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Economic Potential of Networked Lighting Controls in Commercial Buildings

Tapping the Added Value of HVAC Connections

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EXECUTIVE SUMMARY

This report explores the economics of investment in networked lighting controls (NLCs) under current policy frameworks and energy system characteristics in two states typical of the Northeast and the Southwest regions. It presents the technical and economic potential for NLCs for interior lighting in existing non-residential buildings through 2030 and demonstrates whether utilities and/or state programs should incentivize connected lighting; and at what levels. The research builds upon recent integrated lighting controls case studies, assessments of incremental cost, and analyses of the national building stock.

The analysis considers NLC systems with and without plug load control integration, HVAC system control integration, and automated demand response capabilities; the exact control system assumptions and capabilities vary by building size and scenario and are described in more detail in the body of this report. Further, the analysis explores both a "NLC Replacement" scenario whereby an LED luminaire with NLCs is installed at the time a lighting system replacement was already planned and a "Controls-Ready Replacement" which assumes that LED luminaires designed to accommodate the future addition of NLCs are installed at the time of planned replacement, then retrofitted with NLCs after five years.

This analysis finds significant cost-effective energy savings potential for NLC systems in both scenarios; select results for the technical and economic potential by state and scenario are presented in Table ES-1 below.

Table ES-1: Summary of 2030 and 2035 Cumulative Potential by State and Scenario Relative to 2020 Consumption and Net Summer Capacity

State		CT				AZ			
Potential Scenario		Technical		Economic		Technical		Economic	
Sub Scenario		NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.
Cumulative Electric Savings as % 2020 Sales	2030	9.7%	3.7%	9.5%	3.4%	6.7%	2.5%	4.9%	1.7%
	2035	8.8%	9.7%	8.6%	9.0%	6.0%	6.7%	4.4%	4.4%
Cumulative Elec. Summer Pk Coincident Demand Savings As % 2020 Net Sum. Capacity	2030	1.8%	0.7%	1.8%	0.6%	1.1%	0.4%	0.7%	0.2%
	2035	1.7%	1.8%	1.6%	1.7%	1.0%	1.1%	0.6%	0.6%
Cumulative Natural Gas Savings As % 2020 Sales	2030	1.3%	0.5%	1.3%	0.5%	0.5%	0.2%	0.5%	0.2%
	2035	1.1%	1.3%	1.1%	1.2%	0.4%	0.5%	0.4%	0.5%

In the NLC replacement scenario, 2030 electric energy consumption by commercial buildings is reduced by nearly 10% in Connecticut and 5% in Arizona. NLCs can reduce 2030 peak demand by approximately 1.8% in Connecticut and 0.7% in Arizona. Further, NLCs with HVAC integration can reduce 2030 natural gas consumption by 1.3% and 0.5% in Connecticut and Arizona, respectively.

The analysis demonstrates that most NLC system-building type combinations pass the Societal Cost Test in Connecticut—a jurisdiction with favorably high avoided energy costs. In Arizona, measures assessing lighting savings alone only pass the cost-effectiveness screening in building types with the highest interior lighting end-use energy intensities such as retail and quick service restaurants. When NLCs are integrated with HVAC systems to enable cost-efficient control of heating, cooling, and ventilation loads, NLC measures are generally cost-effective from the societal perspective in both jurisdictions assessed. Potential savings are highest in large offices, retail, and health facilities and other buildings with high energy-use intensity.

For both scenarios, this analysis demonstrates that the incentive costs to achieve the identified potential for NLC+HVAC integration measures are not significantly higher than the average incentives per unit savings currently paid by representative energy efficiency programs in CT but are far higher than incentives paid in AZ. In any case, it is clear that business-as-usual incentive levels and program designs are not effectively capturing that potential.

While the economic energy savings and demand reduction potential is substantial, capturing this potential will require addressing technical, program, and policy barriers to effectively support and prioritize NLCs over shorter term solutions such as TLEDs and uncontrolled LED fixtures. Further, continued support from state and utility programs, and market actors is necessary to reduce technical and cost barriers associated with effective NLC installation. Future efforts should focus on strategies and tactics to unlock this potential in the near term before the commercial lighting market is fully saturated with minimally-controlled equipment.

INTRODUCTION

LED lighting has delivered extensive energy savings for commercial and industrial efficiency programs over the past decade, but penetration of networked lighting controls (NLCs) remains low. DLC defines NLC systems as "…the combination of sensors, network interfaces, and controllers that effect lighting changes in luminaires, retrofit kits or lamps" (DLC 2021). While capabilities vary by system type, NLCs typically enable advanced lighting control strategies, networking or luminaires and devices, individual addressability, and energy monitoring, and may enable advanced demand response and integration with external buildings systems among other capabilities. In this document, the terms NLC and "connected lighting" are used interchangeably.

Despite saving roughly 50% of lighting energy (NEEA, DLC 2020), connected lighting controls had estimated national penetration of less than 1% in 2017 (U.S. DOE 2019a).[1] Integrating granular occupancy data from connected lighting with other building systems can yield additional benefits to meet aggressive goals for savings and capacity. Further, the ubiquitous nature of lighting unlocks the technical potential for grid-interactive efficient buildings, enabling advanced demand response capabilities to reduce peak demand and modulate load at scale across the commercial building stock. However, installing NLCs on existing LED lighting is often impractical and/or prohibitively expensive, so the potential benefits are "stranded" by every new LED lighting system installed without these controls.

This report explores the economics of investment in NLCs under current policy frameworks and energy system characteristics in two states typical of the Northeast and the Southwest regions. It presents the technical and economic potential[2] for networked lighting controls for interior lighting in existing buildings through 2030 and demonstrates whether utilities and/or state programs should incentivize connected lighting; and at what levels. The research builds upon recent integrated lighting controls case studies, assessments of incremental cost, and analyses of the national building stock.

[1] While the U.S. DOE assumed more optimistic forecasts, recent evaluation work in Massachusetts, a national leader in energy efficiency programs, reported that less that 1% of lighting fixtures were controlled by NLCs in 2020 (DNV 2021b).

[2] Energy, demand, natural gas, and delivered fuels reductions, emissions impacts, and associated costs and benefits are reported.

