for the luminaires along the perimeter of the second floor, which benefited from natural light throughout the day. Exterior south-facing windows line the exterior wall of the open office space, which can greatly benefit from dimming the lighting levels on sunny days, as shown in Figure 6.

Figure 6. Second floor open office showing wall of windows and natural light

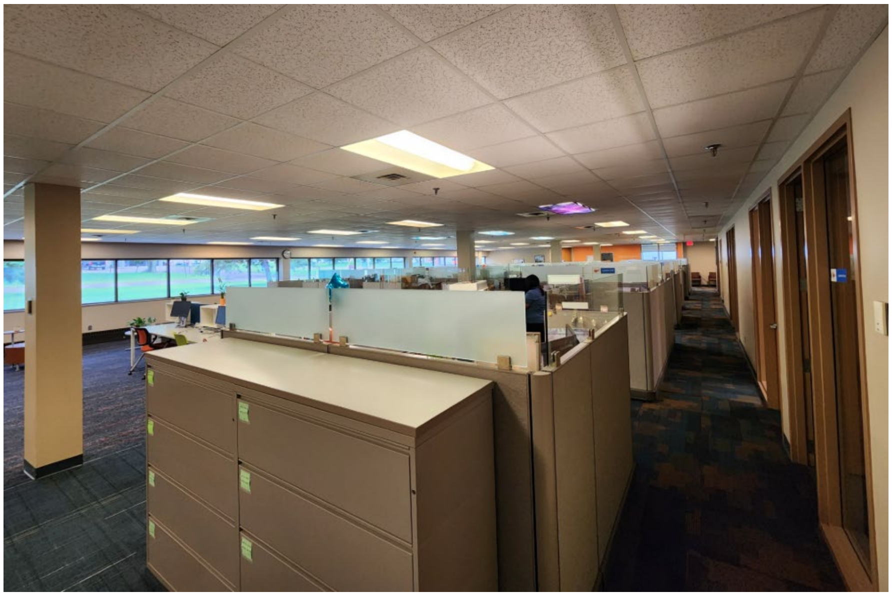


Figure 7 represents a typical week of operation for the perimeter office circuit on the second floor. Lighting power reaches a maximum power around .7 kW at the start of the day before significant daylight is available. As natural light enters the building, the LLLCs reduce fixture output, resulting in a clear reduction in lighting power. Power reductions throughout the daytime hours illustrate effective daylight harvesting shown in the gradual downward curve, as the LLLCs modulate light levels to maintain target illuminance while minimizing energy use. As the sun starts to set later in the day, power gradually increases to provide more lighting output in the building.

