Commercial & Industrial Lighting Lifetime and Peak Demand Savings Analysis

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Prepared for:

Alliance to Save Energy, (funded by GE Current, a Daintree company), in partnership with the DesignLights Consortium (DLC)

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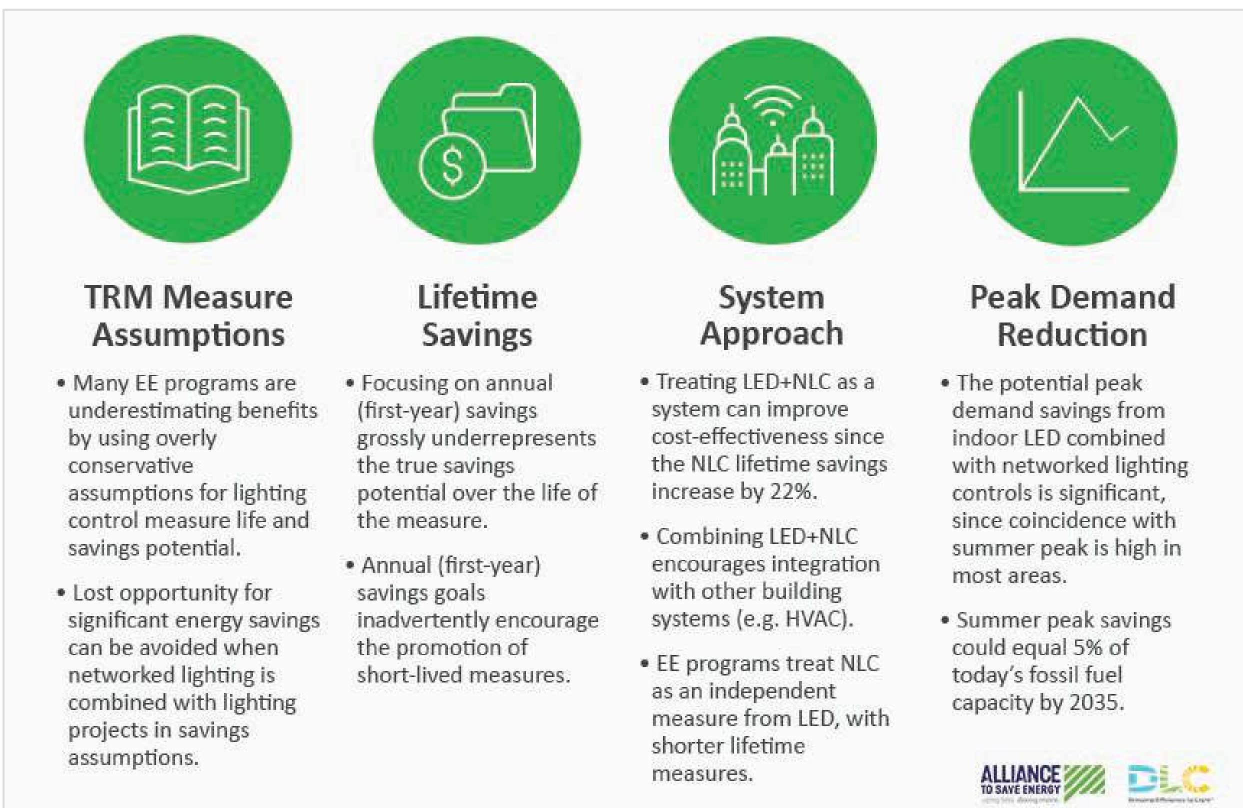
Executive Summary

Prior research by the DesignLights Consortium (DLC), among other institutions, has illustrated the significant unrealized energy and demand savings potential for commercial and industrial light-emitting diode (LED) lighting and networked lighting controls. However, this potential is underrepresented by the reliance on annual (first-year) energy savings as a decision-making tool for utility energy efficiency programs. Since energy efficiency measures can last many years, often 10-15 years for commercial lighting, the annual savings metric ignores a majority of the benefit realized. Lifetime savings – which is the sum of a measure's annual savings over its expected useful life – better represents the lifetime economic value and environmental impact of a measure. And peak demand savings – which represents the demand (power) savings expected during a utility's peak demand periods – often reflects the most important grid system impacts expected from a measure.

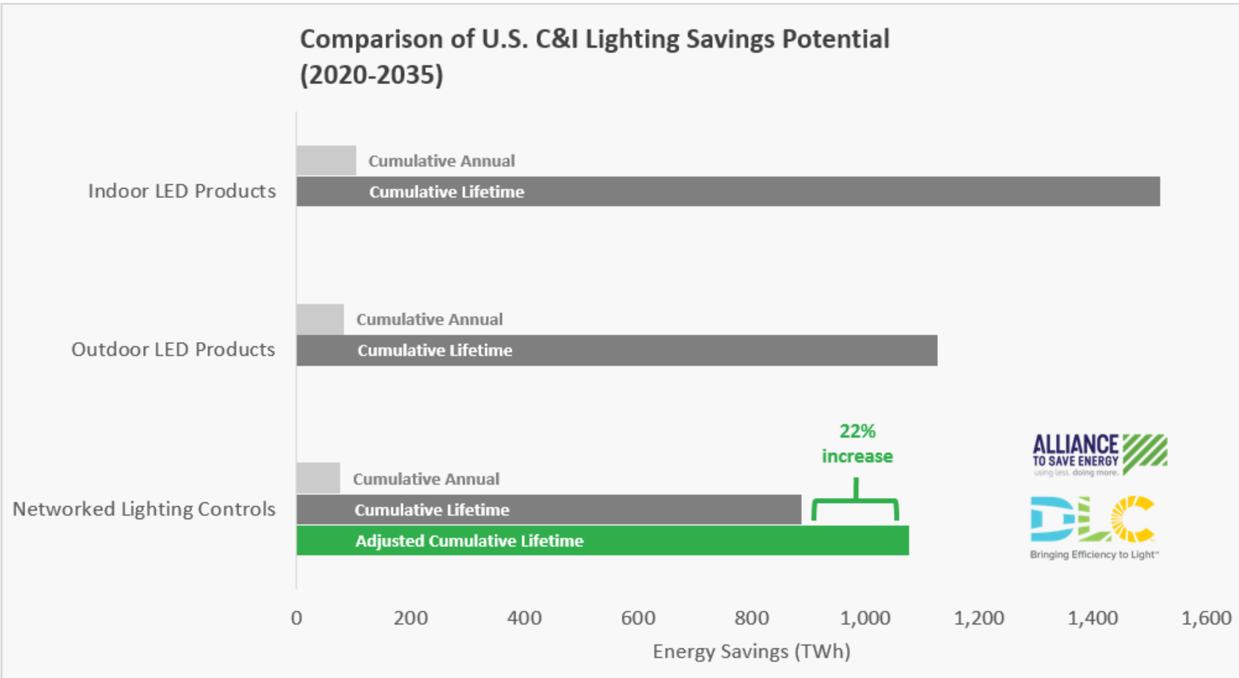
This research project's goal is to better understand the lifetime and peak demand savings potential from commercial and industrial lighting efficiency measures. Key insights are shown in Figure 1.

Figure 1: *Key Research Insights*



While all energy efficiency (EE) programs consider product lifetime and peak demand savings when evaluating cost-effectiveness, program plans and incentive offers are almost universally designed around annual (first-year) energy savings potential. As a result, a bias is created toward measures with the lowest first-year cost ($ per kWh). Measures with longer lifetimes and/or greater peak demand impacts receive no additional emphasis even though such measures deliver more significant benefits to program participants. A comparison of the energy savings impact in terms of first-year savings and lifetime savings is shown in Figure 2.

Figure 2: *C&I Lighting Savings Potential*



An analysis of technical reference manuals (TRMs) from twelve geographically diverse jurisdictions revealed a wide variety of assumptions for commercial lighting measures across EE programs—varying more than can be explained by regional differences. The constant among these variations is that relatively conservative values are used for lighting controls. Two-thirds of the TRMs reviewed do not include a measure for networked lighting controls – a technology that is key in capturing the fullest long-term savings potential. The TRMs that do include an NLC measure assume a shorter measure lifetime compared to the LED lighting with which they are associated, even though networked lighting controls and LED lighting operate as a system. If the assumed measure lifetime for networked lighting controls is adjusted to align it to the lighting equipment with which it is associated, the lifetime savings potential increases by 22% as shown in Figure 2.

In terms of Peak Demand savings, the TRM research found significant variation among lighting control coincidence factor assumptions. As a result, the same lighting control measure will have drastically different assumed peak demand savings depending on the state and utility even though virtually all states assume a similar system peak timeframe. Among lighting control measures, networked lighting controls have the highest average assumed coincidence factor at 74%. In total, the summer peak demand impact from the installation of indoor LED and networked lighting control measures between 2020 and 2035 is equal to seventy-four 500-megawatt power plants, or 5% of the generating capacity of the entire fleet of U.S fossil fuel power plants, as of 2017.

