

Re-commissioning Networked Lighting Controls is a Bright Idea

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ABSTRACT

Lighting is the most common building system with 98% of total commercial floorspace currently illuminated according to the 2018 Commercial Buildings Energy Consumption Survey (CBECS) by the US Energy Information Administration (EIA). Given the ubiquity of commercial lighting, many facilities continue to adopt LED lighting and basic lighting controls to lower operating costs. Properly commissioned networked lighting control (NLC) systems save a substantial amount of lighting energy, integrate into other building systems, and produce advanced non-energy benefits such as asset tracking. However, expert interviews conducted by DNV identified the high probability that existing NLC systems were incorrectly commissioned, resulting in lower annual energy savings and impacting lifetime savings assumptions. To test these assumptions, DNV partnered with Consumers Energy, an investor-owned utility in Michigan, and Digital Lumens and RAB Lighting, NLC manufacturers, to determine if recommissioning existing NLC systems resulted in incremental energy savings.

To recommission a NLC system, the existing equipment must provide a central programming and control interface that is connected to all devices and luminaires throughout the network, provide lighting zone energy and occupancy data in hourly monitoring intervals, and store this data, either locally or in the cloud, for at least one year. A technical review of Consumers Energy's base-NLC technical specifications confirmed the above requirements, allowing the DNV project team to mine past NLC program participants to develop recommissioning targets. To find additional energy savings, the project team first analyzed the system's stored energy and occupancy data to determine the effectiveness of the initial commissioning strategies, adequateness of lighting zones, and schedules. Then the project team worked with our manufacturing partners to update the system's sequence of operations (SOO) to align zonal-level energy consumption with occupancy patterns.

The final determination of the project team is that NLC program designs should evolve by offering past participants new incentives for proactively recommissioning systems to correct deficiencies in a system's initial commissioning or prevent building energy-savings drift from occurring. For utilities, this will result in more robust lifetime savings assumptions.

Introduction

Lighting systems are one of the major end-users of electricity in commercial facilities. According to CBECS, from 2012 to 2018 there has been a five-fold increase in LED installations (EIA 2018). LEDs are inherently controllable, which is a prerequisite for installing NLC systems. Yet while LED lighting has been rapidly scaling, installation of lighting controls over the same reporting period has been stubbornly slow, showing only about 2% increase over the reporting period.(CBECS, 2018). This indicates that a large majority of commercial buildings and floorspaces have yet to adopt some form of lighting automation to maximize the benefits of

LEDs. Figure 1 shows building stock information for lighting control features as a function of total available commercial floorspace and buildings obtained from 2018 CBECS.

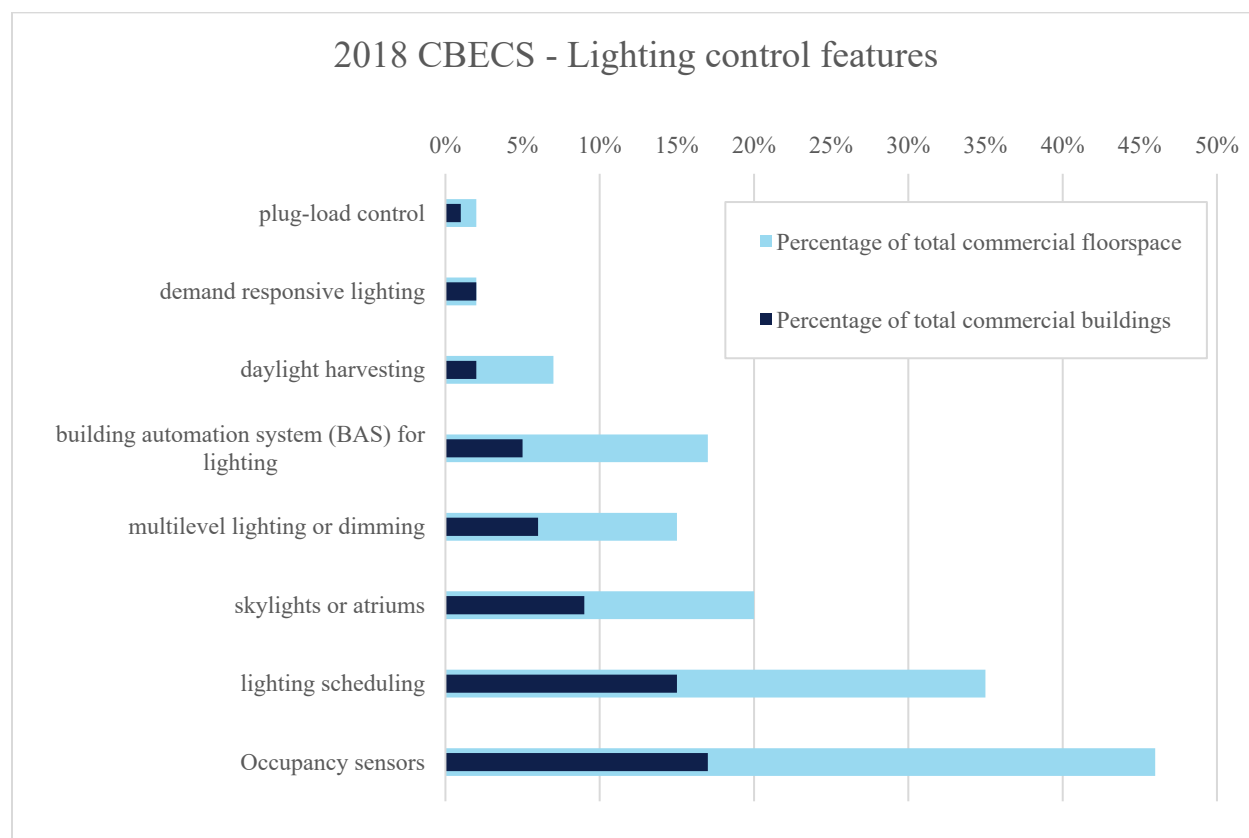


Figure 1. Lighting control features by percent of total commercial floorspace and total commercial buildings