Figure 7. Second floor, office perimeter daylight harvesting sample week

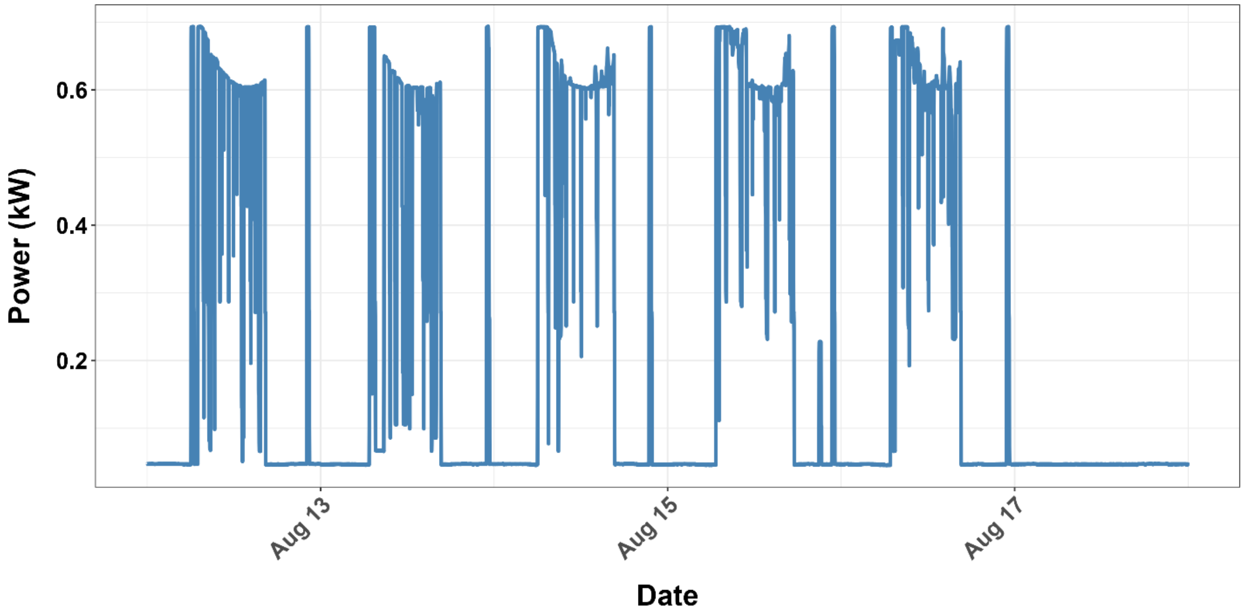
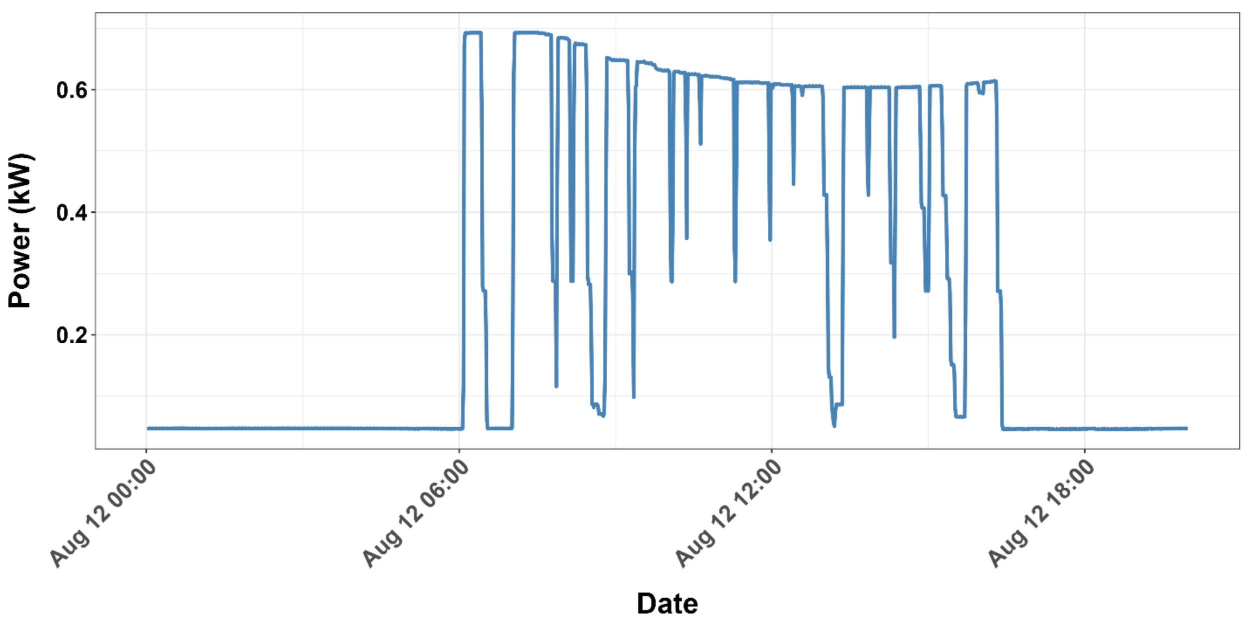


Figure 8 represents a typical sunny day and shows the impact of both daylight harvesting and motion control. Power decreases from .7 kW to approximately .6 kW around midday, providing a 14% reduction for lighting on this circuit. In addition to daylight harvesting, this example shows short-duration power reductions due to motion control, which offers additional energy savings as building occupants leave the area and lights shut off.

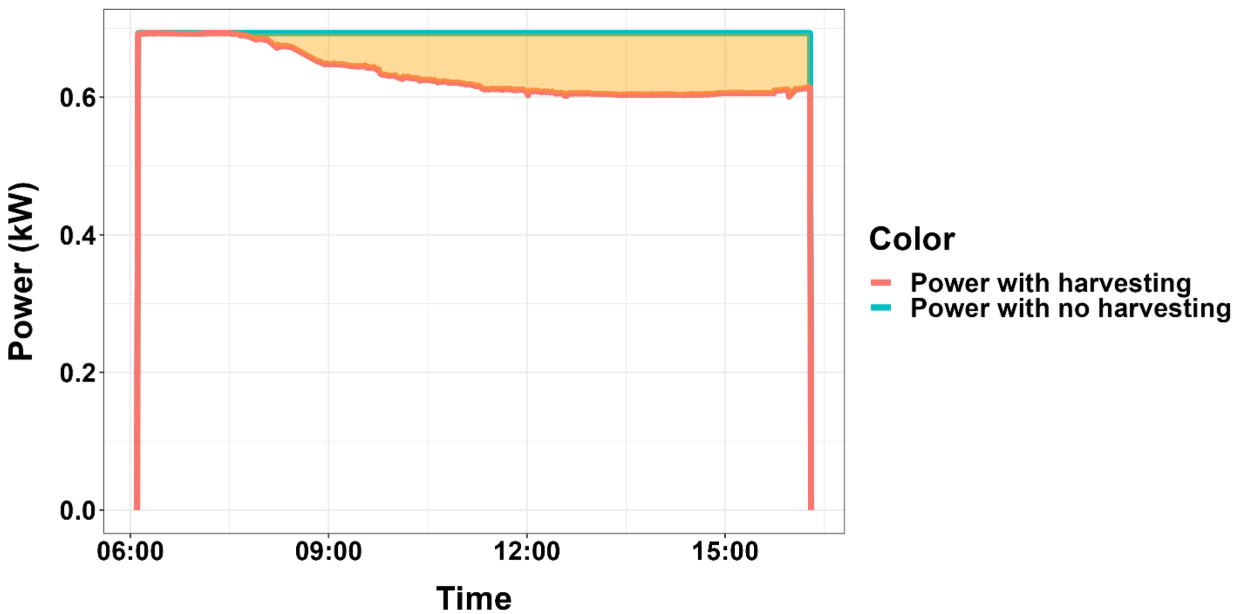
Figure 8. Second floor, office perimeter single day