Based on the insights identified during this research project, the following actions are recommended to maximize the adoption, lifetime savings, and peak demand savings potential of commercial LED and networked lighting controls:

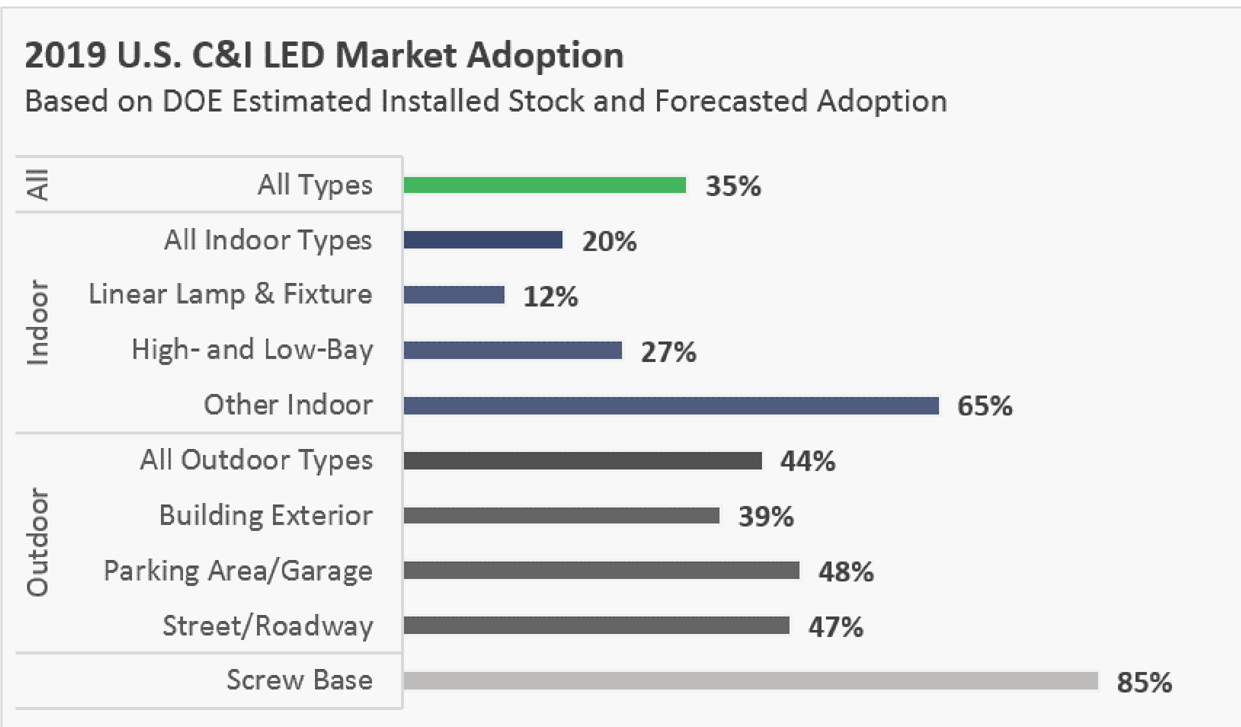
- EE programs, regulators, and state policy makers should increase focus on lifetime savings instead of annual (first-year) savings to better represent the impacts of policies and programs.
- EE programs should be allowed and encouraged to concentrate their goals and program incentives on specific lifetime savings targets.
- The assumed measure lifetime for networked lighting control measures should be increased to be consistent with lifetime of indoor LED fixtures unless there are specific program reasons to the contrary.
- A measure characterization for networked lighting controls is needed within all TRMs.
- Ideally, networked lighting controls should be characterized as a single LED + NLC system measure within TRMs. Doing so can minimize cost-effectiveness challenges, maximize lifetime and peak savings, limit stranded savings, and encourage integration with other building systems.
- EE programs should evaluate program design opportunities and incentive strategies that promote LED lighting and networked lighting controls as a system. Not only will this place program design in alignment with current practices while maximizing savings, but it establishes a foundation for more advanced system-level interests such as grid-interactive efficient buildings (GEB).

C&I lighting programs, and the lighting industry in general, are at a crossroads: EE programs can follow the current path which is expected to realize decreasing C&I lighting energy savings moving forward. Alternately, EE programs should be encouraged to adopt program strategies that emphasize and leverage a systems approach for LEDs and NLCs. At a minimum, shifting focus to lifetime savings will provide a more realistic capture of the energy savings potential. In addition, following the recommendations outlined above can lead to sustained C&I lighting program portfolios through at least the next decade, benefiting the utilities immediate energy savings objectives and setting the stage for the future.

Introduction

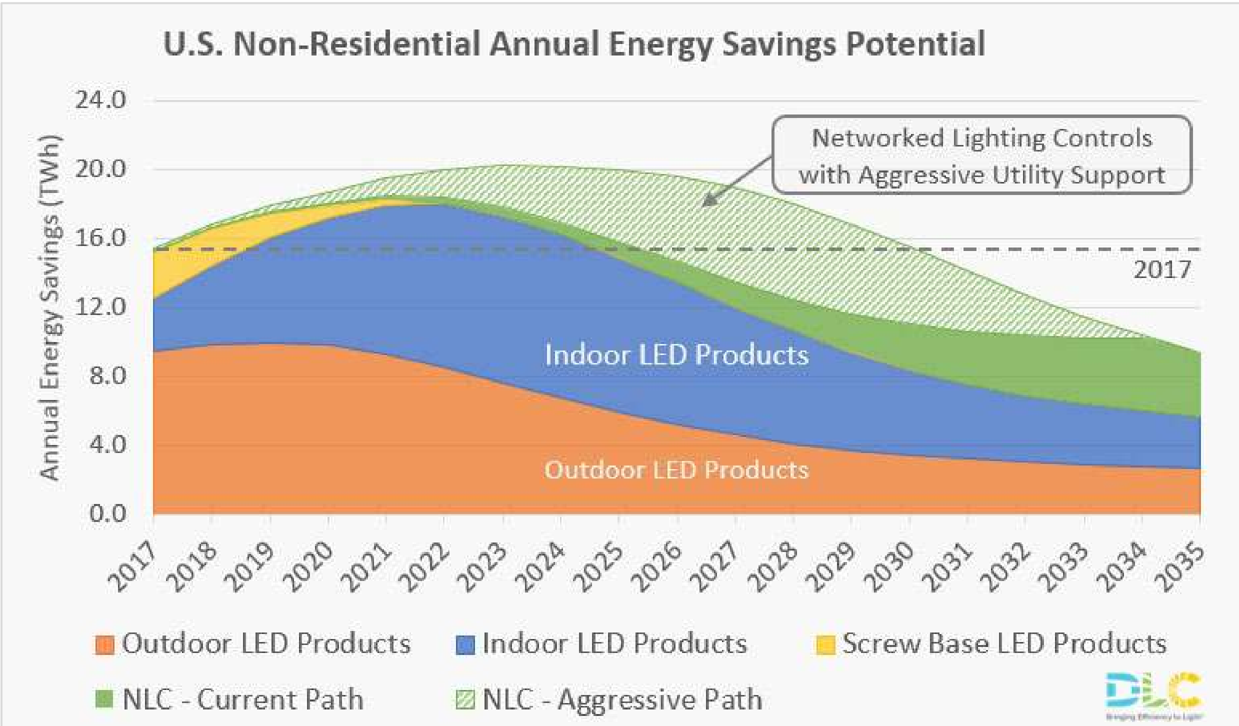
Commercial and industrial (C&I) lighting technologies play a prominent role within utility-sponsored EE programs throughout the United States. Initially, EE programs provided incentives for the installation of efficient fluorescent lighting systems as a replacement for less efficient fluorescent and incandescent lighting. In the past decade, the emphasis has shifted to replacing fluorescent and incandescent lighting with LED technologies (also known as solid-state lighting or SSL). A rapid expansion of available LED products with ever-increasing efficiency has enabled utilities to promote, and their customers to install, energy-saving lighting in nearly any application. This technology shift often has ancillary benefits such as improved lighting quality (resulting in improved comfort, safety and productivity), longer operational life, and increased operational savings. Adoption has varied across LED product categories depending on customer needs and technology capabilities, product availability, cost, and incumbent technology. Screw-based LED bulbs were an early area of focus, followed by outdoor LED fixtures; most recently, the adoption of indoor LED fixtures has been an area of growth. The estimated current market saturations of each of these product groups are shown in Figure 3.

Figure 3: *2019 C&I LED Market Adoption*



As the LED revolution has matured, the question of remaining savings potential has been a frequent consideration among EE program administrators. To address this unknown, the DLC published a report in July 2018 which provided an estimate of remaining C&I lighting energy savings potential from LED and networked lighting controls.[1] Figure 4 shows the key DLC finding that significant energy savings opportunities remain, particularly from indoor LED products and networked lighting controls (NLC).

Figure 4: *DLC Estimate of C&I Lighting Energy Savings Potential (DLC 2018)*



The DLC analysis evaluated the annual, or first-year, savings potential from C&I lighting measures. This approach aligns with typical EE program convention, allowing the results to be easily understood and compared against EE program portfolio forecasts and plans. However, focusing on annual savings can significantly understate the lifetime benefit that these technologies provide. To accurately evaluate the economic and energy impact, the savings must be considered over the estimated useful life of the measure.

Building upon the DLC analysis from 2018, the Alliance to Save Energy, in partnership with DLC and GE Current, a Daintree company, collaborated to explore the extent to which the benefits of EE programs are underestimated, using traditional evaluation methods. The group investigated the following questions:

- What measure assumptions are EE programs using for LED and NLC?
- How are EE programs accounting for lifetime savings?
- What is the savings potential for C&I lighting product types in terms of *lifetime savings?*
- What are the cost-effectiveness implications when considering lifetime savings for LED and NLC?

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[1] *Energy Savings Potential of DLC Commercial Lighting and Networked Lighting Controls*, available at https://www.designlights.org/resources/energy-savings-potential-of-dlc-commercial-lighting-and-networked-lighting-controls/

- To what extent can C&I lighting technologies contribute to peak demand savings?
- In the context of lifetime and peak demand savings, which C&I lighting technologies have the biggest potential impact?

TRM Research

Utility EE programs often use a document comprising a database of EE measures to develop the energy savings characterization for common products and technologies that they promote as "deemed" measures through new construction, prescriptive and/or midstream programs. Typically, this document is referred to as a technical reference manual (TRM). TRMs provide the algorithms, values, and assumptions necessary to calculate energy savings and evaluate measure cost-effectiveness. In most cases, a TRM is a state-wide resource that is approved by a regulatory body. A review of twelve TRMs/databases from a geographically diverse set of EE programs was performed to understand the various assumptions used for C&I lighting measures. The EE programs reviewed, and the associated measures that were evaluated within their TRM/databases, are shown below in Table 1. The table represents the most recent version of a TRM for each state that was publicly available at the time of this research.