Successive building energy code enhancement initiatives through The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1 and local codes like California Title 24 Building Energy Efficiency Standards have lowered the lighting power density requirement for various building space types. To comply with tightening energy code standards, specifiers increasingly favor LED applications over legacy technology, such as linear fluorescent or high intensity discharge lighting. Additionally, most building energy codes now require basic lighting control strategies, such as light scheduling, that achieve higher lighting energy savings. While energy code enhancements have led to increases for basic controls, NLC systems have seen a smaller uptick over the CBECS reporting period. This represents a lost opportunity, as NLC systems can save on average 49% more lighting energy than just a LED only retrofit (Yao-Jung et al., 2020).

To move the market past code-based lighting systems, lighting and control manufacturers commonly market the enhanced energy savings potential of NLC systems. These systems have a network of sensors and interfaces that provide control of multiple LED fixtures simultaneously. They also collect and store granular energy, occupancy, and operational data in short time intervals. However, for a facility to receive the maximum energy benefit from a NLC project, the system's initial commissioning must reflect the occupancy patterns of the space and be updated as the needs of the space change over time. To determine the health of existing NLC systems,

DNV interviewed 10 leading lighting controls manufacturers about the possibility of finding additional energy savings post-commissioning. Each manufacturer felt that there was a high likelihood of finding additional savings through correcting deficiencies in the initial commissioning or updating the system's sequence of operations (SOO) to reflect new occupancy patterns.

Approach

To test these assumptions DNV partnered with Consumers Energy, an investor-owned utility in Michigan, and Digital Lumens and RAB Lighting—leading NLC manufacturers, to determine if recommissioning an existing NLC systems resulted in incremental energy savings. Together, NLC projects from Digital Lumens and RAB accounted for over 80% of all projects submitted to the Consumers Energy NLC program since 2016. DNV dubbed this pilot “NLCx” and established a primary objective of determining if additional energy savings or demand reduction opportunities can be found by examining data stored in NLC systems. Project success criteria was established as over 5% additional energy savings in at least 50% of sites.

- Prior to recruiting customers, DNV conducted an in-depth participation analysis of all past NLC projects. We found that 89% of all NLC projects were installed in industrial or warehousing applications, with the remaining 11% being installed in light commercial or office applications. DNV then segmented each project into three bins based on square footage data that was collected through the initial NLC application process
- Of the total projects studied, 30% of all systems were installed in space types $\leq 100,000$ sq. ft. As these projects only accounted for 4% of total savings DNV exclude these projects from the NLCx effort.¹ Facilities over 100,000 sq. ft. and $\leq 499,999$ sq. ft. accounted for 50% of all projects and 20% of all savings. Finally, facilities $>500,000$ sq. ft. accounted for 20% of projects and 76% of total savings.
- Based on our historical project participation and subsequent data synthesis, DNV adopted a program design that split participants into two building footprint tiers: Tier 1 is all non-residential buildings $\leq 150,000$ sq.ft with an existing NLC system with at least a years' worth of hourly interval energy use data. Customers received up-to a \$5,000 per site incentive to cover costs associated with updating the system's SOO and a \$500 data sharing bonus.
- Tier 2 is all non-residential buildings $> 150,000$ sq. ft. with an existing NLC system with at least a years' worth of hourly interval energy use data. Customer received an incentive of up to \$15,000 per site incentive to cover costs associated with updating the system's SOO and a \$1,200 bonus for nominating an energy champion, who acted as the customer's lead for the project.

For the NLCx pilot, DNV sought to study three Tier 1 customer sites and two Tier 2 customer sites. While the project team succeeded in collecting historical system data from all our target customers, technical limitations, which we describe below, prevented the project team from recommissioning Tier 1 sites. As such, we will first discuss the results from Tier 2 sites before describing the technical limitations that caused us to furlough our Tier 1 sites.

¹ An engineering analysis determined that the likely cost-of-delivery would be $> \$1.00$ per kWh saved and that it would not be cost-effective to serve these customers.

Tier 2 Buildings

For all Tier 2 sites, DNV partnered with Digital Lumens, a leading lighting, and controls manufacturer. Digital Lumens Intelligent Highbays and Light Rules® software was the most employed system in the Consumers Energy dataset for facilities over 150,000 sq. ft. DNV worked with Digital Lumens to reengage past participants and select two large implementations in central Michigan. Digital Lumens worked directly with each site's Energy Champion to obtain the historical system data to perform a re-commissioning analysis and update the system's SOO based on the analysis. In both instances, Consumers Energy covered the full cost of the re-commissioning study and updated programming.

All controlled fixtures at both sites were Luminaire Level Lighting Controls (LLLC)—meaning each fixture has an integrated digital driver that allows for individual control and have an integrated dual purpose occupancy sensor and photocell. Each fixture was networked backed to a central server that housed the system's commissioning and stored the system's historical energy and occupancy data. Upon updating the SOO, DNV's engineering team used zonal level pre/post data stored by the system to calculate and verify the project's energy savings.