To estimate the energy savings of daylight harvesting, a sunny day (8/12/24) and a cloudy day (10/30/24) were chosen to compare daily energy consumption for the perimeter lighting on the second floor. Power reductions due to motion sensing have been removed to calculate energy savings from just daylight harvesting. To achieve this, the raw power data was manipulated so all motion sensing events were removed, and the data was interpolated to simulate how the circuit would operate if there was only daylight harvesting, shown as the pink line in Figure 9.

Data was analyzed from a nearby National Oceanic and Atmospheric Administration (NOAA) weather station to evaluate sunlight levels throughout the day. The data provides hourly sky conditions, which denote how much cloud cover is present each hour. A sunny day was chosen that had the lowest amount of cloud cover throughout the day, compared to a day that had steady cloud cover for an entire day. It should be noted that the circuit in this example contains perimeter lighting using daylight harvesting, as well as interior lighting that does not as power data was only collected on a circuit level for this study. Savings from lighting using daylight harvesting has the potential to be far greater than what is represented below.

Figure 9. Second floor energy consumption on a sunny day



As shown in Figure 9, the lights turn on before 8:00 a.m. and remain on until workers leave the office around 4:00 p.m. During that time, the lighting automatically adjusts intensity to maintain a consistent light level on the work plane, in this case, the desks below the light fixtures where light intensity is measured by sensors integrated into the light fixtures. The green line shows the amount of power that these light fixtures would have consumed had there not been daylight harvesting, maintaining consistent power consumption throughout the day. The area shaded in yellow, between these two lines, represents the energy saved by daylight harvesting.
Figure 10 represents a period with high cloud cover, producing little natural lighting.

Figure 10. Second floor energy consumption on a cloudy day

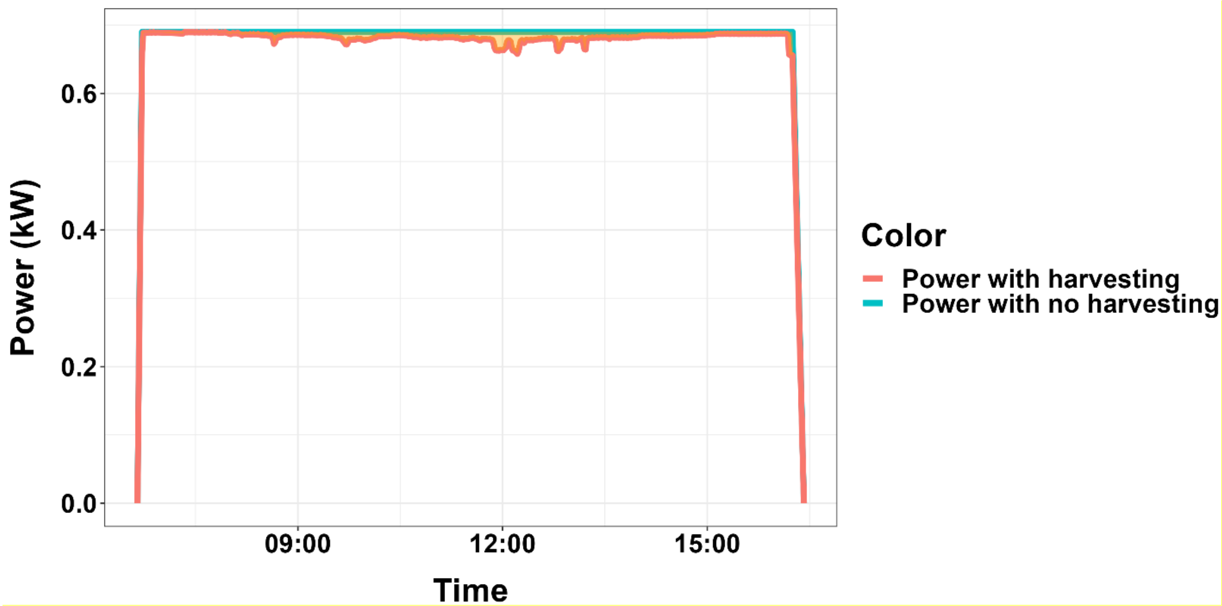


Table 3. Second floor energy consumption: sunny day compared to cloudy day

Daylight Harvesting Example	Sunny Day Energy Consumption (kWh)	Cloudy Day Energy Consumption (kWh)
With Harvesting	6.45	6.15
Without Harvesting	7.06	6.22
Total circuit daily energy savings	**8.6%**	**1.1%**