Table 1: *TRMs and Measures Reviewed*

Region	State	Version	Fixtures			Lamps		Controls			
			LED Exterior	LED High Bay	LED Troffer	LED Linear Lamp	LED Screw Base Lamp	Occupancy Sensor	Daylight Sensor	Dual Occ/Day Sensor	Networked Lighting Control
Northeast	Massachusetts	2019	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Mid-Atlantic	2018	✓	✓	✓	✓	✓	✓	✓		
	Vermont	2017	✓	✓	✓	✓	✓	✓	✓	✓	
Midwest	Illinois	2019	✓	✓	✓	✓	✓	✓	✓	✓	
	Michigan	2019	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Minnesota	2019	✓	✓	✓	✓	✓	✓	✓		
	Wisconsin	2019	✓	✓	✓	✓	✓	✓	✓	✓	✓
South	Arkansas	2017	✓	✓	✓	✓	✓	✓	✓	✓	
	Tennessee	2017				✓	✓	✓	✓	✓	
	Texas	2018	✓	✓	✓	✓	✓	✓	✓		✓
West	California	2017	✓	✓	✓	✓	✓	✓	✓	✓	
	New Mexico	2016	✓				✓	✓	✓		
Count of States			11	10	10	11	12	12	12	8	4
% of States (out of 12)			92%	83%	83%	92%	100%	100%	100%	67%	33%

Each measure was reviewed for lifetime, operating hours, control savings factor, summer coincidence factor, summer peak timeframe, and measure cost (high and low values). For the purpose of this analysis, measure types were constrained to the most common products: LED exterior, LED high/low bay, LED troffer/linear fixtures, LED linear replacement lamps, LED screw base lamps, occupancy sensors, daylight sensors, dual occupancy/daylight sensors, and networked lighting controls.

Most of the measures researched were found in TRMs and databases across a high percentage of states. However, one measure – networked lighting controls – was notably underrepresented with only one-third of the TRMs containing the measure. This technology is not necessarily new but is still emerging, and it can be difficult to characterize the energy savings from using NLC in general terms. As a result, many EE programs limit NLC incentives to custom / calculated programs. The 2018 DLC research showed significant remaining energy savings are possible from networked lighting controls, but this potential can only be realized if EE programs can promote the measure through multiple avenues. With a TRM measure, EE programs can more easily and effectively promote NLCs through a broad range of programs.

Measure Lifetime

Measure lifetime, or estimated useful life (EUL), describes the median length of time for which a measure is functional and energy savings can be counted by an EE program. A product may have a functional lifetime that is longer than a measure's assumed EUL. Measure lifetime is used in calculating cost-effectiveness to ensure that the benefits of a measure – including energy savings over the useful life – outweigh the costs before a measure can be included in an EE program portfolio. While the methods used to calculate benefits and costs vary widely across states and EE programs, all cost-effectiveness calculations rely on measure lifetime to some extent. The average and range of measure lifetimes identified during the TRM analysis are shown in Figure 5. Measure lifetimes for indoor LED fixtures average approximately 15 years, although several programs claim as few as 10 years for the measure life. Lifetimes assigned to linear replacement lamps are similar to those for linear fixtures. Screw base lamps have the lowest assumed measure lifetime since they tend to have shorter rated lifetimes compared to commercial fixtures,[2] they can be easily removed by a customer, and they may be subject to federal standards which would limit the energy savings and/or useful life that a utility can claim.

Figure 5: *C&I Lighting Measure Lifetimes Based on the TRMs of Twelve EE Programs*

[2] While lamps can achieve long life comparable to a fixture, the ENERGY STAR qualification requirement for most incentive programs requires a minimum of 15,000 hours for LED lamps compared to the DLC requirement of 50,000 hours for LED fixtures. https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Lamps%20V2.1%20Final%20Specification.pdf https://www.designlights.org/solid-state-lighting/qualification-requirements/

It is particularly noteworthy that the control measures are assigned shorter measure lifetimes than their fixture counterparts. In all cases reviewed, EE programs treat the control products as an independent measure for the purpose of energy savings and cost-effectiveness calculations. Historically, the reasons for a shorter lighting control lifetime were justified since controls were an add-on measure that in many cases failed (or were disabled) long before the lighting with which they were associated. Poor sensor coverage or placement, unpredictable operation, and incompatibility with fluorescent lighting were common issues. Networked lighting controls greatly improve upon the earlier generation of controls, and when coupled with LED technology they provider superior performance. Many networked lighting control products are embedded directly within LED fixtures. There is little reason to maintain the assumption that control measures will have a shorter useful lifetime than the associated LED equipment, but EE programs continue to do so. As a result, it is more difficult for lighting controls to pass a cost-effectiveness test and the measure may be perceived as a drag on any portfolio that considers lifetime savings or benefits. Looking specifically at networked lighting controls, a technology that operates as a system with LED, the average measure lifetime of 11.5 years is 22% shorter than the measure lifetime of LED troffers at 14.8 years.

Operating Hours

Operating hour assumptions are used by EE programs when the actual lighting operating hours are not provided or are not known. Most TRMs establish lighting operating hours according to the space type, such as an office or warehouse. The TRM values shown in Figure 6 represent the operating hour assumptions for the space types most likely to be associated with each product type—i.e., offices for LED troffers and linear lamps; warehouses for LED high bay; and retail for LED screw base. If such space types were not defined, then the operating hours value for “commercial unknown” was used.

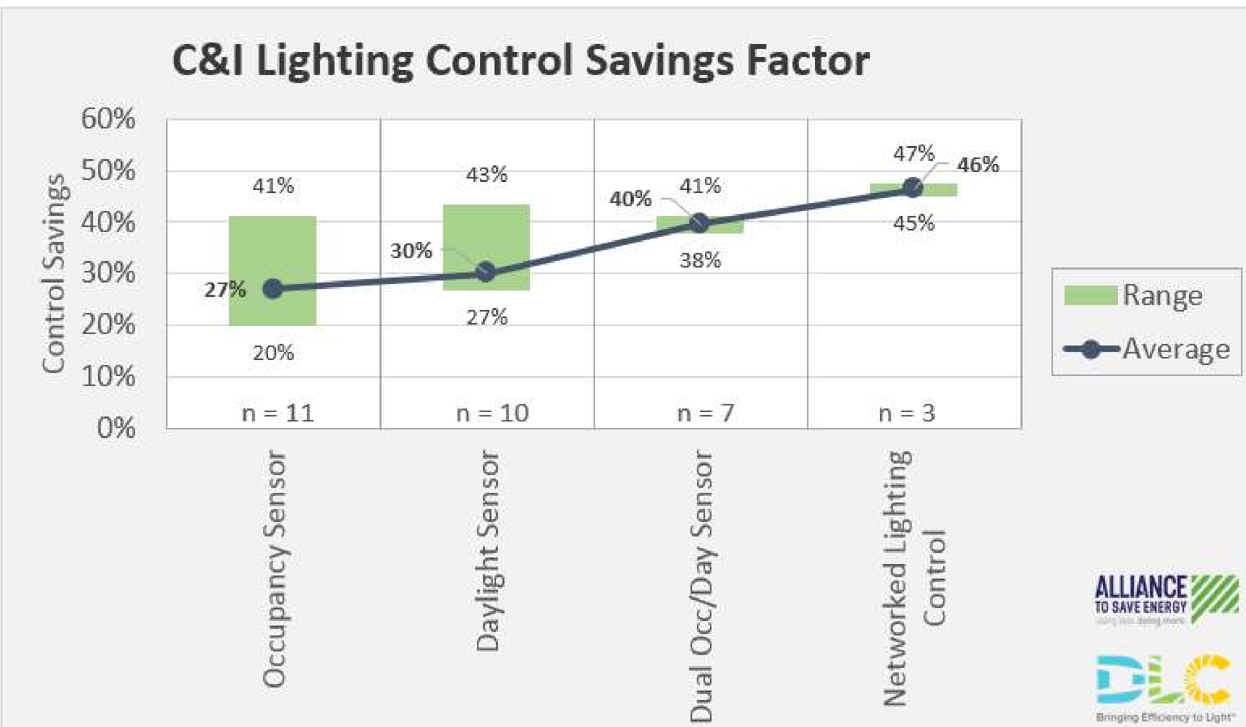
Figure 6: *C&I Lighting Daily Operating Hours*

Interestingly, LED troffers have a high degree of variability among programs, with operating hours ranging from 6.7 hours per day up to 12.2. Troffers are most commonly installed in office space types, which tend to have consistent operating hours regardless of region. Therefore, the degree of variation observed for LED troffer operation hours is surprising. As a point of comparison, the average daily operating hours identified by the DOE in the U.S. Lighting Market Characterization are also shown in Figure 6. In every product category, the average operating hour values from the EE program TRMs are more conservative than the DOE estimates.

Control Savings Factor

Lighting control measures are assigned an energy savings factor (SF), as a percentage of full load hours, to calculate savings within a TRM. For some control measures such as occupancy sensors, the SF represents the percent of time that the measure is applicable. For other control measures such as daylighting dimming, the SF represents a blend of load reduction and percent of time. The savings factors identified through the TRM research are shown in Figure 7.