LightRules® is the lighting management software that is intended to be used with the Digital Lumen Intelligent Highbay LLLC. In addition to hosting basic functions, like calendar scheduling, LightRules® provides a web-based interface and facility map which overlays lighting system information over a facility floor plan. LightRules® allows the user to configure lighting zones, create control profiles, establish settings, and create rules. It also acts as a reporting interface that provides 'what if' analysis for estimating energy savings from applying different settings across a zone, room, or facility.

LightRules® Terminology

Total Time: Is the total amount of time the LightRules® has reporting data for lights in an interval. It functions as a baseline to understand how many fixtures were communicating with LightRules® during the interval. A designated room has a certain number of fixtures that are grouped under the room name and each fixture is considered as a node which communicate with a particular gateway(s) assigned to the room. These nodes are in constant communication with the gateway, which routes the data back to server hosting the LightRules® software. The project team looked for communication deficiencies that could occur due to a combination of the following:

- Lights are offline/not powered
- Malfunctioning
- Lights are moved or replaced but LightRules® is not updated with the changes
- Gateway is disconnected
- Latency in communication from overcrowding gateway beyond maximum number of connected fixtures. This latency also causes any system/room changes to be delayed before they take effect

Sensor Active: The total amount of time that lights reported the motion sensors are active during an interval. A motion sensor is active when it detects motion and is inactive during

periods of vacancy. Whenever occupancy is detected by the sensor, the time is counted towards sensor active. Each sensor active is one second when a motion sensor detects motion, and the value is summed up for that time interval for every fixture in the room. Also, the sensor active profiles will closely resemble the facility's active operation hours as motion will be detected when the space is being occupied. Percentage of occupancy is calculated by dividing the sensor active by total time which can then be used to identify building space usage patterns and better calendar scheduling.

Light Active: The total amount of time that lights reported they were in the active state during an interval. Lights switch between the active level (light output in active state) and inactive level (light output in inactive state) based on motion sensor activity and the delay time associated with the active profile. Where delay time is the amount of time a given fixture is required to wait to go to inactive state unless the motion sensor detects presence in which case the delay time is reset, and the countdown begins again. Normally, active level is not equal to the inactive level, which results in the light dimming when it switches from the active state to the inactive state. Additionally, active level is generally associated with higher light output. It would be expected that higher sensor active times (in seconds) and light active times (in seconds) would correlate with higher energy usage

Results — Tier 2 Site A

Site A is an automotive compressor parts manufacturing facility in Parma, MI with an open floor manufacturing space of 750,000 sq. ft. The site's NLC system was originally commissioned in 2019 and enabled with high-end trim,² occupancy sensing, and calendar scheduling. The facility has 940 nodes/fixtures with 64 individual zones controlled by 21 network gateways.

Analysis of site data showed network congestion due to too many fixture nodes per gateway, which created latency. Additionally, a feature called coordinated control was enabled, which resulted in one set of fixtures being the parent and the remaining fixtures being the child. Coordinated control resulted in increased energy consumption as it effected the ramp down³ time of each fixture. Furthermore, the majority of fixtures had 120-sec timeouts, which is the time it takes the fixture to move from active light-level setting to a lower-power inactive light-level setting when no occupancy is detected.

Recommissioning Strategies Employed

Network congestion was addressed by moving fixtures from one gateway to another to prevent bandwidth issues and communication delays between gateways and fixtures. We also ensured that all fixtures/nodes in the facility were distributed evenly among the gateways. Coordinated control was disabled in a few zones to facilitate faster transition to inactive states. Finally, the timeout was changed to 60 sec for the fixtures that were set at 120 sec and night lights were reduced from 35% inactive power down to 20% inactive power throughout the zones. This means that when no occupancy is detected for a pre-defined amount of time, fixtures that were previously ramping down to 35% power dropped to 20% power.

² High-end trim is defined in the proceeding glossary.

³ Ramp down is the time it takes a fixture to move from an active to an inactive state.

Results

The optimization strategies resulted in an overall reduction in kW usage during all hours, barring a couple of instances where the post kW usage is slightly higher compared to the same time of day. This is illustrated in Figure 2, which shows energy usage “heat maps” of Site A. The chart on the left shows pre-treatment energy usage and the one on the right shows post-energy usage. Rows indicate building operating hours (0-23) and columns indicate days of the week (1 is Monday and 7 is Sunday). The below heat mats employ a red-yellow-green color scale. The color in each scale represents the value within the range of the table, with small values being shaded green and large values being shaded red.