Energy Savings

Total lighting energy savings were calculated by analyzing power meter data collected during the pre-retrofit and post-retrofit periods. For each period, metered power data was summed to calculate daily lighting energy use, and these totals were averaged to calculate before and after installation consumption levels. This comparison provides a measure of the energy reduction achieved by the lighting upgrade to efficient LLLC fixtures, and the impact of scheduling, high-end trim, motion controls, and daylight harvesting. These savings reflect only the circuits that were metered as part of the study, which is a portion of the building's total lighting load.

Table 4. Daily energy consumption before and after retrofit

Daily Energy Consumption for Monitored Circuits	Daily kWh
Before retrofit	142
After retrofit	36
% Savings	**74%**

BI WORLDWIDE

Methodology

Power meters were installed to measure lighting power for two sections of the building, the main open office area and the warehouse. Similar to ISD 287, power meters were installed inside breaker panels that contained the lighting circuits. Current transformers were also installed to separately meter individual circuits for each area. Power measurements were taken at one-minute intervals, and the data was continuously uploaded to the eGauge server using a cellular modem connected to each meter. Both instantaneous power and total energy consumption were used for data analysis.

Space and Metering Overview

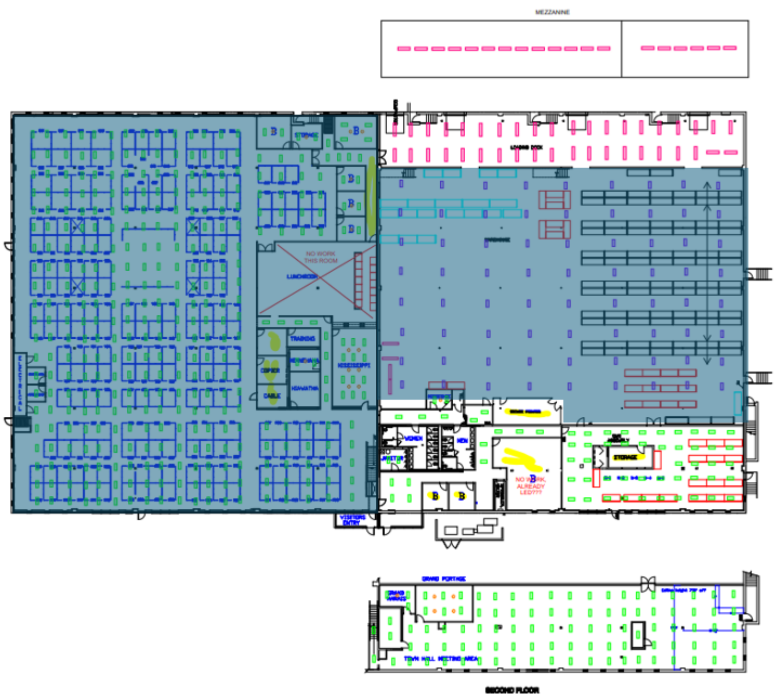
The BI Worldwide site is a single-story building containing a mixture of office and warehouse space. The office area consists of a primarily open workspace with cubicles and some small, enclosed offices. There are also some small conference rooms and a shared lunchroom. The warehouse is split into two main areas. One is a large open space used for light manufacturing and packaging. The other area is dedicated to a storage space containing several rows of large racks with walkways in-between.

These spaces differ in occupancy patterns and functional use. Table 5 provides an overview of the office and warehouse spaces and the number of metered circuits and luminaires. Figure 11 shows the building floor plan with shaded areas that represent spaces in the building that include lighting that was metered as part of this study.

Table 5. Overview of office and warehouse spaces and number of metered circuits

Site	Power meter	Number of metered Lighting Circuits	Metered Space Types	Number of Metered Luminaires
BI Worldwide	Office	10	Open office, cubicle	151
BI Worldwide	Warehouse	16	Open warehouse	66

Figure 11. Building floor plan that includes metered lighting



Analysis

Data analysis was completed to compare energy consumption of baseline lighting operation to post-retrofit LLLC lighting. Power data was used to calculate energy savings due to LLLC lighting and control strategies of motion sensing, and high-end trim since the site elected not to implement daylight harvesting at this building at the time of our field work.

Power Consumption by Area

Power data for each area was totaled to calculate the energy consumption for each day of the monitoring period in kilowatt hours (kWh) as shown in Figure 12. To calculate total energy consumption, all metered circuits were added together to represent total energy consumed across all metered lighting circuits.