BACKGROUND

Lighting measures have long contributed to the majority of commercial energy efficiency program electric savings. Before the emergence of LED technologies, programs incentivized high efficiency linear fluorescent lamps, among other technologies, to replace inefficient fluorescent lamps (e.g., T12s) and other competing technologies. As LED technologies have matured, programs have shifted to promoting LED technologies nearly exclusively. This heightened program support has accelerated the adoption of LEDs. Even in leading jurisdictions with diverse energy efficiency offerings, lighting measures still have an outsized role in commercial program portfolios. For example, in Massachusetts, lighting measures contributed over 60% of the total non-residential electric energy savings in 2021 (MSD 2023). However, most of these systems were LED linear replacement lamps (i.e., TLEDs) and LED luminaries without networked controls. The U.S. DOE projects that by 2030, LEDs will represent 88% of all installed lighting systems in commercial buildings nationwide, up from an estimated 26% installed in 2017 (U.S. DOE 2019a). Concerningly, the same forecast projects that only 14% of installed lighting systems will be connected systems (either lamps or luminaires), and there are indications that even this projection is optimistic. Because of the associated expense and technical barriers posed by retrofitting existing LED lighting systems with NLCs, each TLED and LED luminaire installed without NLCs represents significant "stranded" savings that cannot be effectively captured until the lighting systems are again in need of replacement many years in the future.

Previous research has demonstrated the large savings potential for networked lighting controls nationally (DLC 2018) and has shown that promotion of LED lighting retrofits with networked lighting controls substantially increases the cost-effectiveness of lighting systems relative to NLCs alone (ASE, DLC 2019). Despite these demonstrable benefits, energy efficiency programs have failed to effectively capitalize on this opportunity, and penetration of NLC systems remains low. In addition to long-standing barriers such as high initial expense, system complexity, and inadequate contractor training; the adoption of NLCs has been hampered by efficiency programs that fail to adequately incentivize NLC systems relative to TLEDs and LED luminaires without NLCs which typically have lower incremental costs.

It is anticipated that standard LED luminaires will, in the near term, become the assumed baseline technology for commercial lighting replacement measures in many jurisdictions.[3] In light of these market dynamics, this study assesses the *incremental* energy efficiency potential for networked lighting control systems and "controls-ready" systems in existing buildings relative to the installation of standard LED luminaires at the time of natural replacement.[4] Further, this analysis quantifies the additional energy efficiency and demand reduction potential that can be unlocked when integrating NLCs with other building systems to better manage HVAC and plug loads and estimates the additional demand reduction potential when NLCs are leveraged to reduce peak loads via demand response. When considered together, these capabilities can yield substantial energy and demand savings, greenhouse gas emissions reductions, and societal benefits.

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[3] For example, in Massachusetts, net-to-gross (NTG) ratios for upstream LED fixture measures are already assumed to be 0.17 for 2024, meaning that just 17% of the savings from LED fixtures promoted through incentives at the distributor level are assumed to be induced by the program (DNV 2021a). The other 83% represent free-riders, or those who would have installed LED fixtures even in the absence of program support. This is an indication of a replacement lighting market nearing total transformation.

[4] In other words, at the rate the facility would have naturally replaced its lighting.

SUMMARY OF APPROACH

This study quantifies the technical and economic energy efficiency and demand reduction potential for NLCs through 2030 in two states, Connecticut and Arizona, intended to represent current policy environments and energy system characteristics representative of the Northeast and Southwest, respectively. The *technical potential* refers to all potential that is technically feasible without regard to project economics or other market barriers. The *economic potential* refers to the subset of the technical potential that is cost-effective according to some cost-effectiveness test. While the mandated primary cost-effectiveness test varies within the Northeast and Southeast regions, this study uniformly applies the Societal Cost Test (SCT) to determine the cost-effective potential.[5] However, the scope and magnitude of the various costs and benefits included in the test vary by jurisdiction and are described in more detail in Appendix A.

MARKET MODELED

This analysis explores two hypothetical scenarios. In the first case, denoted as "NLC Replacement," an LED luminaire with NLCs is installed at the time a lighting system replacement was already planned. The second case, denoted as "Controls-Ready Replacement," assumes that LED luminaires designed to accommodate the future addition of NLCs are installed at the time of planned replacement, then retrofitted with NLCs after five years.[6]

In both cases, the baseline measure is assumed to be an LED luminaire without networked lighting controls.[7] The analysis assumes that existing lighting systems are replaced, on average every 10 years, consistent with assumptions in ComStock (NREL 2023). In other words, the estimated potential can be interpreted as the savings associated with the lighting controls only—exclusive of savings from the increased efficacy of the new LED light fixture, if any.

MEASURES ASSESSED

While this study uses the term "networked lighting controls" throughout, the exact control system assumptions and capabilities vary by building size. For small buildings, defined as those less than 25,000 ft^2, the analysis assumes that room-level lighting controls are installed. These are essentially luminaire-level lighting controls (LLLCs) that communicate locally within a given space and can only be controlled by an occupant of that space. For buildings 25,000 ft^2 and larger, the analysis assumes the installation of

[5] While CT currently uses the Utility Cost Test as the primary test, the Connecticut Department of Energy and Environmental Protection recently recommended adopting a "Connecticut Efficiency Test" that is more similar to the SCT (CT DEEP 2022).

[6] In both scenarios, the installation period spans from 2023 to 2030; however, in the Controls-Ready Replacement scenario it is assumed that retrofits of lighting systems with controls continues through 2035.

[7] While current NLC penetration is non-zero, it is assumed to be small enough to be negligible relative to the total remaining potential. Further, while current penetrations of other control technologies are higher (approximately 34% of commercial lighting systems employed some form of lighting control in 2017 nationally per U.S. DOE 2019a), the impacts of these control technologies on the resulting incremental savings estimates are partially addressed in that the interior lighting end-use energy consumption estimated in ComStock already accounts for the existing controls savings. Future work could explicitly account for the incremental savings available from improving existing control strategies.

a comprehensive networked lighting controls system with a dedicated internet gateway that can be controlled remotely from any internet location.[8] These controls can typically support integration with building automation systems for HVAC control, plug load control, and automated demand response. While NLC systems not utilizing a gateway are appropriate for some buildings smaller than 50,000 ft^2, the analysis assumes this configuration to support the economic assessment of plug load control integration and automated demand response capabilities in medium-sized buildings. NLCs have been demonstrated to yield, on average, 49% energy savings across different building types (NEEA, DLC 2020).[9]

For medium (25,000-50,000 ft^2) and large (>50,000 ft^2) buildings, the analysis assesses the potential of NLC systems with plug load integration. Retrofit plug load controls require the installation of controllable receptacles that can leverage the occupancy signal from the NLCs to remove power from equipment not being used or that continue to draw power in an off or standby state. Plug load control is assumed to achieve 25% energy savings for applicable loads (PNNL 2022). It is assumed that due to fixed costs, plug load integration is not suitable for smaller buildings.