Figure 7: *C&I Lighting Control Savings Factor*



Many programs reference the 2011 LBNL lighting controls meta-analysis findings when assigning savings factors for occupancy (24%), daylight (28%) and dual/multi (38%) controls.[3] Among the programs that

[3] *A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings*, available at http://efficiency.lbl.gov/sites/all/files/a_meta-analysis_of_energy_savings_from_lighting_controls_in_commercial_buildings_lbnl-5095e.pdf

include a networked lighting control measure, all reference the DLC networked lighting controls specification and/or use the 47% savings estimate identified by DLC research completed in 2017.[4] It is this higher savings value of 47% that is the basis for the unrealized savings potential estimated in this paper.

Coincidence Factor and Summer Peak Demand

TRM research findings regarding peak coincidence factor and peak timeframe are discussed within the Peak Demand Savings section.

TRM Research Conclusions

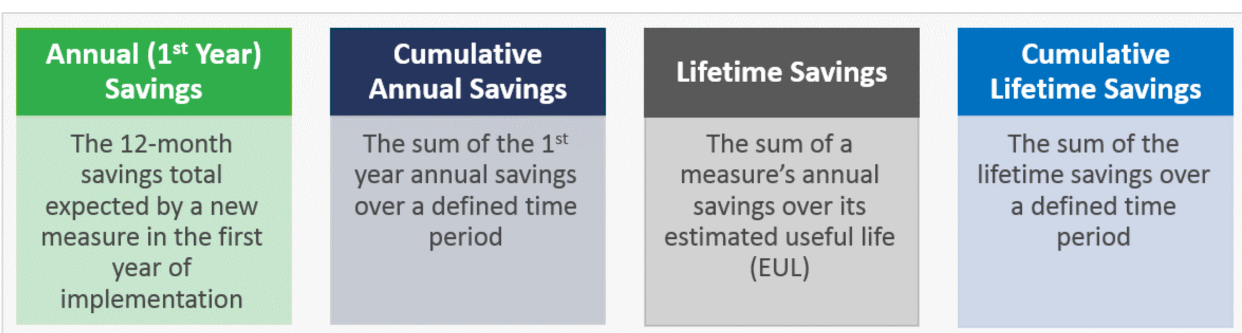
With LED and lighting control technology evolving rapidly, EE programs need to keep measures up to date in order to claim full and accurate energy savings. Networked lighting controls should be prioritized for inclusion within TRMs, and the measure should be characterized as a controlled LED system with equal lifetime and combined energy and demand savings. For program designs that require stand-alone networked lighting control measures, the assigned measure lifetime should be consistent with the lifetime of indoor LED fixtures.

Lifetime Savings Potential

Definitions

Most utility EE programs measure and report energy savings in terms of annual (first-year) totals. These are the savings that a measure can be expected to deliver in its first full year of implementation. It is also common practice to reference cumulative annual savings, which is simply the sum of the annual savings over a certain time period such as a 3-year plan. Less often, EE programs will measure and report *lifetime* savings. Lifetime savings more adequately represents the energy and economic potential of a measure, since most measures last far longer than one year.

Figure 8: *Annual and Lifetime Savings Definitions*



[4] *Energy Savings from Networked Lighting Control (NLC) Systems*, available at https://www.designlights.org/lighting-controls/reports-tools-resources/nlc-energy-savings-report/

Despite being an imperfect metric, there are many reasons why EE programs use annual savings to track and report progress. Chief among the reasons are simplicity and historical precedent. Many state policies such as energy efficiency resource standards rely on first-year savings rather than lifetime.[5] Aside from the issue of misrepresenting full potential, focusing on annual savings can result in EE program incentives directed toward measures that have good initial savings with a short lifetimes instead of measures that may be more expensive but have a greater lifetime benefit.

Some states have recently increased their focus on lifetime savings, either by setting specific lifetime savings goals or by coupling a utility's performance incentive to lifetime savings or benefits. Examples include California, Connecticut, Illinois, Michigan, Oregon, and Rhode Island.[6, 7]

Lifetime Savings Estimate

To evaluate the C&I lighting lifetime savings potential, the following resources and assumptions were used:

- Installed lighting inventory, wattage, and operating hours per DOE U.S. Lighting Market Characterization[8]
- LED adoption and efficacy improvement forecast according to DOE[9]
- Continued levels of utility and industry promotion of LED achieve adoption levels of 83% (indoor) and 90% (outdoor) by 2035
- Utilities and industry aggressively promote NLC to achieve adoption levels of 58% (indoor) and 65% (outdoor) by 2035
- Measure lifetimes identified during the TRM review, as shown in Table 2

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[5] 25 out of 27 states with EERS use first-year savings, according to ACEEE. https://aceee.org/sites/default/files/publications/researchreports/u1902.pdf

[6] California, Illinois, Michigan, Oregon and Rhode Island are identified in the ACEEE report *Energy Efficiency Over Time: Measuring and Valuing Lifetime Energy Savings in Policy and Planning*, available at https://aceee.org/sites/default/files/publications/researchreports/u1902.pdf.

[7] The 2019-2021 Connecticut Conservation & Load Management Plan includes performance indicators for Lifetime kWh. https://www.energizect.com/sites/default/files/FINAL%202019%202021%20Plan%20%283-1-19%29.pdf

[8] *2015 U.S. Lighting Market Characterization*, available at https://www.energy.gov/sites/prod/files/2017/12/f46/lmc2015_nov17.pdf

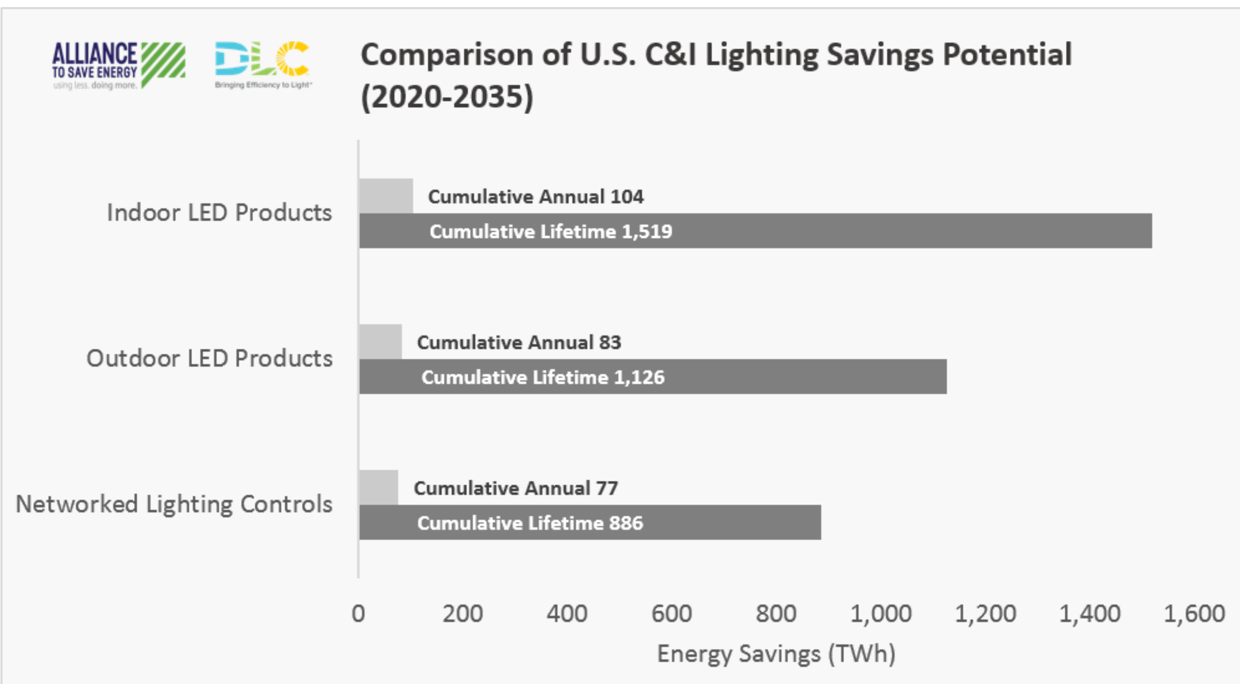
[9] *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications*, available at https://www.energy.gov/sites/prod/files/2016/09/f33/energysavingsforecast16_2.pdf

Table 2: *TRM Average Measure Lifetime (years)*

Product Type	TRM Avg. Measure Life
High/Low Bay	14.8
Linear Lamp/Fixture	14.5
Building Exterior	13.5
Street/Roadway	13.5
Parking Area/Garage	13.5
Networked Lighting Controls	11.5

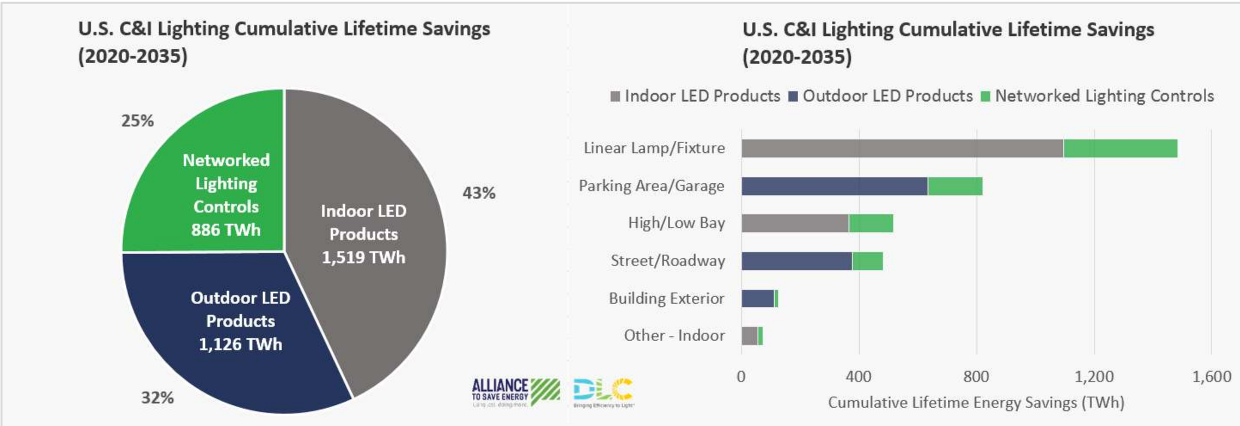
The lifetime savings analysis leveraged the work already completed for the DLC analysis in 2018—estimating remaining C&I lighting energy savings potential from LED and networked lighting controls—with revisions for an additional year of adoption and the inclusion of measure lifetimes. The resulting lifetime savings potential, summed over the 2020-2035 analysis period, is shown below in Figure 9. The lifetime savings potential is an order of magnitude larger than the typical tracking and reporting convention of annual (first-year) savings, since it accounts for the savings over the entire measure life.