During the metering period, two changes were made to the initial control setup. The first change occurred on February 26, 2024, after the space had been occupied. Once occupied, the high-end trim and motion sensing was applied to all lighting fixtures in the office area. In the warehouse, the high-end trim was included as part of the planned control adjustments, but only one circuit received the adjustment while the others remained unchanged. Motion sensing was also applied to all fixtures so that they shut off when the warehouse is not in use, which resulted in substantial energy savings.

The second change occurred on August 26, 2024, and was initiated by CEE after power data analysis made it evident that high-end trim was not properly applied to all lights in the warehouse. Aided by several months of monitoring data, additional adjustments were made to the system to better reflect occupancy patterns in the spaces. In the office, motion sensing timeout was reduced from 30 minutes to 20 minutes and the high-end trim was further reduced for three of the ten monitored lighting circuits in the office. In the warehouse, high-end trim was properly applied to all fixtures, and the motion sensing timeout was reduced from 30 minutes to 20 minutes.

As shown in Figure 12, energy consumption for both the warehouse and office decreased significantly after each control change. Warehouse power data initially reflected factory-set operation with 10-minute motion sensing timeouts and no high-end trim, resulting in higher consumption prior to the first control change. After the first control change, the reductions in energy use came as a result of lights turning off during unoccupied periods. The second control change resulted in further reductions in energy use by applying high-end trim.

It should be noted that during the initial monitoring period, the office space was still under construction and was subject to sporadic occupancy by tradespeople. As a result, the monitoring of lighting usage did not represent typical operations. Due to this, the time period during construction (1/21/24–2/26/24) was excluded from the data analysis. The energy savings analysis in this report begins immediately after the first control change. At that time, high-end trim was applied and motion sensing timeout was set to 30 minutes. Savings observed after the second control change can be attributed to further reductions from high-end trim on several circuits, as well as reducing the motion sensing timeout from 30 to 20 minutes. The latter helped keep lights off during unoccupied periods.