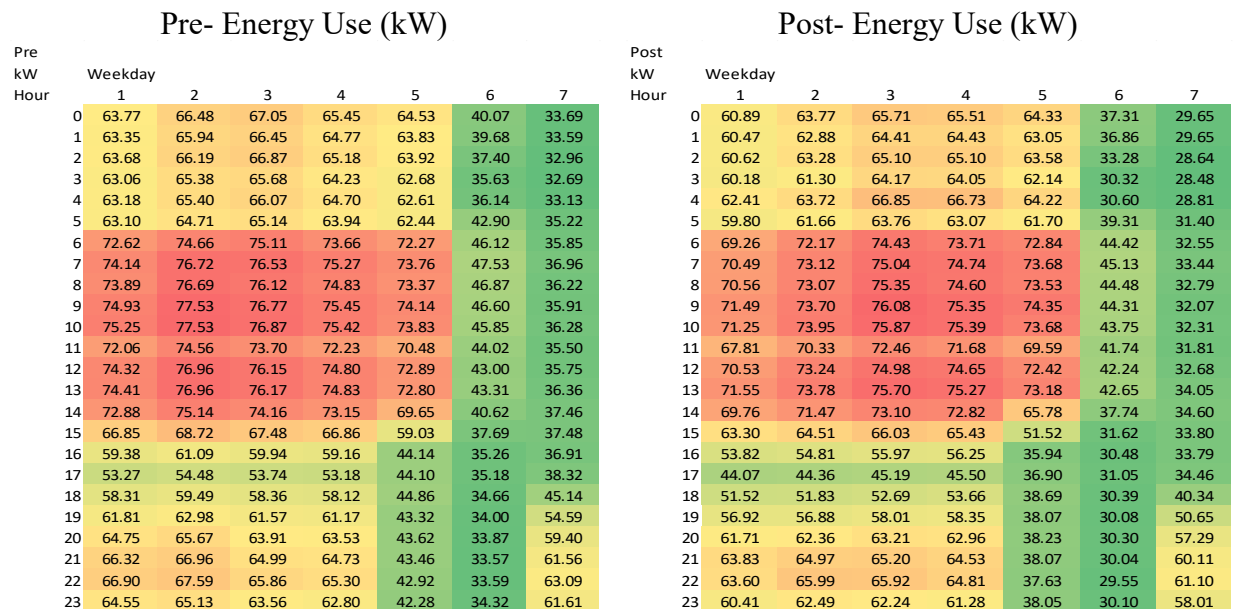


Figure 2. Pre- and post- heat maps of Site A

The difference between pre- and post-treatment can also be shown by highlighting the difference (Δ) in kW usage during various hours. In Figure 3 below, the negative values imply the increase in power consumption (kW) and the positive values imply the decrease in power consumption (kW). For Figure 3 and 4 the heat mat's shading for the darker red indicates a lower negative value and the darker blue indicates a higher positive value.

Hour	Weekday						
	1	2	3	4	5	6	7
0	2.88	2.71	1.34	-0.06	0.20	2.76	4.04
1	2.88	3.06	2.03	0.34	0.77	2.81	3.94
2	3.05	2.91	1.76	0.09	0.34	4.12	4.33
3	2.88	4.09	1.51	0.19	0.54	5.30	4.22
4	0.76	1.68	-0.78	-2.03	-1.61	5.54	4.32
5	3.29	3.05	1.38	0.87	0.73	3.59	3.82
6	3.36	2.49	0.68	-0.05	-0.57	1.70	3.30
7	3.65	3.60	1.49	0.53	0.08	2.40	3.53
8	3.32	3.62	0.77	0.23	-0.16	2.39	3.43
9	3.44	3.83	0.69	0.10	-0.20	2.29	3.84
10	4.00	3.58	1.00	0.03	0.15	2.09	3.97
11	4.25	4.22	1.24	0.56	0.89	2.29	3.69
12	3.79	3.72	1.17	0.15	0.48	0.77	3.07
13	2.87	3.18	0.47	-0.45	-0.38	0.65	2.31
14	3.13	3.67	1.06	0.33	3.88	2.87	2.86
15	3.55	4.21	1.45	1.43	7.51	6.07	3.69
16	5.56	6.28	3.97	2.90	8.20	4.78	3.12
17	9.20	10.12	8.55	7.68	7.20	4.13	3.85
18	6.78	7.66	5.68	4.47	6.17	4.27	4.79
19	4.88	6.09	3.57	2.82	5.26	3.92	3.94
20	3.04	3.31	0.70	0.56	5.39	3.58	2.12
21	2.49	1.98	-0.22	0.21	5.39	3.52	1.45
22	3.30	1.60	-0.06	0.49	5.29	4.04	1.99
23	4.14	2.64	1.31	1.52	4.23	4.23	3.60

Figure 3. Delta kW between pre- and post- of Site A

Another way to look at the pre and post effects is the reduction in lights that are in the active state. In Figure 4, the negative sign in front of a value implies the percent reduction in lights in the active state and the preceding number indicates the magnitude of change in lights being active in relation to the system status before implementing the recommendations.

Hour	%Light Active change						
	1	2	3	4	5	6	7
0	0%	0%	4%	8%	7%	7%	5%
1	0%	-1%	3%	7%	6%	8%	7%
2	0%	-1%	3%	8%	7%	-1%	2%
3	0%	-3%	4%	7%	7%	-11%	3%
4	5%	3%	10%	13%	12%	-11%	2%
5	-1%	-1%	4%	5%	6%	2%	4%
6	-1%	0%	5%	6%	7%	9%	7%
7	-2%	-2%	3%	5%	6%	6%	5%
8	-1%	-1%	4%	5%	7%	6%	6%
9	-2%	-1%	4%	5%	6%	6%	3%
10	-2%	-1%	4%	6%	6%	8%	1%
11	-3%	-1%	3%	5%	5%	8%	5%
12	-2%	0%	4%	6%	6%	15%	8%
13	-1%	1%	5%	7%	7%	15%	14%
14	-1%	-1%	4%	6%	-1%	7%	9%
15	-1%	-2%	4%	5%	-11%	-14%	5%
16	-5%	-7%	-1%	2%	-21%	-8%	10%
17	-18%	-20%	-15%	-13%	-16%	-2%	3%
18	-9%	-11%	-5%	-2%	-12%	-2%	-3%
19	-4%	-7%	0%	1%	-8%	1%	-1%
20	0%	0%	6%	7%	-9%	2%	3%
21	0%	3%	8%	7%	-9%	0%	4%
22	-2%	4%	7%	6%	-8%	0%	2%
23	-3%	2%	5%	4%	-2%	1%	-2%