Figure 9: *C&I Lighting Annual vs. Lifetime Savings Potential*



The lifetime savings potential by product category is shown in Figure 10. Indoor LED products represent the most significant reservoir of potential savings (43%), followed by outdoor LED (32%) and networked lighting controls (25%). Among specific product types, linear lamps & fixtures far and away offer the greatest lifetime savings potential.

Figure 10: *C&I Lighting Lifetime Savings Potential for Products Installed 2020-2035*



Lifetime Savings Estimate with Adjusted NLC Measure Life

The lifetime savings estimates presented in Figure 10 are based on the measure lifetimes of each component, with separate values applied for the lighting equipment and networked lighting controls as identified in the TRM research. However, as previously discussed, networked lighting controls and lighting lamps/fixtures increasingly operate as a system. LEDs and NLCs are dependent on each other to achieve the full savings potential, and in some cases are inseparable. If the assumed measure lifetime for networked lighting controls were adjusted to align it to the lighting equipment with which it is associated, as shown in Table 3, the lifetime savings potential would increase by 22%. This adjusted savings value may represent a more realistic estimate of LED and NLC measures operating as a system. Figure 11 presents the 2020-2035 cumulative savings potential by measure, with an increment of savings included from an adjusted NLC measure life. Figure 12 compares the 2020-2035 cumulative savings potential among annual savings, lifetime savings, and adjusted lifetime savings using the NLC measure life.

Table 3: *Adjusted TRM Average Measure Lifetime (years)*

Product Type	LED TRM Measure Life	NLC TRM Measure Life	Adjusted NLC TRM Measure Life
High/Low Bay	14.8	11.5	14.8
Linear Lamp/Fixture	14.5	11.5	14.5
Building Exterior	13.5	11.5	13.5
Street/Roadway	13.5	11.5	13.5
Parking Area/Garage	13.5	11.5	13.5

Figure 11: Cumulative Lifetime Savings Potential with an Adjusted NLC Lifetime

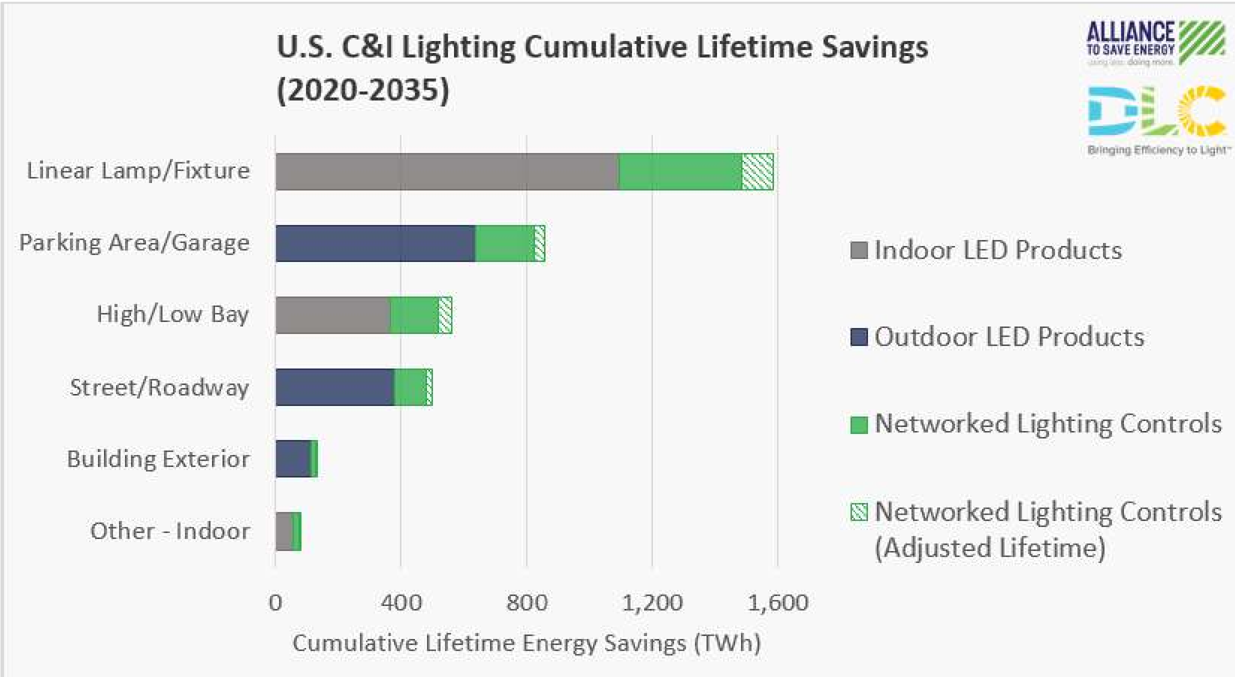
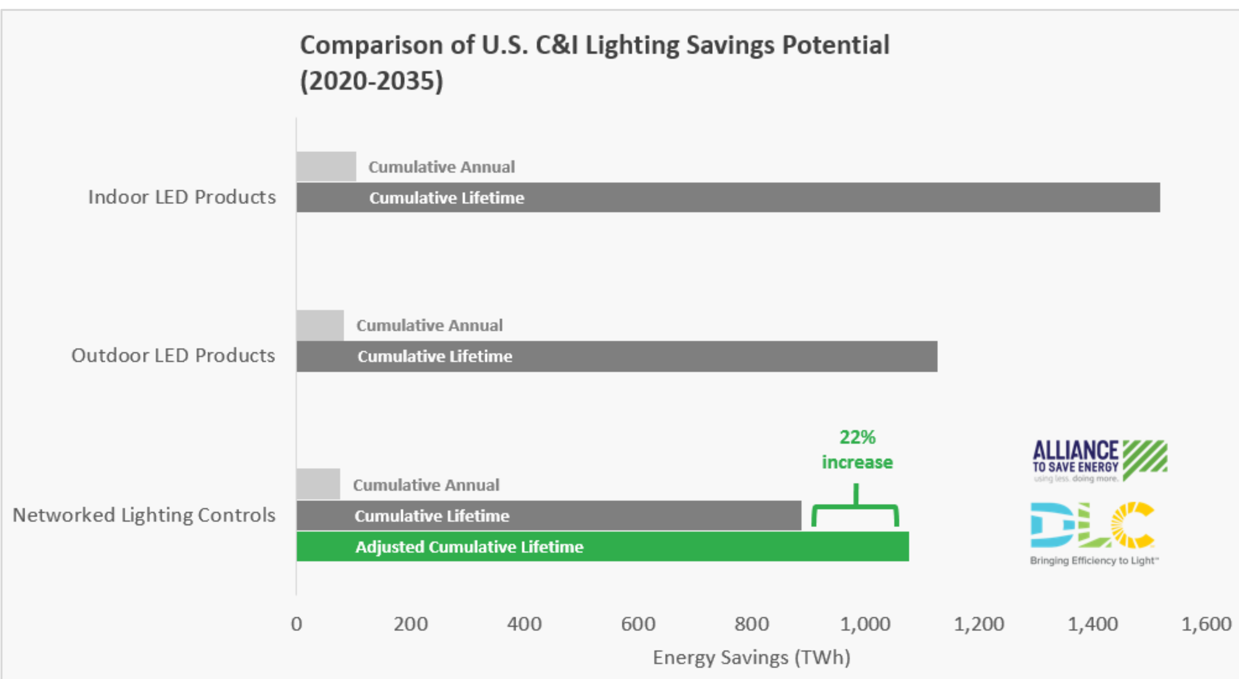


Figure 12: Comparison of C&I Lighting Savings Potential



With an adjusted measure life, the cumulative lifetime savings potential of networked lighting controls (1,077 TWh, 29% of total potential) nearly equals that of outdoor LED products (1,126 TWh, 30% of total potential). Despite the similar savings potential, an important distinction between the two measures must be considered: the adoption of networked lighting controls is just beginning, while outdoor LED lighting is at or near an apex of adoption and will start to decline in coming years. This fact is critically important for utilities to understand so that programs can be appropriately designed to focus on areas of growth.

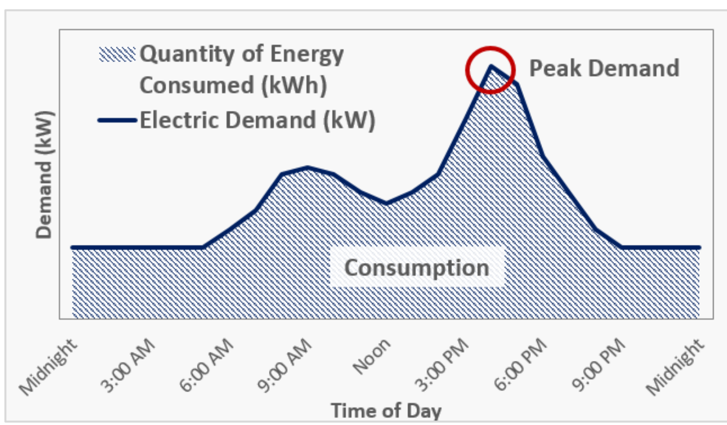
The lifetime savings forecast shown in Figure 12 will vary by state region, based on factors such as existing C&I electricity consumption, baseline technology efficiency, state energy policies, and current LED adoption levels. This issue was evaluated in the 2018 DLC report, and the key regional findings from that report[10] are also applicable to the lifetime savings forecast.