Figure 12. Power consumption by area

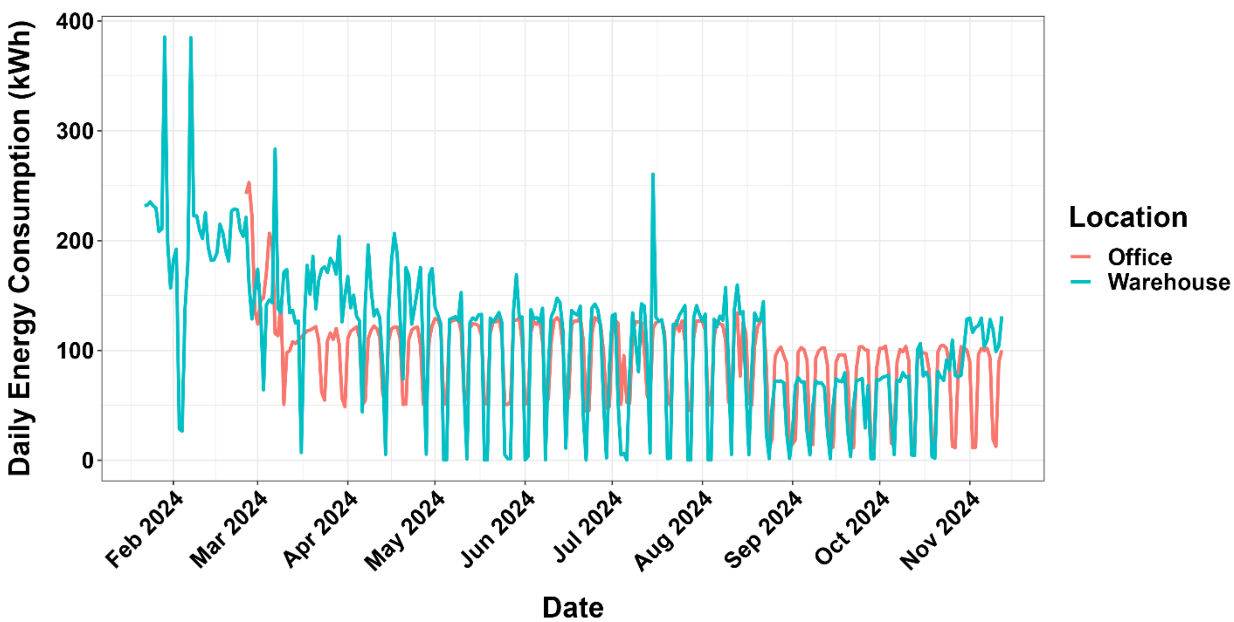
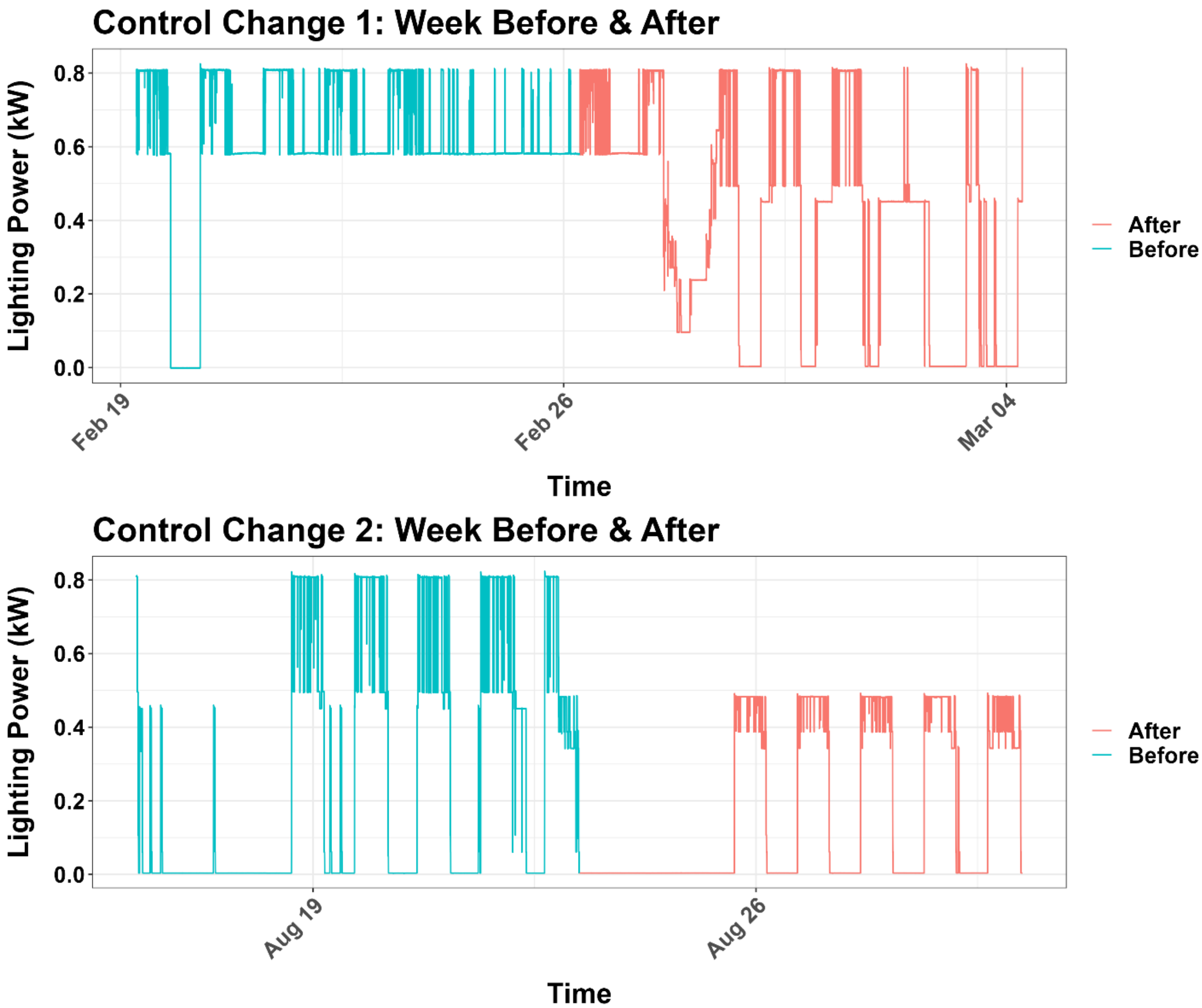


Figure 13 represents raw power data from a metered circuit in the warehouse a week before and after both control changes. As shown, power values remain steady between .55 and .8 kW aside from one day where they shut off completely. After motion sensing is implemented, lights turn off fully when the space is unoccupied, significantly impacting nights and weekends when the warehouse is rarely fully occupied.

After the second control change, the impact of high-end trim was shown to reduce the power levels of this circuit from a maximum value of about .8 kW to just under .5 kW. Both control strategies dropped the maximum power draw and overall energy consumption.