For the 60% of large buildings with existing building automation systems (BAS) to control heating and cooling, the analysis also considers NLC system integration for HVAC control. Future work could refine this 60% number, to include buildings that have remote digital HVAC controls but no BAS; and to omit building types that are unsuitable for occupancy-based ventilation reduction or broader temperature setpoints, and also older buildings that lack variable air volume (VAV) design with HVAC zones that are not too large. With a BAS, occupancy data from the lighting system can be used to control thermostat setbacks, temperature and ventilation resets, and air flow rates to achieve significant energy savings in heating, cooling, and ventilation end-use energy consumption. The analysis assumes a 30% reduction in HVAC energy consumption due to integration (PNNL 2022). A measure permutation considering both HVAC and plug integration is also considered. While NLC-HVAC system integration is theoretically feasible in buildings less than 50,000 ft^2 that have HVAC systems with digitally controlled remote access, reasonably sized control zones, and VAV design, these buildings are not included in this analysis because further standardization is needed before such integration will be practical at a large scale.

Finally, a permutation of each measure reflecting—in addition to lighting, HVAC, and/or plug load savings—demand response program participation to reduce lighting loads during summer coincident peak demand periods. The analysis assumes that non-critical lighting loads could be reduced by a maximum of 40% during peak periods, provided that passive lighting controls are not already reducing lighting levels beyond this point (NRC 2008). For small buildings, it is assumed that building occupants would manually decrease lighting levels in response to a message from the utility or grid operator (e.g., delivered via text message). For larger buildings, it is assumed that NLC systems would be capable of automated demand response (ADR). All measure permutations and their associated building size applicability are summarized in

[8] Due to the approximate parity of savings estimates associated with networked lighting control systems employing LLLCs and more comprehensive NLC redesign solutions and the fact that systems using LLLCs are much lower cost, this analysis assumes that all NLC systems employ LLLCs (NEEA 2020).

[9] Because this study seeks to estimate the incremental savings opportunities from NLCs and not the savings associated with improved lighting efficacy, the analysis assumes that baseline interior lighting end-use energy consumption can be reduced prior to consideration of the 49% savings for controls, yielding a lower effective percent savings factor. Effective percent savings factors by building type are provided in Appendix A.

Table 1. Note: The "(CR+)" in the Measure ID column indicates that a measure applies to the Controls-Ready Replacement scenario in addition to the NLC Replacement scenario.

Table 1: Measure Permutations, Descriptions, and Applicability

Measure ID	Measure Description	Baseline	Small, <25,000 ft²	Medium, 25,000-50,000 ft²	Large, >50,000 ft²
(CR+)NLC	LED luminaire with room-level lighting control or NLC system	LED luminaire w/o NLC	✓	✓	✓
(CR+)NLC+PL	LED luminaire with NLC system, integrated plug load control	LED luminaire w/o NLC		✓	✓
(CR+)NLC+HVAC	LED luminaire with NLC system, integrated HVAC system control	LED luminaire w/o NLC			✓
(CR+)NLC+PL+HVAC	LED luminaire with NLC system, integrated plug load and HVAC system control	LED luminaire w/o NLC			✓
(CR+)NLC+DR	LED luminaire with room-level lighting control or NLC system, lighting demand response	LED luminaire w/o NLC	✓	✓	✓
(CR+)NLC+PL+DR	LED luminaire with NLC system, integrated plug load control, lighting demand response	LED luminaire w/o NLC		✓	✓
(CR+)NLC+HVAC+DR	LED luminaire with NLC system, integrated HVAC system control, lighting demand response	LED luminaire w/o NLC			✓
(CR+)NLC+PL+HVAC+DR	LED luminaire with NLC system, integrated plug load and HVAC system control, lighting demand response	LED luminaire w/o NLC			✓

BUILDING STOCK AND END-USE CHARACTERIZATION

This study leverages the National Renewable Energy Laboratory's (NREL) ComStock data to characterize end-use energy, equipment saturation, and key building characteristics by building type. As described by NREL:

> *The commercial building sector stock model, or ComStock™, is a highly granular, bottom-up model that uses multiple data sources, statistical sampling methods, and advanced building energy simulations to estimate the annual subhourly energy consumption of the commercial building stock across the United States* (NREL 2023).

Because ComStock only models approximately 62% of the national total commercial floorspace as determined by the Commercial Building Energy Consumption Survey (CBECS), floor space for building types that were not modeled in ComStock were mapped to ComStock-modeled building types based on estimated interior lighting end-use energy density and qualitative consideration of the primary building activity. The results of this mapping are presented in Table 2.

Table 2: CBECS to ComStock Building Type Mapping

CBECS, PBAPLUS	ComStock Building Type
College/university	SecondarySchool
Convenience store (w/ or w/out gas station)	Hospital
Courthouse/probation office	Outpatient
Dormitory/fraternity/sorority	MediumOffice
Enclosed mall	RetailStripmall
Entertainment/culture	PrimarySchool
Fire station/police station	PrimarySchool
Grocery store/food market	Hospital
Laboratory	Outpatient
Library	Warehouse
Mixed-use office	Outpatient
Nursing home/assisted living	SmallHotel
Other	Outpatient
Other classroom education	SecondarySchool
Other food service	SecondarySchool
Other lodging	LargeHotel
Other public assembly	SecondarySchool
Other public order and safety	RetailStandalone
Other service	RetailStandalone
Post office/postal center	RetailStandalone
Preschool/daycare	PrimarySchool
Recreation	PrimarySchool
Refrigerated warehouse	Warehouse
Religious worship	SmallOffice
Social/meeting	SmallOffice
Vacant	MediumOffice
Vehicle service/repair shop	Outpatient
Vehicle storage/maintenance	Outpatient

Using this mapping, the floor space for non-ComStock-modeled building types was added to the totals for the appropriate ComStock-modeled building types. Building type and geography-specific end-use energy intensity estimates by fuel from ComStock were applied to these square footage values to estimate total end-use energy consumption by state and building type. Finally, energy consumption was disaggregated into small (<25,000 ft^2), medium (25,000-50,000 ft^2), and large (>50,000 ft^2) building size categories using data from CBECS 2018.

RESULTS

Table 3 below presents a summary of the resulting technical and economic potential for the NLC Replacement and Controls-Ready Replacement scenarios in both analysis states. As previously discussed, the technical potential refers to all potential that is technically feasible without regard to project economics or other market barriers. The economic potential refers to the subset of the technical potential that is cost-effective according to the Societal Cost Test.