- The Southeast region holds the highest remaining potential for C&I lighting savings – nearly 50% more compared to the next closest region
- The impact of networked lighting controls varies from one region to the next due to differences in the timing of LED adoption and the efficiency of baseline technologies
- Networked lighting controls represent roughly one-third of the remaining C&I lighting savings potential within the Northeast, Northwest, and California regions
- Regardless of state or region, a path exists to maintain C&I lighting portfolios at or above 2017 levels until at least 2028

Peak Demand Savings

Definitions

Figure 13: *Illustration of Consumption, Demand, and Peak Demand*



Electricity is measured in terms of consumption (energy) and demand (power). Electricity *consumption* represents the power used over time, measured in kilowatt-hours (kWh); reductions in electricity consumption through energy efficiency are also measured in and reported on in kWh. Electricity *demand* represents the instantaneous power required to meet the electrical loads of the utility, measured in kilowatts (kW). *Peak demand* represents the highest electric power demand over a time period (month, year, summer, winter, etc.). An illustration of consumption, demand, and peak demand is shown in Figure 13.

[10] *Energy Savings from Networked Lighting Control (NLC) Systems*, available at https://www.designlights.org/lighting-controls/reports-tools-resources/nlc-energy-savings-report/

Why Peak Demand Matters

Peak demand determines the maximum power plant capacity necessary to serve a utility's customers and is therefore a critical factor in managing the environmental and economic impacts of energy. Energy produced and purchased at the time of system peak is typically the most expensive, due to supply constraints, and those costs are ultimately passed on to customers. Furthermore, the additional energy required to meet demand during peak periods often comes from the least clean power sources, such as oil and gas "peaker" power plants. Therefore, measures that reduce peak demand can have profoundly positive economic and environmental benefits. Finally, system instability is far more likely to occur during times of peak demand. If demand exceeds capacity, or if a utility is unable to adequately respond to a steep demand increase (such as the afternoon timeframe of the so-called duck curve[11]), system outages can occur. System reliability can be improved by minimizing and managing peak demand.

Peak Demand Reduction Through Energy Efficiency

Measures that reduce energy through efficiency can also deliver peak demand savings, but not always. Since peak demand occurs during specific timeframes and seasons, the overlap of an energy efficiency measure with that timeframe matters. For example, LED street lights save energy during the night, and summer peak demand typically occurs during the afternoon, so the energy savings from LED street lighting is unlikely to have any impact on summer peak demand (this is not the case for winter peak demand). Off-peak savings are still important and can provide economic and environmental benefits, but not to the same degree as on-peak savings.

How much a measure overlaps with a peak demand timeframe is called coincidence. EE programs assign all measures a coincidence factor (CF), often for both winter and summer seasons; as an example, Table 4 shows lighting CFs used in the Massachusetts TRM. These coincidence factors, when combined with a measure's actual (or estimated) total demand savings, are used to estimate the impact that a measure has on peak demand for the associated season.

Table 4: *Example Summer Peak Lighting Coincidence Factors from Massachusetts TRM*[12]

Example Coincidence Factors	**Summer Peak Coincidence** (Weekdays 1-5pm Jun-Aug)	**Winter Peak Coincidence** (Weekdays 5-7pm Dec-Jan)
Residential Indoor Lighting	55%	85%
Commercial Indoor Lighting	83%	65%
Commercial Outdoor Lighting	0%	100%
Industrial (24/7) Lighting	100%	100%

Timeframes vary by region and utility

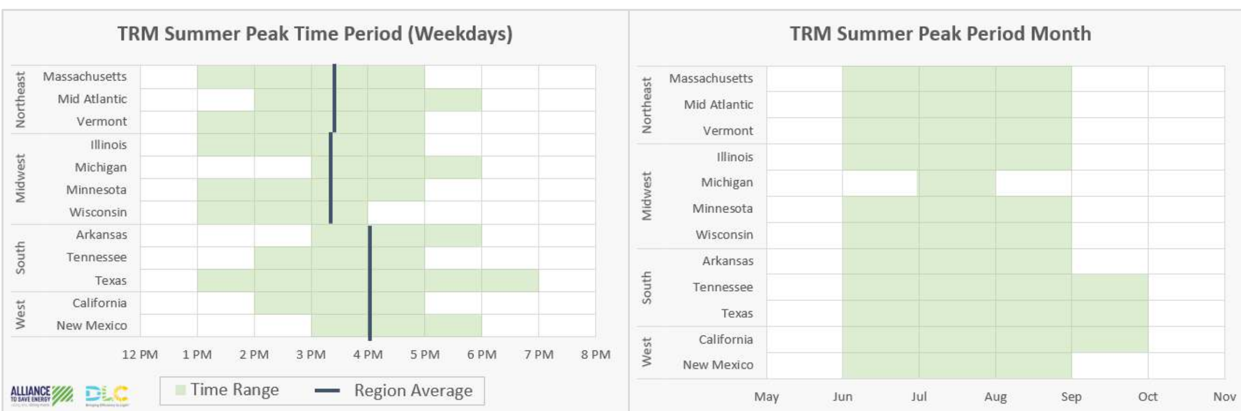
[11] https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy
[12] Based on the Massachusetts Technical Resource Manual, 2019-2021, available at https://www.masssavedata.com/Public/TechnicalReferenceLibrary

Finally, it should be noted that peak demand savings achieved through energy efficiency differ from an approach called *demand response.* Demand response is a strategy to reduce the power demand of existing equipment during the time of a system peak (or during on-peak hours) for economic reasons, either manually or through an automated signal. Demand response measures are utilized only during these peak timeframes to save money for the customer and improve grid operations, unlike energy efficiency which occurs any time the equipment is operated. In some cases, demand response shifts load from on-peak to off-peak time periods, which can have an economic benefit but does not result in any energy savings.

Peak Demand TRM Research Insights

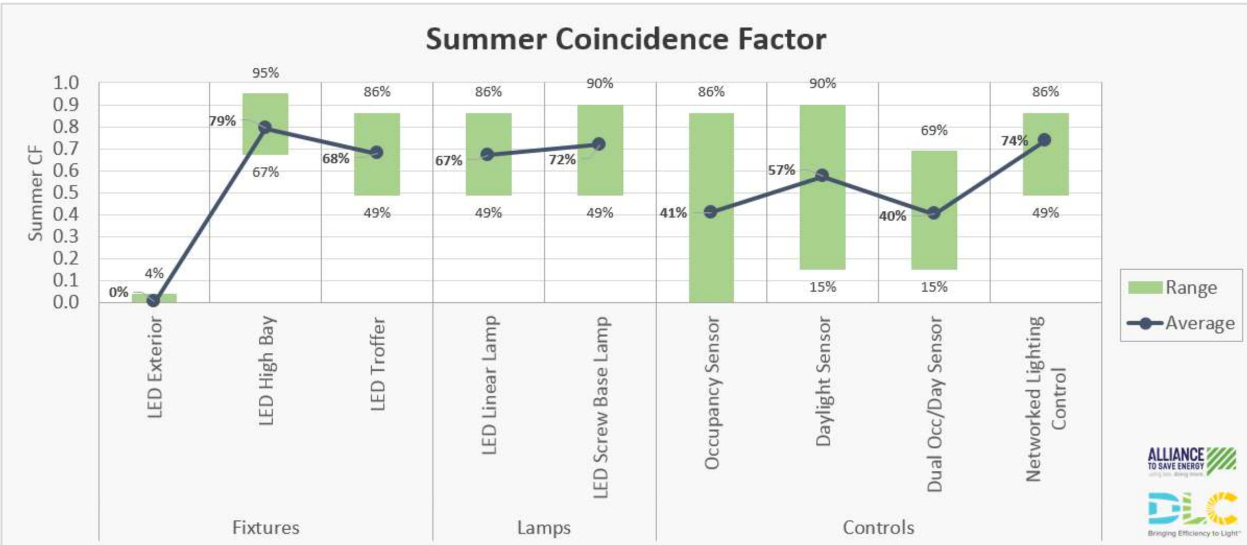
During the review of TRM resources described earlier, factors relating to commercial lighting summer peak demand were collected and evaluated. Summer peak was selected since most utilities face a greater capacity constraint during the summer months. Most TRMs reviewed define summer peak time period as late afternoon weekdays in June through July. The specific time of day can vary, as shown in Figure 14, and in general the time period is later in the day for TRMs in the U.S. South and West. As this time frame starts to extend beyond a typical commercial workday, the overlap (coincidence) between the peak period and interior lighting measures will decline.

Figure 14: *Summer Peak Definitions from TRM Research*



The average assumed coincidence factors for commercial lighting measures are shown in Figure 15. As with operating hours, coincidence factors are typically associated with an end use and space type combination (such as commercial lighting – offices). CF was evaluated for the space type most likely to be associated with each commercial lighting measure. Not surprisingly, nearly all EE programs assume a 0% coincidence factor for exterior lighting. During the summer months, exterior lights that operate on dusk-to-dawn schedules won't turn on until approximately 8 or 9pm, which is entirely outside the peak demand period. Interior lighting measures show a much greater level of summer peak coincidence – 67 to 78%. As the operating hours of a measure increase, such as with LED high bay, the summer peak CF will rise. Lighting control measures generally have a lower average assumed CF, since these measures are applicable during a subset of the full lighting operating hours. The significant variation among lighting control CF assumptions is noteworthy since the same lighting measure will have drastically different assumed peak demand savings depending on the state and utility. For example, some TRMs provide no summer peak demand savings at all for occupancy sensors while other TRMs assume 86% coincidence. Among lighting control measures, networked lighting controls have the highest average assumed CF at 74%.