Figure 13. Raw power data from metered circuit

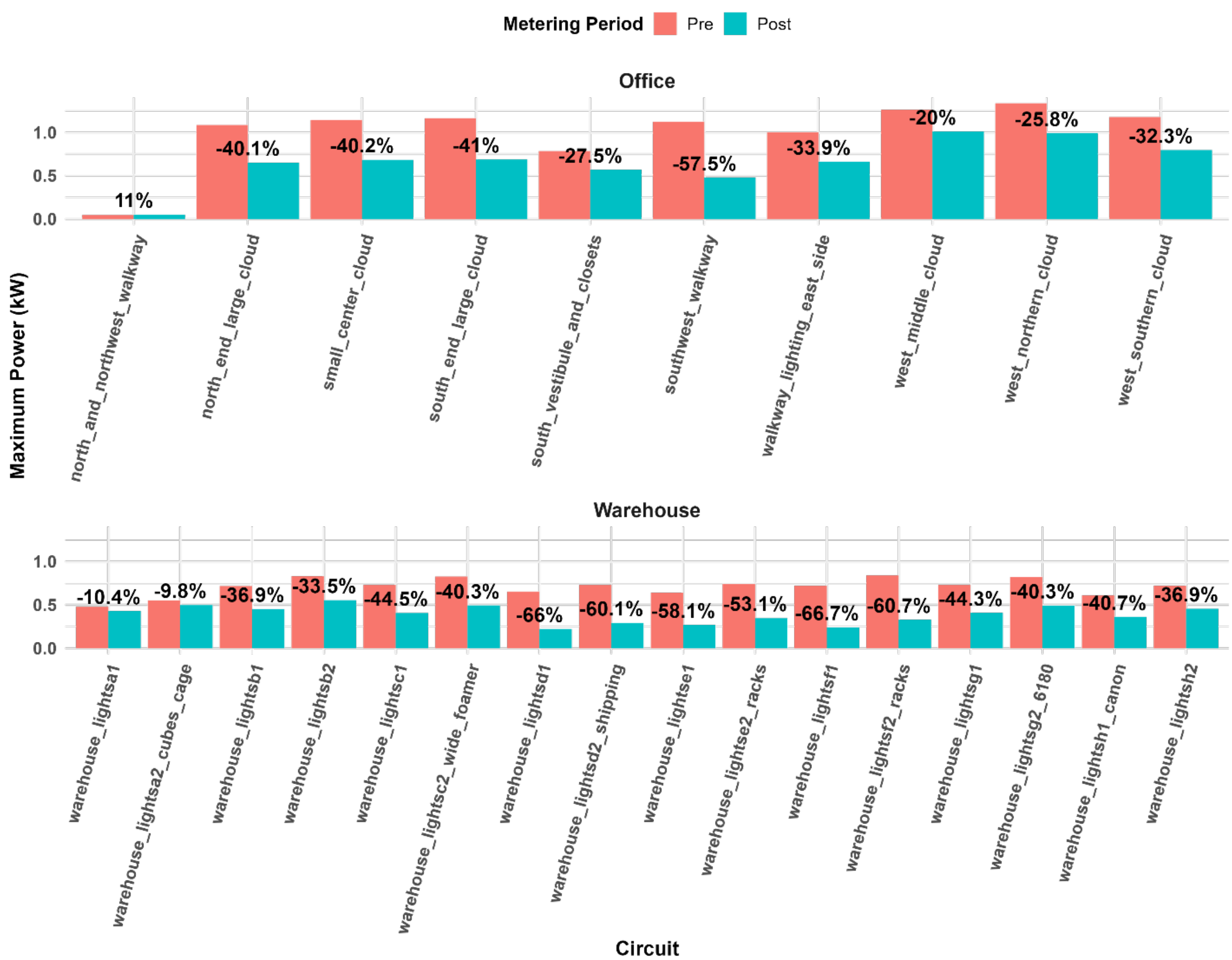


High-End Trim

High-end trim was implemented on all lights and accounted for a large portion of the overall energy savings. Both control changes resulted in varying levels of high-end trim adjustment, with the office receiving adjustments after control change one and the warehouse receiving adjustments after control change two. The high-end trim was programmed for a 20% reduction, but in practice several of the circuits saw a far greater reduction.

Figure 14 represents the maximum power for each metered circuit during the metering periods, comparing standard LLLC lighting settings to their final configuration. For the office and warehouse, the period labeled as “Pre” accounts for metering before the first control change, and the period labeled as “Post” accounts for metering after the second control change.