Table 3: Summary of 2030 and 2035 Cumulative Potential by State and Scenario

State		CT				AZ			
Potential Scenario		Technical		Economic		Technical		Economic	
Sub Scenario		NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.
Cumulative Electric Savings (GWh)	2030	1,085	407	1,064	377	1,957	734	1,422	482
	2035	976	1,085	958	1,006	1,762	1,957	1,280	1,285
Cumululative Electric Summer Peak Coincident Demand Savings (MW)	2030	189	71	186	67	288	108	176	60
	2035	170	189	167	178	260	288	159	159
Cumulative Natural Gas Savings (BBtu)	2030	692	259	692	252	152	57	151	57
	2035	622	692	622	671	137	152	136	151
Cumulative Other Fossil Fuel Savings (BBtu)	2030	83	31	83	31	25	9	25	9
	2035	75	83	75	83	22	25	22	25
Total Societal Benefits (Million $)		$1,946	$1,677	$1,911	$1,567	$1,022	$781	$724	$500
Total Societal Costs (Million $)		$767	$891	$717	$712	$1,127	$1,098	$507	$357
Total Societal Net Bens (Million $)		$1,179	$786	$1,194	$855	-$105	-$317	$217	$143
Societal Cost Test BCR		2.5	1.9	2.7	2.2	0.9	0.7	1.4	1.4

The savings values presented in Table 3 for a given year represent the cumulative savings in that year from all measures installed since 2023, the beginning of the analysis period, that have not exceeded their effective useful lives. The societal costs and benefits represent present value totals in 2023 dollars realized over the entire analysis period (i.e., the costs and benefits for all measures installed over the analysis period accrued during their entire lifetimes). The natural gas and other fossil fuel savings presented are end-use fuel savings resulting from reduced space heating energy use achieved through NLC-HVAC integration.

To give these values additional context, selected results are presented relative to a 2020 baseline in Table 4 below. Note that electric energy savings are presented relative to 2020 *commercial* electric sales, but because generating capacity is not typically disaggregated by sector, electric peak demand reductions are presented relative to 2020 *total system* net summer generating capacity. Natural gas savings are presented relative to 2020 commercial natural gas sales.

Table 4: Summary of 2030 and 2035 Cumulative Potential by State and Scenario Relative to 2020 Consumption and Net Summer Capacity

State		CT				AZ			
Potential Scenario		Technical		Economic		Technical		Economic	
Sub Scenario		NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.	NLC Repl.	Controls-Ready Repl.
Cumulative Electric Savings as % 2020 Sales	2030	9.7%	3.7%	9.5%	3.4%	6.7%	2.5%	4.9%	1.7%
	2035	8.8%	9.7%	8.6%	9.0%	6.0%	6.7%	4.4%	4.4%
Cumulative Elec. Summer Pk Coincident Demand Savings As % 2020 Net Sum. Capacity	2030	1.8%	0.7%	1.8%	0.6%	1.1%	0.4%	0.7%	0.2%
	2035	1.7%	1.8%	1.6%	1.7%	1.0%	1.1%	0.6%	0.6%
Cumulative Natural Gas Savings As % 2020 Sales	2030	1.3%	0.5%	1.3%	0.5%	0.5%	0.2%	0.5%	0.2%
	2035	1.1%	1.3%	1.1%	1.2%	0.4%	0.5%	0.4%	0.5%

The economic, or cost-effective, energy efficiency potential associated with NLCs is significant. In the most optimistic scenario, 2030 electric energy consumption by commercial buildings is reduced by nearly 10% in Connecticut and 5% in Arizona. NLCs can reduce 2030 peak demand by approximately 1.8% in Connecticut and 0.7% in Arizona. Further, NLCs with HVAC integration can reduce 2030 natural gas consumption by 1.3% and 0.5% in Connecticut and Arizona, respectively.

Notably, the maximum cumulative potential is similar in both the NLC Replacement and Controls-Ready Replacement scenarios, but the maximum is reached 5 years later in the Controls-Ready Replacement scenario owing to the assumption that the lighting equipment would be retrofitted with controls (and integrated with other building systems, if applicable) 5 years after installation. For instance, the CT 2030 cumulative economic electric savings for the NLC Replacement scenario is 1,064 GWh, whereas the 2035 value for the Control-Ready Replacement scenario is a very similar 1,006 GWh. This implies that the increased incremental costs associated with installing the controls at a later date and additional discounting of benefits that are realized further in the future do not cause a substantial portion of the technical potential to fail the SCT cost-effectiveness screening.

CONNECTICUT DETAILED RESULTS

To assess measure-level cost effectiveness, both the *Societal Cost Test* (SCT) and the *Utility Cost Test* (UCT) were applied to each measure permutation presented in

Table 1. The Societal Cost Test (SCT) indicates whether the benefits of a measure will exceed its costs from the perspective of society as a whole. This test provides the most comprehensive picture of the total impacts of an efficiency measure. The test considers all costs incurred to acquire the measure, including all utility system and all non-utility system costs.

In contrast, the UCT indicates whether the benefits of a measure will exceed its costs from the perspective of only the utility system. The UCT considers all benefits and costs that impact the operation of the utility system and the provision of electric and gas services to customers. Note that the UCT applied in this study assumes a combined electric and gas utility test. For both tests, a benefit-cost ratio (BCR) of greater than 1.0 indicates that the benefits exceed the costs.

Table 5 through Table 8 below present the results of the SCT and UCT by analysis scenario, measure, building type, and building size for Connecticut. Note: In the tables below, the "_E," "_G", and "_O" designations at the end of the measure names indicate the primary space heating fuel applicable to the measure permutation: electric resistance, natural gas-fired, or other fuels, respectively. The other fuels category represents propane, fuel oil, and district heating systems. The "_All" designation, meaning all space heating fuels, is used where space heating fuel type is irrelevant. This distinction is important as costs vary considerably among the heating fuels assessed.