Figure 4. Active light change pre- and post- of Site A

Similarly, when we compare pre- and post-treatment on energy usage, we also see changes in building occupancy patterns as illustrated in Figure 5. Darker red shading indicates higher levels of energy savings from decreasing sensor timeouts and more efficiently moving the

lighting into an unoccupied state, whereas the darker blue indicates an increase in energy from the pre state.

		%Occupancy change						
Hour	Weekday							
	1	2	3	4	5	6	7	
0	-1%	0%	-4%	-8%	-7%	-10%	-9%	
1	-1%	1%	-3%	-7%	-6%	-11%	-11%	
2	-1%	1%	-3%	-8%	-6%	-2%	-8%	
3	-2%	3%	-4%	-8%	-7%	6%	-8%	
4	-6%	-3%	-9%	-13%	-12%	6%	-7%	
5	0%	1%	-4%	-5%	-6%	-7%	-10%	
6	0%	0%	-4%	-6%	-7%	-14%	-14%	
7	1%	2%	-3%	-5%	-6%	-12%	-13%	
8	1%	1%	-4%	-5%	-6%	-12%	-13%	
9	1%	1%	-4%	-5%	-6%	-13%	-12%	
10	2%	1%	-4%	-6%	-5%	-15%	-10%	
11	1%	1%	-4%	-6%	-5%	-15%	-13%	
12	1%	0%	-4%	-6%	-5%	-20%	-16%	
13	-1%	-1%	-5%	-7%	-7%	-20%	-19%	
14	0%	1%	-4%	-6%	3%	-10%	-16%	
15	0%	1%	-5%	-6%	13%	7%	-14%	
16	4%	7%	0%	-4%	22%	1%	-16%	
17	23%	26%	19%	15%	15%	-4%	-12%	
18	12%	13%	7%	2%	8%	-5%	-2%	
19	6%	8%	1%	-2%	3%	-7%	0%	
20	2%	2%	-6%	-6%	4%	-7%	-3%	
21	0%	-3%	-9%	-8%	4%	-6%	-5%	
22	1%	-4%	-8%	-7%	4%	-7%	-4%	
23	4%	-1%	-5%	-4%	-3%	-8%	1%	

Figure 5. Changes in occupancy patterns pre- and post- of Site A

Results – Tier 2 Site B

Site B is a furniture manufacturing company in Holland, MI with roughly 450,000 sq. ft. About 400,000 sq. ft. is manufacturing space and 50,000 sq. ft. is office space. The facility's NLC system was originally commissioned in 2018 with occupancy sensing, high-end trim, and enabled calendar scheduling. There are a total of 615 nodes/fixtures split into 57 zones controlled by 14 network gateways.

Site data analysis showed that active light levels measured during facility on hours (i.e., Monday through Saturday, 6 a.m. to 5 p.m.) were below Illuminating Engineering Society (IES) recommended levels.⁴ Furthermore, calendar scheduling was only partially employed, resulting in over consumption during unoccupied periods. Besides updating the system's calendar, the project team identified further savings opportunities through rezoning fixtures, disabling coordinated control, adjusting the ramp down speed below 60 sec, and limiting network congestion.

Recommissioning Strategies Employed

The active light levels during facility on hours were increased and calendar scheduling was implemented more aggressively to change light levels during facility off hours (Monday through Saturday, 6 a.m. to 4:30 a.m. and all of Sunday) and increase light levels during facility on hours. Fixtures were re-zoned to facilitate faster timeouts, coordinated control was disabled in a few select zones, and the ramp down speed was reduced to 5 sec. Additionally, inactive light levels were changed from 20% to 0% throughout the zones. When no occupancy is detected for a pre-defined amount of time, fixtures which were previously ramping down to 20% power were

⁴ Light level recommendations come from the 10th addition of the IES Lighting Handbook.

now dropping all the way down to 0% power. Network congestion was addressed by moving fixtures from one gateway to another to prevent bandwidth issues and communication delays.

Results

Implementing the above strategies resulted in an increase in power consumption (kW) during facility on hours that can be seen in the pre- and post-heat maps in Figure 6. This increase is related to raising overall facility lighting levels to align with IES space type recommendations. The below heat mats employ a red-yellow-green color scale. The color in each scale represents the value within the range of the table, with small values being shaded green and large values being shaded red.