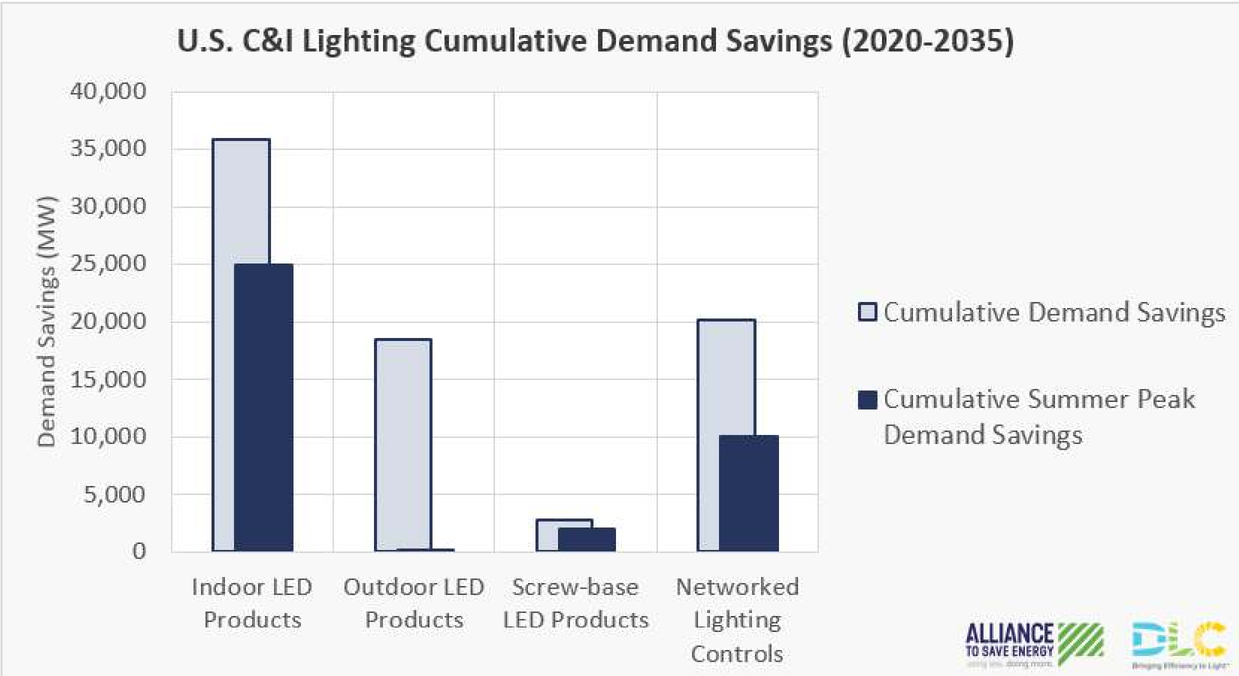
Figure 15: *Summer Peak Coincidence Factors for Commercial Lighting*



Peak Demand Analysis

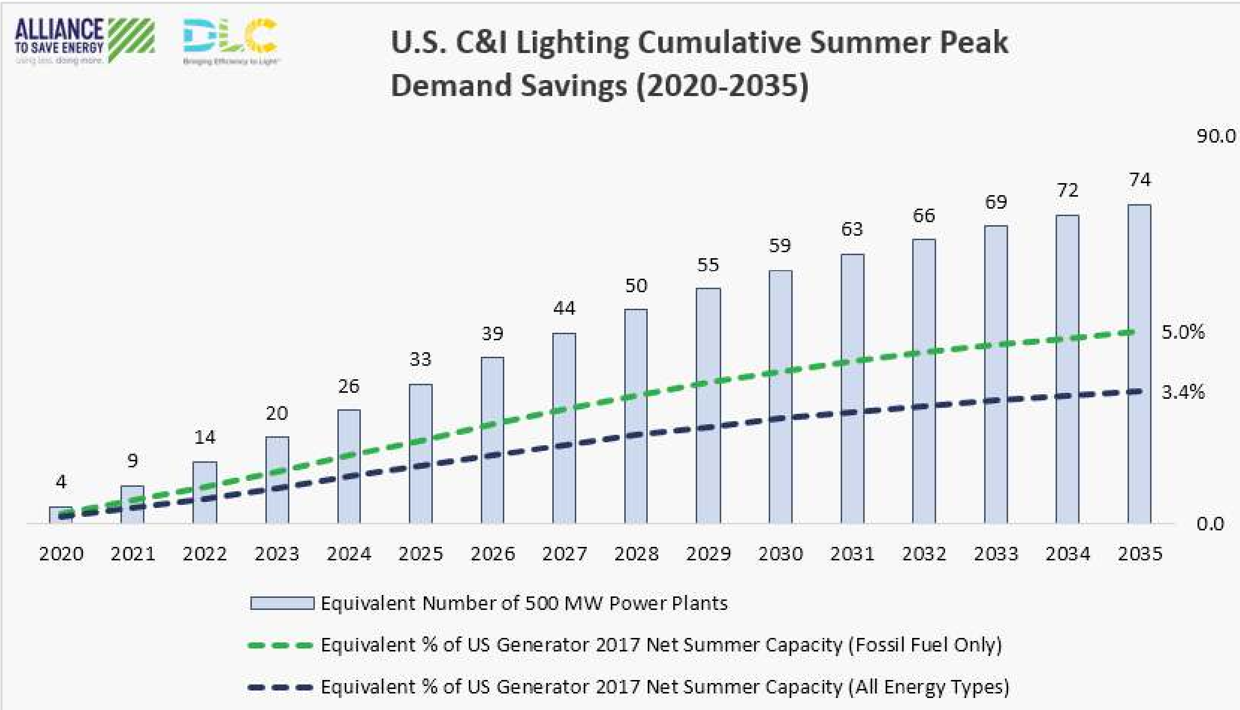
The full demand savings potential for each commercial lighting measure was first calculated using the wattages provided by the DOE U.S. Lighting Market Characterization, future efficacy improvement estimates from the DOE Energy Savings Forecast of Solid-State Lighting, and future inventory estimates developed for the lifetime savings estimate. Using the average coincidence factors identified in Figure 15, summer peak demand savings potential was estimated for commercial lighting measures. These results are shown in Figure 16, with light blue representing full demand savings and dark blue representing peak demand savings potential. In the context of summer peak, indoor LED lighting and networked lighting controls are far and away the most important commercial lighting measures going forward for EE programs, and the best way to achieve both measures is to promote LED + NLC as a system. A program that relies on separate measures is bound to strand savings potential when LED is installed absent controls.

Figure 16: *Cumulative Demand Savings Potential from C&I Lighting*



By 2035, the cumulative summer peak demand savings from C&I lighting totals 37,111 MW. Putting this summer peak savings potential in context, the installation of indoor LED and networked lighting control measures between 2020 and 2035 could displace seventy-four 500-megawatt power plants, or 5% of the generating capacity of the entire fleet of U.S fossil fuel power plants, as of 2017 (Figure 17). This forecast depends on the successful adoption of LED and networked lighting controls, as previously described. The forecast may also be impacted by external factors such as the amount of renewable generation and/or energy storage systems brought on-line to help balance system loads.

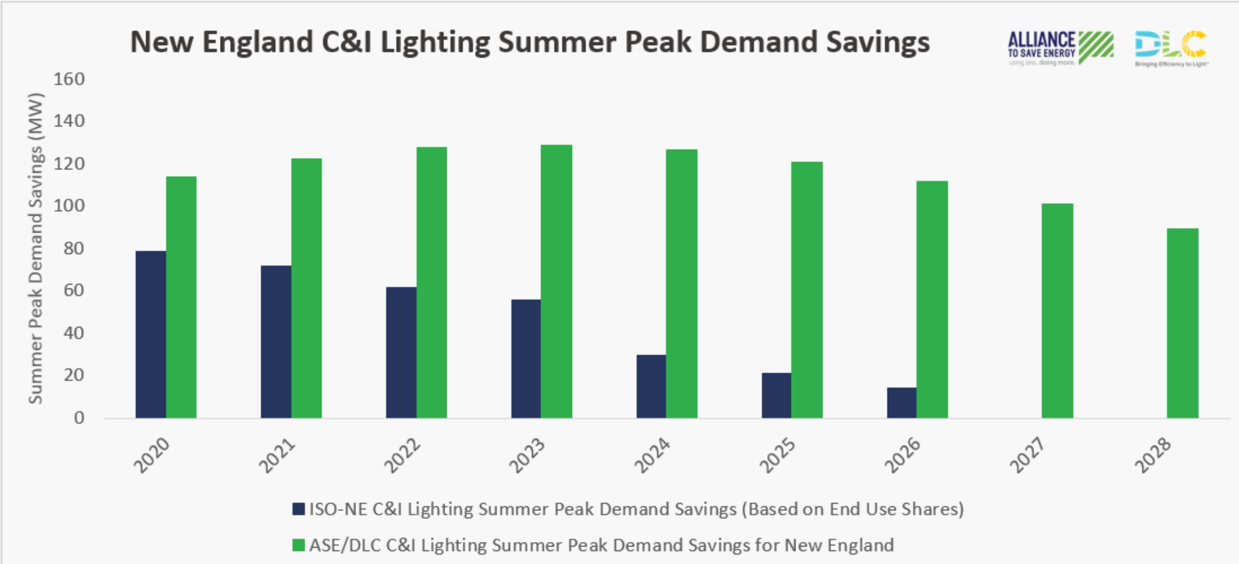
Figure 17: *C&I Lighting Summer Peak Demand Savings Relative to Power Plant Capacity*[13]



The research into summer peak demand savings also highlighted an issue that electric grid system planners may be under estimating future contributions from C&I lighting. For example, ISO New England (the regional transmission organization serving the New England states) provides an annual forecast of energy efficiency and peak demand savings potential. In contrast to the forecast developed through this research project (Figure 18, shown in yellow), ISO-NE forecasts that C&I lighting summer peak demand savings will fall precipitously between 2020 and 2026 (Figure 18, shown in blue). Forecasts developed by ISO-NE (and regional transmission orgs elsewhere) play an important role in system planning decisions such as capacity planning. Therefore, if contributions from C&I lighting, or any other technology, are not adequately accounted for in a system planner's forecast, energy resource decisions may be misguided.