Table 5: Measure Level Screening, Societal Cost Test BCR, NLC Replacement Scenario, Connecticut

Building Type_Size	NLC_All	NLC+PL_All	NLC+HVAC_E	NLC+HVAC_G	NLC+HVAC_O	NLC+PL+HVAC_E	NLC+PL+HVAC_G	NLC+PL+HVAC_O	NLC+DR_All	NLC+PL+DR_All	NLC+HVAC+DR_E	NLC+HVAC+DR_G	NLC+HVAC+DR_O	NLC+PL+HVAC+DR_E	NLC+PL+HVAC+DR_G	NLC+PL+HVAC+DR_O
Education_Large	1.0	0.9	7.4	4.0	4.2	7.2	4.0	4.1	1.1	1.1	7.5	4.1	4.4	7.4	4.1	4.3
Education_Medium	1.0	0.9	---	---	---	---	---	---	1.1	1.1	---	---	---	---	---	---
Education_Small	1.8	---	---	---	---	---	---	---	2.2	---	---	---	---	---	---	---
FullServiceRestaurant_Small	3.0	---	---	---	---	---	---	---	3.5	---	---	---	---	---	---	---
Hospital_Large	1.5	1.5	---	9.5	---	---	9.0	---	1.9	1.8	---	9.7	---	---	9.2	---
Hospital_Medium	1.5	1.5	---	---	---	---	---	---	1.9	1.8	---	---	---	---	---	---
Hospital_Small	2.9	---	---	---	---	---	---	---	3.6	---	---	---	---	---	---	---
Hotel_Large	0.5	0.5	3.1	4.1	---	3.1	4.1	---	0.6	0.6	3.2	4.2	---	3.2	4.2	---
Hotel_Small	1.0	---	---	---	---	---	---	---	1.2	---	---	---	---	---	---	---
Office_Large	1.0	0.9	4.2	2.8	3.1	3.2	2.2	2.5	1.3	1.0	4.4	3.0	3.3	3.4	2.3	2.6
Office_Medium	1.0	0.9	---	---	---	---	---	---	1.3	1.0	---	---	---	---	---	---
Office_Small	1.9	---	---	---	---	---	---	---	2.4	---	---	---	---	---	---	---
Outpatient_Large	1.2	0.9	6.3	5.0	6.3	4.4	3.6	4.4	1.5	1.1	6.5	5.2	6.5	4.5	3.7	4.5
Outpatient_Medium	1.2	0.9	---	---	---	---	---	---	1.5	1.1	---	---	---	---	---	---
Outpatient_Small	2.2	---	---	---	---	---	---	---	2.8	---	---	---	---	---	---	---
QuickServiceRestaurant_Small	3.7	---	---	---	---	---	---	---	4.3	---	---	---	---	---	---	---
RetailStandalone_Large	1.8	1.8	5.9	3.7	4.7	5.9	3.7	4.7	2.1	2.1	6.1	3.9	4.9	6.1	3.9	4.9
RetailStandalone_Medium	1.8	1.8	---	---	---	---	---	---	2.1	2.1	---	---	---	---	---	---
RetailStandalone_Small	3.3	---	---	---	---	---	---	---	3.9	---	---	---	---	---	---	---
RetailStripmall_Large	2.7	2.7	8.7	6.0	7.4	8.7	6.0	7.4	3.1	3.1	9.0	6.2	7.7	9.0	6.2	7.7
Warehouse_Large	0.6	0.6	1.3	0.9	1.3	1.2	0.8	1.1	0.8	0.7	1.4	1.0	1.4	1.3	0.9	1.2
Warehouse_Medium	0.6	0.6	---	---	---	---	---	---	0.8	0.7	---	---	---	---	---	---
Warehouse_Small	1.2	---	---	---	---	---	---	---	1.4	---	---	---	---	---	---	---

Table 6: Measure Level Screening, Societal Cost Test BCR, Controls-Ready Replacement Scenario, Connecticut

Building Type_Size	CR+NLC_All	CR+NLC+PL_All	CR+NLC+HVAC_E	CR+NLC+HVAC_G	CR+NLC+HVAC_O	CR+NLC+PL+HVAC_E	CR+NLC+PL+HVAC_G	CR+NLC+PL+HVAC_O	CR+NLC+DR_All	CR+NLC+PL+DR_All	CR+NLC+HVAC+DR_E	CR+NLC+HVAC+DR_G	CR+NLC+HVAC+DR_O	CR+NLC+PL+HVAC+DR_E	CR+NLC+PL+HVAC+DR_G	CR+NLC+PL+HVAC+DR_O
Education_Large	0.8	0.8	6.6	3.7	3.6	6.5	3.6	3.6	1.0	0.9	6.7	3.7	3.8	6.6	3.7	3.7
Education_Medium	0.8	0.8	---	---	---	---	---	---	0.9	0.9	---	---	---	---	---	---
Education_Small	1.1	---	---	---	---	---	---	---	1.4	---	---	---	---	---	---	---
FullServiceRestaurant_Small	1.9	---	---	---	---	---	---	---	2.2	---	---	---	---	---	---	---
Hospital_Large	1.3	1.2	---	8.5	---	---	8.1	---	1.6	1.5	---	8.7	---	---	8.3	---
Hospital_Medium	1.2	1.2	---	---	---	---	---	---	1.5	1.5	---	---	---	---	---	---
Hospital_Small	1.8	---	---	---	---	---	---	---	2.3	---	---	---	---	---	---	---
Hotel_Large	0.4	0.4	2.8	3.7	---	2.8	3.7	---	0.5	0.5	2.9	3.8	---	2.9	3.8	---
Hotel_Small	0.6	---	---	---	---	---	---	---	0.7	---	---	---	---	---	---	---
Office_Large	0.8	0.8	3.8	2.5	2.8	3.0	2.0	2.3	1.1	0.9	3.9	2.6	2.9	3.1	2.1	2.4
Office_Medium	0.8	0.7	---	---	---	---	---	---	1.0	0.9	---	---	---	---	---	---
Office_Small	1.2	---	---	---	---	---	---	---	1.5	---	---	---	---	---	---	---
Outpatient_Large	1.0	0.8	5.7	4.6	5.8	4.1	3.4	4.1	1.2	1.0	5.8	4.7	5.9	4.2	3.5	4.2
Outpatient_Medium	0.9	0.8	---	---	---	---	---	---	1.2	0.9	---	---	---	---	---	---
Outpatient_Small	1.4	---	---	---	---	---	---	---	1.7	---	---	---	---	---	---	---
QuickServiceRestaurant_Small	2.3	---	---	---	---	---	---	---	2.7	---	---	---	---	---	---	---
RetailStandalone_Large	1.5	1.5	5.3	3.3	4.2	5.3	3.3	4.2	1.7	1.7	5.5	3.4	4.4	5.5	3.4	4.4
RetailStandalone_Medium	1.4	1.4	---	---	---	---	---	---	1.7	1.7	---	---	---	---	---	---
RetailStandalone_Small	2.1	---	---	---	---	---	---	---	2.5	---	---	---	---	---	---	---
RetailStripmall_Large	2.2	2.2	7.8	5.3	6.6	7.8	5.3	6.6	2.6	2.6	8.0	5.6	6.8	8.0	5.6	6.8
Warehouse_Large	0.5	0.5	1.2	0.7	1.1	1.1	0.7	1.0	0.6	0.6	1.2	0.8	1.2	1.2	0.8	1.1
Warehouse_Medium	0.5	0.5	---	---	---	---	---	---	0.6	0.6	---	---	---	---	---	---
Warehouse_Small	0.7	---	---	---	---	---	---	---	0.9	---	---	---	---	---	---	---