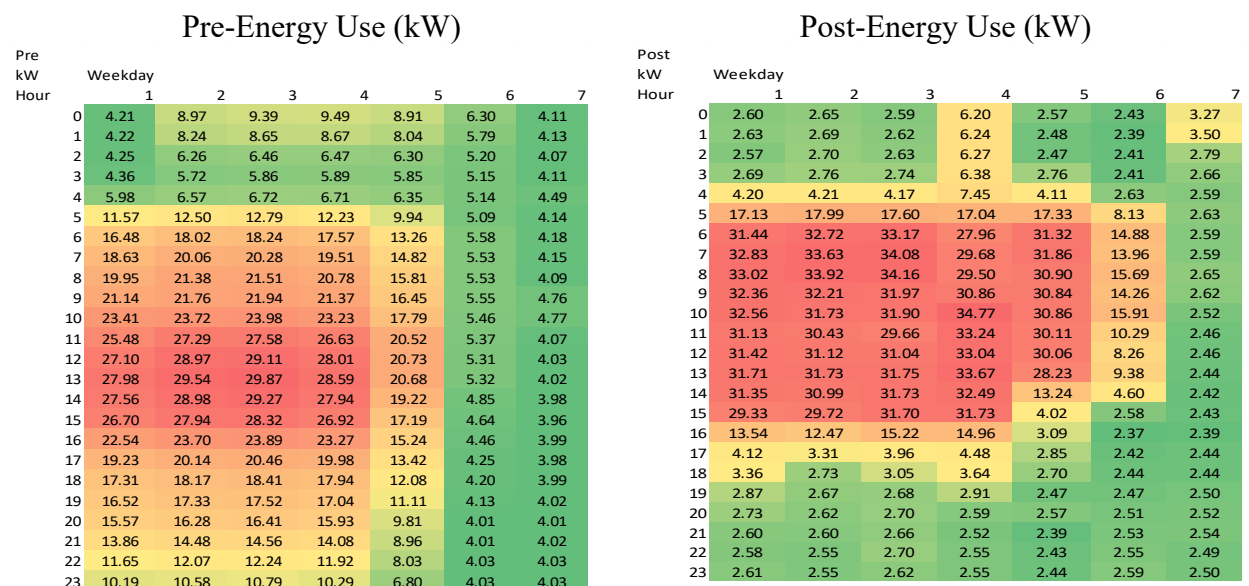


Figure 6. Pre- and post-heat maps of Site B

For Figure 7 and 8 the heat mat's shading for the darker red indicates a lower negative value and the darker blue indicates a higher positive value. Figure 7 highlights the magnitude of the reduction in kW usage (Δ kW) during facility off hours. The negative numbers in Figure 7 imply the increase in power consumption (kW) and positive numbers imply the decrease in power consumption (kW).

Δ kW Hour	Weekday						
	1	2	3	4	5	6	7
0	1.61	6.33	6.80	3.29	6.35	3.87	0.84
1	1.58	5.55	6.03	2.43	5.56	3.39	0.64
2	1.68	3.56	3.83	0.20	3.83	2.79	1.28
3	1.67	2.96	3.12	-0.49	3.09	2.73	1.46
4	1.78	2.36	2.55	-0.74	2.24	2.51	1.90
5	-5.56	-5.49	-4.81	-4.81	-7.39	-3.04	1.51
6	-14.95	-14.70	-14.93	-10.39	-18.06	-9.30	1.59
7	-14.19	-13.57	-13.80	-10.17	-17.04	-8.42	1.56
8	-13.07	-12.53	-12.65	-8.72	-15.09	-10.16	1.43
9	-11.21	-10.46	-10.02	-9.49	-14.39	-8.70	2.14
10	-9.16	-8.01	-7.92	-11.54	-13.08	-10.45	2.25
11	-5.65	-3.13	-2.09	-6.61	-9.59	-4.92	1.60
12	-4.32	-2.15	-1.93	-5.03	-9.33	-2.95	1.58
13	-3.73	-2.19	-1.88	-5.08	-7.55	-4.05	1.58
14	-3.78	-2.01	-2.46	-4.55	5.98	0.24	1.56
15	-2.63	-1.79	-3.38	-4.81	13.18	2.06	1.54
16	9.01	11.23	8.67	8.31	12.15	2.09	1.60
17	15.11	16.83	16.50	15.50	10.57	1.83	1.54
18	13.95	15.44	15.35	14.30	9.37	1.76	1.55
19	13.65	14.65	14.84	14.13	8.65	1.66	1.52
20	12.84	13.65	13.71	13.34	7.24	1.50	1.50
21	11.26	11.89	11.90	11.56	6.57	1.48	1.48
22	9.07	9.53	9.53	9.37	5.60	1.48	1.54
23	7.58	8.03	8.17	7.75	4.36	1.44	1.52

Figure 7. Delta kW between pre- and post- of Site B

Allowing the fixtures to completely turn off in the post produced changes in the percentage of lights that are in the active state (Figure 8). A negative value implies the percent reduction in lights being in the active state and the preceding number indicates the magnitude of change in lights being active in relation to the system status before implementing this change.

Hour	%Light Active change						
	1	2	3	4	5	6	7
0	-16%	-61%	-64%	-54%	-63%	-46%	14%
1	-14%	-56%	-59%	-48%	-61%	-41%	21%
2	-18%	-36%	-40%	-22%	-45%	-36%	-9%
3	-17%	-27%	-29%	-8%	-31%	-34%	-16%
4	8%	2%	-2%	16%	1%	-27%	-16%
5	55%	53%	44%	55%	88%	67%	-13%
6	93%	86%	85%	87%	148%	187%	-19%
7	63%	58%	56%	65%	107%	161%	-18%
8	52%	48%	46%	53%	85%	199%	-14%
9	50%	45%	43%	50%	84%	172%	-15%
10	38%	35%	33%	41%	75%	202%	-20%
11	17%	9%	5%	15%	44%	73%	-21%
12	12%	5%	3%	9%	43%	30%	-24%
13	5%	0%	-1%	4%	27%	54%	-24%
14	3%	-2%	-1%	2%	-35%	-19%	-25%
15	3%	0%	3%	7%	-73%	-19%	-24%
16	-44%	-51%	-39%	-42%	-79%	-43%	-25%
17	-78%	-83%	-78%	-78%	-78%	-35%	-24%
18	-81%	-86%	-84%	-81%	-79%	-33%	-23%
19	-85%	-86%	-86%	-85%	-80%	-28%	-19%
20	-84%	-86%	-84%	-86%	-73%	-20%	-17%
21	-82%	-83%	-82%	-84%	-73%	-19%	-18%
22	-78%	-78%	-76%	-79%	-66%	-19%	-21%
23	-70%	-70%	-70%	-71%	-51%	-17%	-21%