[13] 2017 net summer fossil fuel power plant capacity totaled 745,866 MW according to the Energy Information Administration (https://www.eia.gov/electricity/annual/html/epa_04_03.html).

Figure 18: *New England C&I Lighting Summer Peak Demand Savings Forecast*



Cost-Effectiveness

When EE programs promote products and technology within their portfolio, each measure must first be evaluated against a cost-effectiveness test. According to the National Standard Practice Manual, "Assessing the cost-effectiveness of energy resources such as efficiency involves comparing the costs and benefits of such resources with other resources that meet energy and other applicable objectives."[14] Cost-effectiveness tests can vary to a great degree from one state or utility to the next in terms of the type of test used and the input assumptions. As such, this research did not attempt to evaluate the cost-effectiveness of C&I lighting as an energy resource and/or for inclusion within an EE program portfolio. However, the research did aim to consider the cost-effectiveness of various C&I lighting technologies in the context of customer economics and EE program incentive cost. A summary of the cost-effectiveness analysis approach is shown in Figure 19.

[14] *National Standard Practice Manual,* available at https://nationalefficiencyscreening.org/wp-content/uploads/2017/05/NSPM_May-2017_final.pdf

Figure 19: Cost-effectiveness Analysis Approach Summary

Cost-Effectiveness Measure	Scenarios Considered	Key Inputs
•Customer simple payback (years) •Customer net present value - NPV ($) •Customer internal rate of return - IRR (%) •EE program rebate cost ($/kWh) •EE program lifetime rebate cost ($/lifetime kWh) •EE program levelized cost of energy ($)	•Four LED product types (troffer, highbay, exterior small, and exterior larger) •LED measures alone using TRM lifetime •NLC measures alone using TRM lifetime •LED + NLC system measures using adjusted TRM lifetime	•Measure characterization (watts, hours) •Annual savings •Measure lifetime •Current and future measure costs •Utility incentive •Electric rate •Inflation •Discount rate

An Excel-based cost-effectiveness analysis tool was developed to perform the evaluation of the measurements and scenarios described in Figure 19. Acknowledging that inputs such as electric rate and incentive levels can vary greatly from one jurisdiction to the next, the tool was not used to establish a universal recommendation regarding cost-effectiveness. Rather, the tool provided insights to the research when evaluating common scenarios with typical or average input assumptions.

The following charts present a few simulated results from the cost-effectiveness tool when evaluating LED troffers with and without networked lighting controls (Figure 20) and LED high-bay with and without networked lighting controls (Figure 21). The results are based on the default input assumptions for the cost-effectiveness analysis tool and as such represent a potential outcome.[15] When considering these results, a few observations become clear:[16]

- By most measurements, networked lighting controls considered as a standalone measure appears to be the least attractive option for customers based on net present value (NPV) and internal rate of return (IRR). The exception is IRR for NLC when installed on LED high-bay equipment. As a result, EE programs that promote NLC as an individual measure may struggle to gain adoption and traction with customers.

[15] Default input assumptions include electric rate ($0.105/kWh), annual operating hours (3375 troffer, 3834 high-bay), baseline power (67.5 watts troffer, 246.6 watts high-bay), LED power (33.5 watts troffer, 128.7 watts high-bay), average annual efficacy change (2.7%), 2019 LED cost ($92 troffer, $229 high-bay), LED average annual cost change (-3.4%), LED utility incentive (30%), LED and NLC measure life (per TRM research), LED installation time (20 minutes troffer, 30 minute high-bay), NLC type (luminaire integrate), NLC savings (47%), 2019 NLC cost ($50), NLC average annual cost change (-7.0%), NLC utility incentive (40%), NLC installation time (15 minutes), inflation (2.0%), discount rate (5.0%), labor rate ($75/hour).

[16] Observations are specific to the scenarios modeled using default inputs.

- Promoting LED + NLC as a system can maximize customer savings and economic benefit with the least cost (or little added cost) to the EE program. From a customer perspective, the cost effectiveness of LED + NLC as a system outperforms (or closely mirrors) standalone LED for both LED troffer and high-bay. From an EE program perspective, the cost effectiveness of LED + NLC as a system modestly underperforms standalone LED troffers and outperforms standalone LED high-bay.
- The cost-effectiveness of networked lighting controls as a standalone measure (shown as squares) is typically less desirable when compared against the scenarios of uncontrolled LED (shown as circles) or LED + NLC as a system (shown in green).[17] EE program incentive offers for and customer adoption of standalone NLC measures may be limited as a result. This issue highlights the importance of promoting NLC as part of a system.

Figure 20: *LED Troffer Cost-Effectiveness Results for Customer NPV (left) and Utility Levelized Cost (right)*

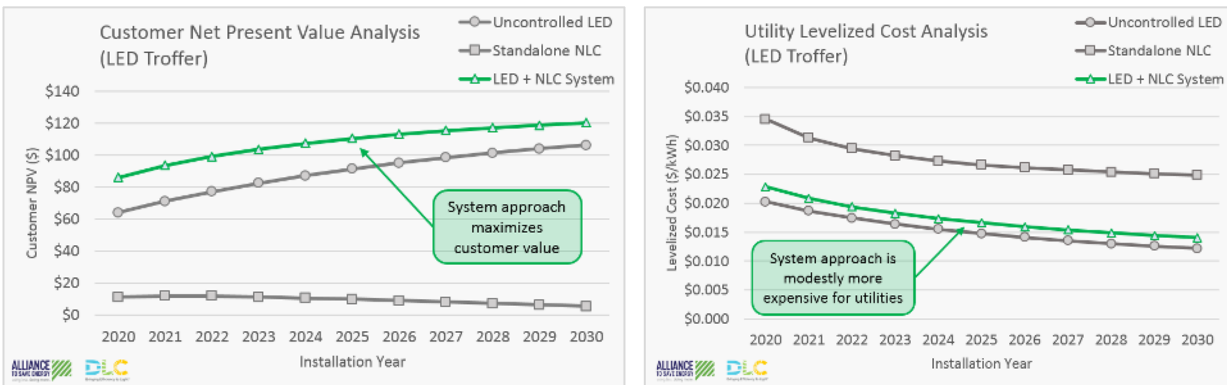
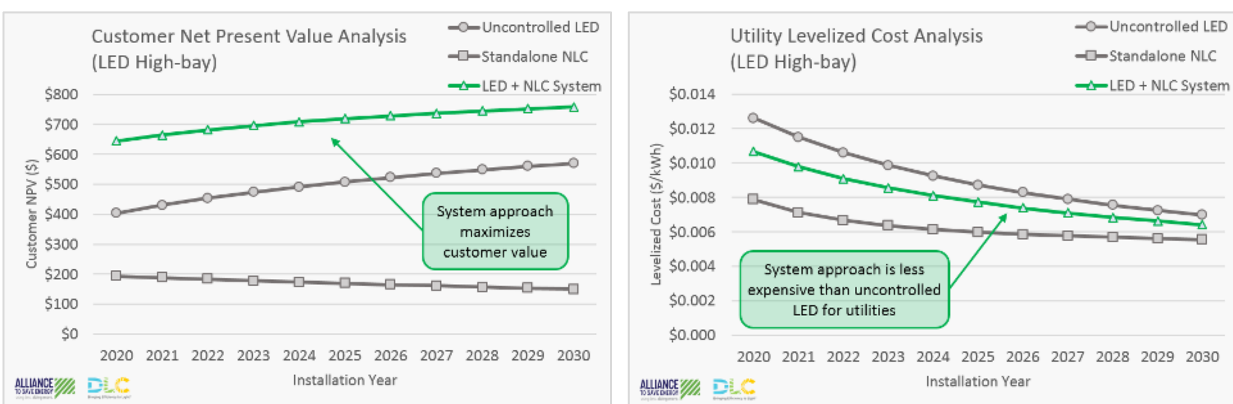


Figure 21: *LED High-bay Cost-Effectiveness Results for Customer NPV (left) and Utility Levelized Cost (right)*



[17] A higher customer NPV is more desirable, and a lower utility levelized cost is more desirable.

Other Considerations

This research paper focused on lifetime savings and peak demand savings related to LED and networked lighting controls. However, there are many other factors that may represent value to a utility and/or a customer. From a utility perspective, LED systems installed with networked lighting controls can be an enabler for connected building systems, which can achieve more sophisticated demand response and provide a dispatchable energy resource through grid-interactive buildings. Installation of networked lighting controls ensures that these capabilities will be accessible as an energy resource in the future. From a customer perspective, networked lighting controls can provide a host of non-energy values such as space utilization, asset tracking, emergency assist, light + health benefits, customer data metrics, and so on. Some of these benefits may be more valuable to a customer than the energy savings alone. These additional considerations are seldom considered in cost effectiveness evaluations, yet they represent real value to utilities and customers and should be leveraged to further promote adoption of LED with networked lighting controls.

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