Table 7: Measure-Level Screening, Utility Cost Test, NLC Replacement Scenario, Connecticut

Building Type_Size	NLC_All	NLC+PL_All	NLC+HVAC_E	NLC+HVAC_G	NLC+HVAC_O	NLC+PL+HVAC_E	NLC+PL+HVAC_G	NLC+PL+HVAC_O	NLC+DR_All	NLC+PL+DR_All	NLC+HVAC+DR_E	NLC+HVAC+DR_G	NLC+HVAC+DR_O	NLC+PL+HVAC+DR_E	NLC+PL+HVAC+DR_G	NLC+PL+HVAC+DR_O
Education_Large	0.6	0.6	5.3	2.6	1.5	5.3	2.5	1.5	0.8	0.8	5.5	2.7	1.6	5.4	2.6	1.6
Education_Medium	0.6	0.6	---	---	---	---	---	---	0.8	0.8	---	---	---	---	---	---
Education_Small	1.2	---	---	---	---	---	---	---	1.5	---	---	---	---	---	---	---
FullServiceRestaurant_Small	1.9	---	---	---	---	---	---	---	2.4	---	---	---	---	---	---	---
Hospital_Large	1.0	1.0	---	5.8	---	---	5.5	---	1.4	1.3	---	6.1	---	---	5.7	---
Hospital_Medium	1.0	1.0	---	---	---	---	---	---	1.4	1.3	---	---	---	---	---	---
Hospital_Small	1.9	---	---	---	---	---	---	---	2.6	---	---	---	---	---	---	---
Hotel_Large	0.3	0.3	2.1	2.6	---	2.1	2.6	---	0.4	0.4	2.2	2.6	---	2.2	2.6	---
Hotel_Small	0.6	---	---	---	---	---	---	---	0.8	---	---	---	---	---	---	---
Office_Large	0.7	0.6	3.1	1.9	1.5	2.3	1.5	1.3	1.0	0.8	3.3	2.0	1.7	2.5	1.6	1.4
Office_Medium	0.7	0.6	---	---	---	---	---	---	1.0	0.7	---	---	---	---	---	---
Office_Small	1.3	---	---	---	---	---	---	---	1.8	---	---	---	---	---	---	---
Outpatient_Large	0.8	0.6	4.5	3.3	2.7	3.2	2.4	1.9	1.1	0.8	4.7	3.5	2.8	3.3	2.5	2.0
Outpatient_Medium	0.8	0.6	---	---	---	---	---	---	1.1	0.8	---	---	---	---	---	---
Outpatient_Small	1.5	---	---	---	---	---	---	---	2.0	---	---	---	---	---	---	---
QuickServiceRestaurant_Small	2.4	---	---	---	---	---	---	---	3.0	---	---	---	---	---	---	---
RetailStandalone_Large	1.1	1.1	4.1	2.3	2.0	4.1	2.3	2.0	1.5	1.5	4.3	2.5	2.2	4.3	2.5	2.2
RetailStandalone_Medium	1.1	1.1	---	---	---	---	---	---	1.5	1.5	---	---	---	---	---	---
RetailStandalone_Small	2.1	---	---	---	---	---	---	---	2.7	---	---	---	---	---	---	---
RetailStripmall_Large	1.7	1.7	6.0	3.8	3.3	6.0	3.8	3.3	2.2	2.2	6.3	4.1	3.6	6.3	4.1	3.6
Warehouse_Large	0.4	0.4	1.0	0.5	0.4	0.9	0.5	0.4	0.5	0.5	1.0	0.6	0.5	0.9	0.6	0.5
Warehouse_Medium	0.4	0.4	---	---	---	---	---	---	0.5	0.5	---	---	---	---	---	---
Warehouse_Small	0.8	---	---	---	---	---	---	---	1.0	---	---	---	---	---	---	---

Table 8: Measure-Level Screening, Utility Cost Test, Controls-Ready Replacement Scenario, Connecticut

Building Type_Size	CR+NLC_All	CR+NLC+PL_All	CR+NLC+HVAC_E	CR+NLC+HVAC_G	CR+NLC+HVAC_O	CR+NLC+PL+HVAC_E	CR+NLC+PL+HVAC_G	CR+NLC+PL+HVAC_O	CR+NLC+DR_All	CR+NLC+PL+DR_All	CR+NLC+HVAC+DR_E	CR+NLC+HVAC+DR_G	CR+NLC+HVAC+DR_O	CR+NLC+PL+HVAC+DR_E	CR+NLC+PL+HVAC+DR_G	CR+NLC+PL+HVAC+DR_O
Education_Large	0.5	0.5	4.8	2.3	1.3	4.7	2.3	1.3	0.7	0.7	4.9	2.4	1.4	4.8	2.4	1.4
Education_Medium	0.5	0.5	---	---	---	---	---	---	0.6	0.6	---	---	---	---	---	---
Education_Small	0.7	---	---	---	---	---	---	---	1.0	---	---	---	---	---	---	---
FullServiceRestaurant_Small	1.2	---	---	---	---	---	---	---	1.5	---	---	---	---	---	---	---
Hospital_Large	0.9	0.8	---	5.2	---	---	5.0	---	1.2	1.1	---	5.4	---	---	5.2	---
Hospital_Medium	0.8	0.8	---	---	---	---	---	---	1.1	1.1	---	---	---	---	---	---
Hospital_Small	1.2	---	---	---	---	---	---	---	1.7	---	---	---	---	---	---	---
Hotel_Large	0.3	0.3	2.0	2.3	---	2.0	2.3	---	0.4	0.4	2.0	2.4	---	2.0	2.4	---
Hotel_Small	0.4	---	---	---	---	---	---	---	0.5	---	---	---	---	---	---	---
Office_Large	0.6	0.5	2.8	1.6	1.4	2.1	1.3	1.2	0.8	0.7	2.9	1.8	1.5	2.3	1.5	1.3
Office_Medium	0.5	0.5	---	---	---	---	---	---	0.8	0.6	---	---	---	---	---	---
Office_Small	0.8	---	---	---	---	---	---	---	1.1	---	---	---	---	---	---	---
Outpatient_Large	0.6	0.5	4.1	3.0	2.5	2.9	2.2	1.8	0.9	0.7	4.2	3.2	2.6	3.0	2.3	1.9
Outpatient_Medium	0.6	0.5	---	---	---	---	---	---	0.9	0.7	---	---	---	---	---	---
Outpatient_Small	0.9	---	---	---	---	---	---	---	1.3	---	---	---	---	---	---	---
QuickServiceRestaurant_Small	1.5	---	---	---	---	---	---	---	1.9	---	---	---	---	---	---	---
RetailStandalone_Large	0.9	0.9	3.6	2.1	1.7	3.6	2.1	1.7	1.2	1.2	3.8	2.2	1.9	3.8	2.2	1.9
RetailStandalone_Medium	0.9	0.9	---	---	---	---	---	---	1.2	1.2	---	---	---	---	---	---
RetailStandalone_Small	1.3	---	---	---	---	---	---	---	1.7	---	---	---	---	---	---	---
RetailStripmall_Large	1.4	1.4	5.4	3.4	2.9	5.4	3.4	2.9	1.8	1.8	5.6	3.7	3.2	5.6	3.7	3.2
Warehouse_Large	0.3	0.3	0.9	0.5	0.4	0.8	0.5	0.4	0.5	0.4	0.9	0.6	0.5	0.9	0.5	0.4
Warehouse_Medium	0.3	0.3	---	---	---	---	---	---	0.4	0.4	---	---	---	---	---	---
Warehouse_Small	0.5	---	---	---	---	---	---	---	0.6	---	---	---	---	---	---	---