Figure 8. Active light change pre- and post- of Site B

Similarly, a positive value implies the percent increase in lights being in the active state due to changes in building occupant patterns, which is shown in Figure 9. The preceding number indicates the magnitude of change in lights being active in relation to the system status before

implementing this change. The number of active lights was increased during facility on hours, which produced an increase in occupancy during facility on hours.

		%Occupancy change						
		Weekday						
Hour		1	2	3	4	5	6	7
0		-10%	-40%	-43%	-33%	-43%	-25%	15%
1		-7%	-38%	-40%	-29%	-42%	-26%	18%
2		-9%	-14%	-15%	0%	-25%	-24%	-4%
3		-9%	-11%	-10%	4%	-16%	-22%	-9%
4		22%	13%	14%	23%	7%	-18%	-5%
5		46%	35%	36%	43%	54%	14%	-4%
6		81%	74%	72%	73%	139%	94%	-12%
7		52%	47%	44%	52%	107%	85%	-11%
8		42%	36%	34%	40%	83%	91%	-6%
9		33%	29%	26%	30%	82%	74%	-4%
10		29%	23%	23%	25%	84%	88%	-9%
11		0%	-4%	-7%	-2%	44%	7%	-10%
12		2%	-2%	-3%	-3%	51%	5%	-14%
13		-5%	-10%	-11%	-10%	25%	-8%	-15%
14		-10%	-15%	-13%	-14%	-55%	-39%	-16%
15		-8%	-10%	-8%	-7%	-67%	-19%	-16%
16		-64%	-68%	-59%	-64%	-73%	-33%	-16%
17		-76%	-79%	-75%	-77%	-70%	-27%	-15%
18		-80%	-83%	-80%	-80%	-71%	-25%	-12%
19		-82%	-83%	-81%	-83%	-70%	-19%	-8%
20		-80%	-81%	-79%	-81%	-61%	-11%	-8%
21		-73%	-74%	-72%	-75%	-57%	-12%	-8%
22		-64%	-63%	-60%	-64%	-47%	-10%	-13%
23		-52%	-52%	-50%	-52%	-28%	-8%	-12%

Figure 9. Changes in occupancy patterns pre- and post- of Site B

Tier 1 Buildings

The NLCx pilot classifies commercial buildings less than 150,000 sq. ft. as Tier 1 sites. A secondary objective of this effort was to quantify the difference in energy savings potential between large and small sites. To quantify the savings potential for Tier 1 sites DNV partnered with RAB Lighting, Inc. whose LightCloud™ system was marketed to facilities with smaller footprints.⁵ With the help of the RAB team, DNV recruited three customer sites with LightCloud™ products to participate in the NLCx pilot. The LightCloud™ system utilizes a combined server/gateway device to store the system's SOO and route data to the RAB cloud. The server/gateway device does not provide true or apparent power readings; rather it estimates energy consumption through correlating a dimming signal to a power curve.

After obtaining the customer site data, the project team discovered that while the LightCloud™ system collects hourly zonal level data, the system stores the data in a single 24-hour period. Further interviews with the VP of Controls & LightCloud™ determined that obtaining hourly data from the tests sites was not possible. The lack of zonal-level hourly data inhibited RAB's applications engineering team from developing specific energy reduction recommendations.

Results

DNV could not validate the secondary objective and hypothesis owing to the stored system data not meeting program requirements and pivoted remaining resources to validating the

⁵ https://www.rablighting.com/sites/default/files/lightcloud_resources/RAB%20LC%20Brochure.pdf

primary objective. While some comprehensive systems provide remote data access, customer security concerns prevent the NLC system manufacturer from remotely accessing these data sets. Optimization carried out without NLC system manufacturer input often results in the customer not being able to take full advantage of NLC capabilities, leaving savings on the table. Conducting focus groups or other customer interviews are needed to better understand their IT data security needs and the reason for utilizing local storage. Customers generally have to purchase a separate service as it is not possible to expand controlled space. More often than not this requires the customer to have two interfaces when interacting with the NLC system.

Conclusion

Utility programs with dedicated NLC programs should consider implementing changes to their program designs that incentivize a post-commissioning health check to ensure that first year annual savings persist over the lifetime of the system. To maximize future opportunities for these long-lived systems utilities should consider modifying NLC system eligibility criteria to include requiring the system to store and report on energy and occupancy data in at least hourly intervals. Furthermore, historical data needs stored for a period of at least one year to allow for the historical analysis that is needed to develop re-commissioning recommendations. Finally, program's should focus group their large energy users to better understand their customer's requirements for sharing system data with their utility partner. Obtaining site-level data was a hurdle for the NLCx pilot.