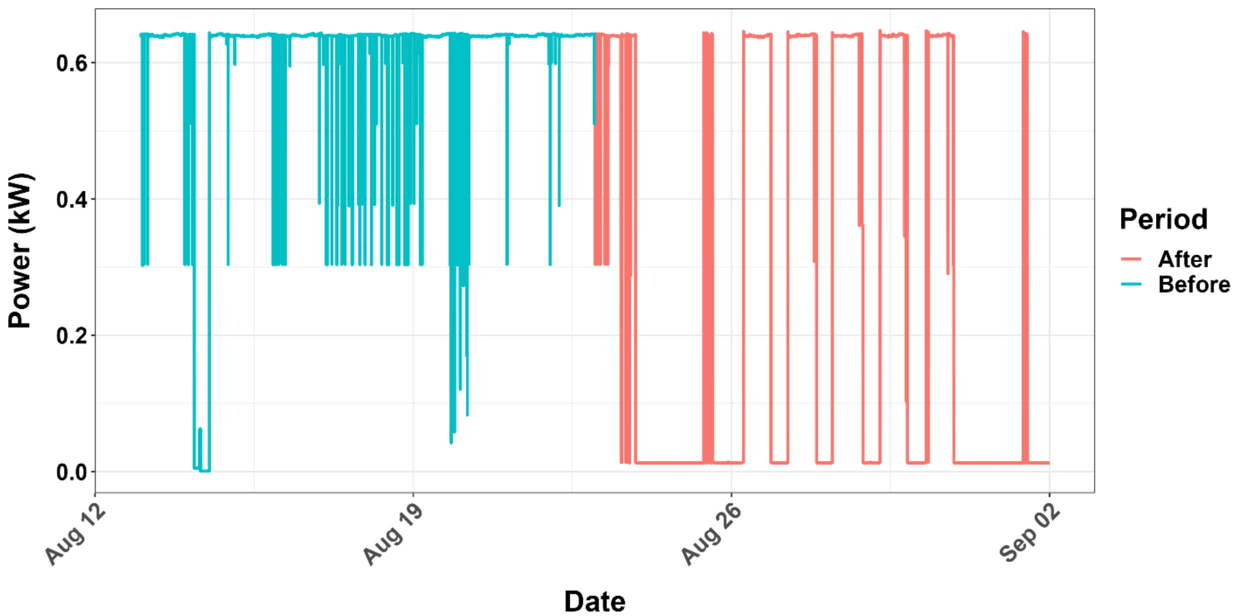
Figure 14. Maximum power for each metered circuit during each metering period



Motion Controls

LLLC lighting with motion control offers significant energy savings compared to standard lighting controlled by a basic switch. Figure 15 represents a lighting circuit in the office 10 days before and after the second control change, which reduced the motion sensing timeout from 30 to 20 minutes. This produced a clear shift in lighting operation for several portions of lighting in the office area. Before the change, lights rarely turned off and dipped down to .3 kW. Lights on this circuit mainly operated at the maximum power for this circuit, around .65 kW. After the change, power data shows that lights remain off for prolonged periods, confirming that the reduced timeout improved shut-off behavior and contributed to lower overall energy consumption.

Figure 15. A lighting circuit in the office 10 days before and after the second control change



Energy Savings

Energy savings were calculated by comparing average daily energy consumption between the before and after retrofit periods. Since the metered study did not capture data from the existing lighting system before they were retrofitted with LLLC luminaires, savings reflect only control changes on luminaires that implemented motion sensing and high-end trim.

For the office area, energy savings were calculated after the first control change, during a period when the building was fully occupied. Power data from the first portion of the metering period, before the first control change, was excluded from the energy savings analysis because it was under construction and did not reflect typical lighting operation. The period after the retrofit includes data gathered after the second control change. For the warehouse, savings were determined by comparing factory setting lighting controls before the first control change to performance after the second control change.

The warehouse exhibited significantly more energy savings than the office, as the control changes significantly reduced light-on time during unoccupied periods, and high-end trim reduced the maximum power consumed by each fixture. While savings in the office area were lower by comparison, they remained substantial, highlighting the value of effective LLLC luminaire programming to fully realize energy savings potential.

Table 6. Daily energy consumption for monitored circuits

Daily Energy Consumption for Monitored Circuits	Pre kWh	Post kWh	Percent Savings
Warehouse	205	68	67%
Office	99	71	27%

CONCLUSION

This study demonstrates that LLLCs can deliver significant energy savings when properly programmed and deployed. We observed reductions in the energy consumption of the lighting we analyzed of up to 78% at BI WORLDWIDE and up to 76% at ISD 287. The three control strategies of high-end trim, motion sensing, and daylight harvesting contributed measurable energy savings individually, while their combined application offered even greater savings.

Key takeaways and lessons learned include:

- Engaging all stakeholders early in the planning process ensures all efficiency and non-energy benefits of a project are accounted for without compromising light levels or occupant comfort.
- Designing granular lighting zones enhances the effectiveness of motion sensing and daylight harvesting strategies.
- Properly programming lighting control strategies during initial setup is crucial to maximize energy savings and ensure optimal system performance.
- To maximize energy savings, minimize unnecessary lighting, and avoid disruption in occupied spaces, motion sensing settings should align with occupancy patterns.
- While LLLCs can produce a considerable amount of energy savings with their default settings, the lighting controls may not necessarily be set for maximum performance without customized adjustments.
- Daylight harvesting should be properly programmed to account for real-time ambient light conditions to reduce artificial lighting when sufficient natural light is accessible.
- Do not be afraid to adjust motion timeouts and/or high-end trim after initial programming to achieve the balance between meeting the lighting needs of a space and maximizing performance settings.
- Incorporating occupant feedback loops over time is an important factor for refining lighting control settings to achieve maximum savings potential and maintain the satisfaction of those dwelling and/or working in a space.

Throughout the study of these two projects, LLLC systems showed a strong promise of achieving significant energy savings over time through the combined use of high-end trim, daylight harvesting, and motion sensing as lighting control strategies. LLLCs also provided customers with enhanced space flexibility to increase the comfort and overall lighting experience of occupants.