NLC Replacement scenario measure permutations pass the SCT in nearly all building types. While additional NLC and NLC+PL measures fail the UCT, most permutations remain cost-effective at comfortable margins, even when assuming incentives that cover 100% of the incremental measure costs. Interestingly, nearly all measures with integrated HVAC control pass the UCT, suggesting that where HVAC integration is feasible, programs can support paying large portions of the incremental cost. A notable exception is the Warehouse building type where many measures fail cost-effectiveness owing to low lighting and HVAC end-use energy intensities in the underlying ComStock data. While policies vary by jurisdiction, measures need not necessarily pass the screening at the measure level. Some jurisdictions only require cost-effectiveness at the program, sector, or portfolio level. Therefore, there is often discretion within the program design to promote measures with UCT <1.0 if this supports overall program goals and still satisfies regulatory requirements.

As an illustrative comparison of the upper boundary of the incentive costs to capture the NLC potential relative to what representative programs—those programs that include the promotion of NLC measures—are currently paying to achieve savings in the C&I sector[10], Table 9 below shows the full incremental cost by NLC measure per unit savings and the planned 2023 incentives per unit savings for representative commercial efficiency programs filed in Connecticut. To facilitate comparison, savings from electric energy, natural gas, and delivered fuels are aggregated into savings in site MMBtus. This implies that offering incentives in Connecticut that cover the full incremental costs of NLC measures would result in incentive dollars per site MMBtu savings at levels:

- With HVAC integration: within 29% of the average cost of representative existing programs *(as shown in the "% Change" column, Rows 3 to 8 and 11 to 16)*,
- Without HVAC integration: 142 to 287% more expensive than representative existing programs, *(as shown in Rows 1, 2, 9, and 10).*

Table 9: Estimated Incremental Cost per Site MMBtu vs. Connecticut Program Incentives

Row	Measure	*Incremental* Cost ($) / Site MMBtu Saved	CT Program Incentive ($) / Site MMBtu Saved	% Change
1	NLC_All	$289	$119*	142%
2	NLC+DR_All	$289		142%
3	NLC+HVAC_E	$101		-15%
4	NLC+HVAC_G	$90		-24%
5	NLC+HVAC_O	$128		7%
6	NLC+HVAC+DR_E	$101		-15%
7	NLC+HVAC+DR_G	$90		-24%
8	NLC+HVAC+DR_O	$128		7%
9	NLC+PL_All	$463		287%
10	NLC+PL+DR_All	$463		287%
11	NLC+PL+HVAC_E	$117		-2%
12	NLC+PL+HVAC_G	$106		-12%
13	NLC+PL+HVAC_O	$154		29%
14	NLC+PL+HVAC+DR_E	$117		-2%
15	NLC+PL+HVAC+DR_G	$106		-12%
16	NLC+PL+HVAC+DR_O	$154		29%

*Source: Eversource 2022. Assumes savings and incentive budgets from the "Energy Conscious Blueprint" program.

[10] The incentive cost per unit saving presented in the table for representative programs are program-wide, not limited to NLC measures.