Additionally, program planners should leverage the native energy monitoring features of NLC systems to better estimate savings claims, align incentives with performance, and predict program cost-effectiveness. Most manufacturers do not have an existing mechanism to easily export the data required for energy efficiency program evaluation. The size of a dataset grows rapidly as the spatial and temporal granularities and the overall duration of measurement increases. The highly granular and long duration datasets used in this study presented challenges, both in terms of the data providers transferring the data, in the time required for the project team to process, normalize, and load the datasets into the NLC database.

The challenges encountered in this study suggest that it would not be a scalable model for utility and energy efficiency programs to require the most granular energy data for NLCs. The program data requirements will need to strike a balance between accuracy and scalability.

For program's looking to implement a NLC recommissioning project, below are some of the lessons learned from the DNV project team:

- Future NLC re-commissioning targets should be limited to customers whose NLC systems have a dedicated, on-site server, or cloud-based system having the ability to retrieve occupancy and energy consumption data in hourly intervals or less. DNV has validated that these systems store information in a manner that facilitates and optimization opportunities.
- There is a need for NLC system manufacturers to have a dedicated application engineering department to develop and implement the recommendations. DNV determined that some system manufacturers we worked with lack the analytic skills needed to identify and implement the system optimization solutions.

- In the event that building use changes along with building drift,⁶ the schedules and light levels are inadvertently changed by the end-user to address the change in lighting needs. This might sometimes lead to overcorrecting setpoints, resulting in longer run hours for the NLC system. To ensure that the system is always functioning at its most optimal point, granularity in data (15-min) is needed to allow for continuous/interval system diagnostics to support activities.
- Occupancy sensing needs to be present. While designing this program we engaged a few NLC manufacturers and customers to gain insights on its viability and relevance. Feedback received from these focus groups pointed towards the fact that the systems were underutilized, in terms of tighter control where possible, either it be due to lack of dedicated personnel or expertise and a few others. This coupled with natural building drift for older systems will negate any savings realized in the first year if not properly maintained or adjusted with changing space needs.
- 15-min interval data is required for picking up changes in relation to occupancy. This not only allows the NLC system to better adapt to space use changes but will allow for BMS integration to control other plug loads along with HVAC if desired by the facility. This helps offset the high upfront costs of comprehensive systems to a certain degree and would have a better chance of an installation being greenlight versus just looking to meet the lighting needs
- It is clear that the initial system settings put in place after being commissioned are in most likelihood never changed by facility personnel. This signals a lost opportunity in terms of a facility making use of the NLC systems features. If the intention is to make the long-term data storage intervals to just show daily usage, it would defeat any opportunity for utilities to revisit the systems and help the facility with its long-term energy waste reduction plans.
- Common practice for newly installed NLC systems is to undergo active light level adjustment among other setting changes for the first few months before arriving at a facility/zone wide optimal point. In addition to this, most utility programs require the implementation of a minimum of two to three advanced control strategies (time scheduling, daylight harvesting, high end trim, etc.) which can be set up for the evaluation period. Also, the utility programs typically consider post evaluation period to be for two to four weeks from installation. Due to this, these programs in most cases do not capture the actual savings or end up just considering the wattage difference if the NLC system is set at 100% light level when post data is downloaded for evaluation
- During the program design phase, it became apparent that system manufacturers have varying abilities to provide data viable to recommission a system. Some manufacturers centrally manage energy data in the cloud and had contractual agreement with customers to access the data. Other manufacturers enable energy monitoring by default or as an option and store energy data locally within the system. Most of these manufacturers rely on sales representative agencies, distributors, and contractors for sales, installation, and commissioning; and therefore, have little or no direct access to or knowledge about the installations.

⁶ Building drift is term to describe the inevitable changes to a building's occupancy and energy use pattern that occur over time, and that are unaccounted for at the time of initial commissioning.

- A standardized data reporting format and requirements will also provide manufacturers clear guidance and motivation to develop NLC energy reporting functionalities that supports the efficiency program needs.
- Changing space use was not something that was high on the list for the first commissioning team. Following this pilot, it has been mentioned by the manufacturer that it would benefit the facilities to use each fixture as an LLLC as they are already equipped to function as such while still having the ability of being grouped/zoned.

Definitions

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

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

Commissioning (Cx): Process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained according to owner's operational needs.⁷

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

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

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

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

Facility on hours: With respect to production schedules. Facility on hours are defined as the time during which a facility is in operation, indicated by a facility-wide higher power consumption

Facility off hours: With respect to production schedules. Facility off hours are defined as the time during which a facility is not in operation, indicated by a facility-wide lower power consumption

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

Luminaire level lighting control (LLLC): The capability to have a networked occupancy sensor and ambient light sensor installed for each luminaire or kit, and directly integrated or embedded into the form factor during the luminaire or kit manufacturing process. LLLCs create independently addressable lighting zones.

Networked lighting control (NLC) systems: NLC systems are lighting systems with a combination of sensors, network interfaces, and controllers that affect lighting changes in luminaires, retrofit kits or lamps. These systems store time-stamped energy and occupancy data in searchable databases.

⁷ ENERGY STAR Building Upgrade Manual Chapter 5: Retro commissioning

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

Monitoring based commissioning (MBCx): Evolution of Cx. Continuous application of the commissioning process to a building or energy system

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

Recommissioning : Term for applying the commissioning process to a full-building or at an equipment-level (lighting, HVAC and other) which have been previously commissioned.⁸

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

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

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

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

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⁸ ENERGY STAR Building Upgrade Manual Chapter 5: Retro commissioning