Figure 1 through

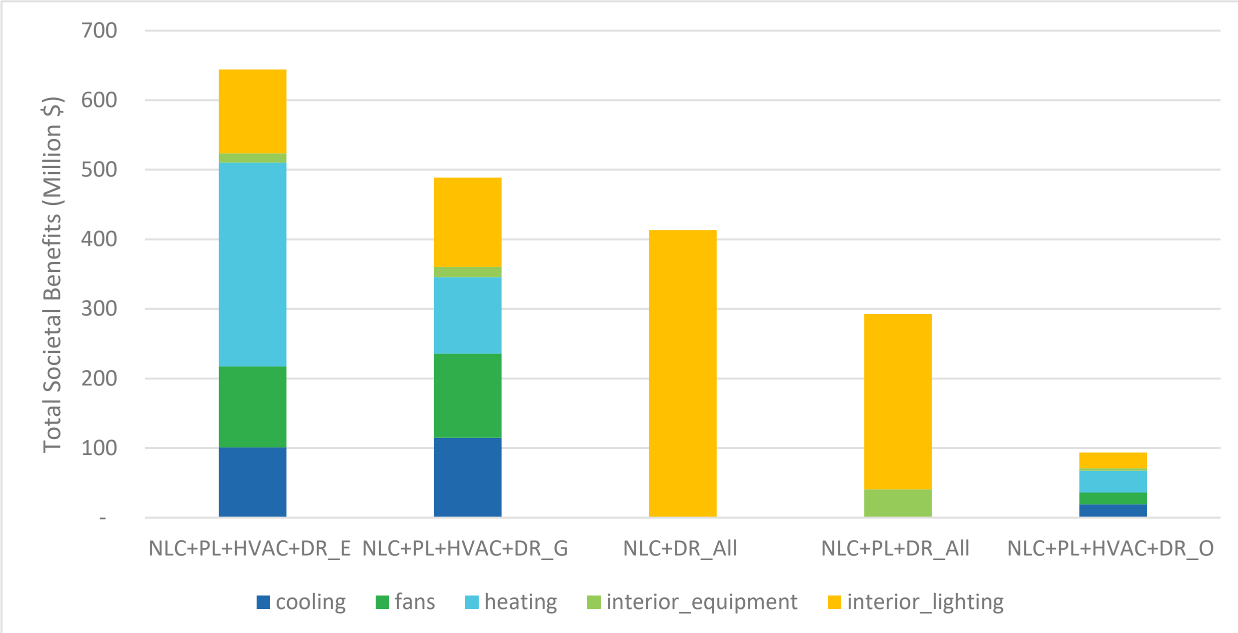


Figure 6 present the electric savings, demand savings, natural gas savings, other fuel savings, and societal benefits and costs associated with the economic potential for the NLC Replacement scenario in Connecticut. These figures illustrate that this analytical methodology could be used to target an incentive program on a few building types that offer the most potential savings in each region.

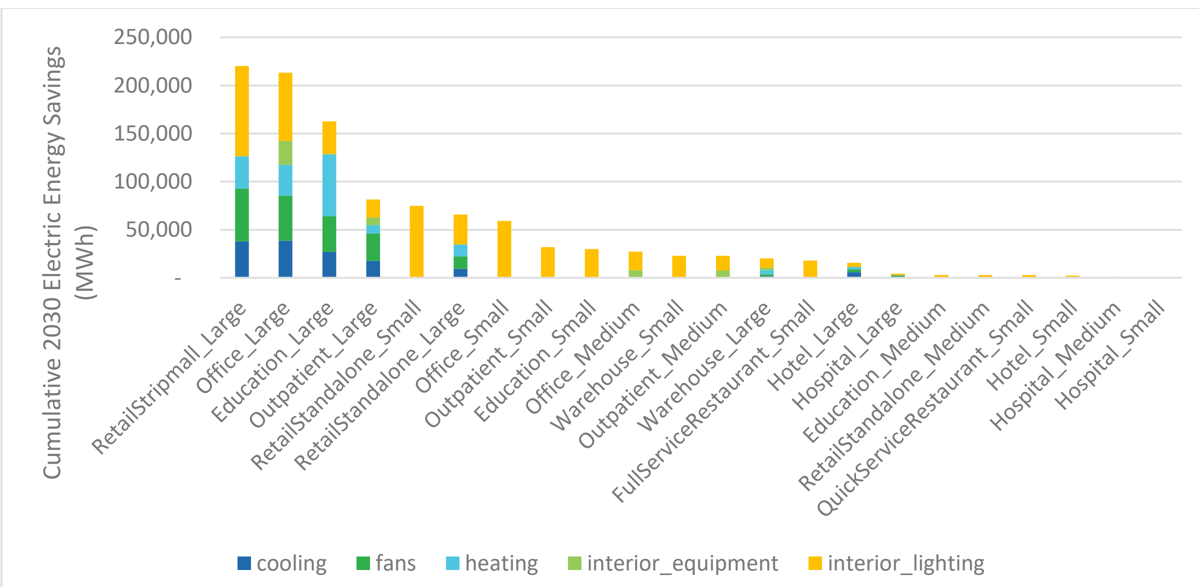


Figure 1: Economic Potential, Cumulative 2030 Electric Savings (MWh) by Building Type and End-Use, NLC Replacement Scenario, Connecticut

For reference, the maximum value on the y-axis in Figure 1 (250,000 MWh) is approximately 2.2% of 2020 Connecticut commercial electric sales.

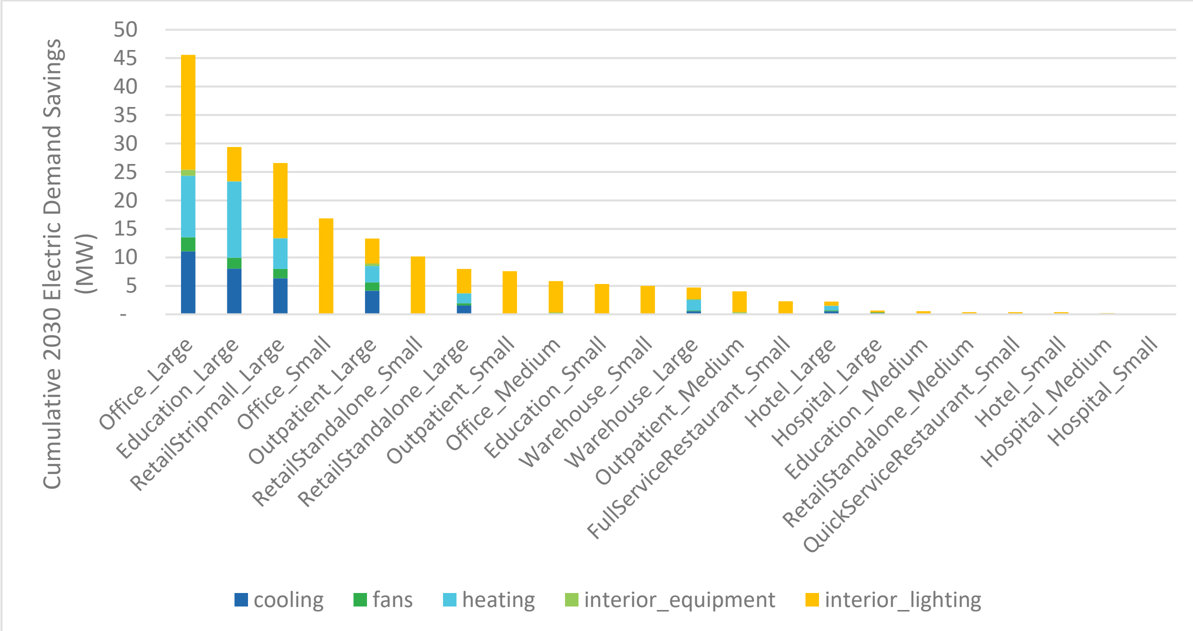


Figure 2: Economic Potential, Cumulative 2030 Electric Summer Peak Demand Savings (MW) by Building Type and End-Use, NLC Replacement Scenario, Connecticut

For reference, the maximum value on the y-axis in

Figure 2 (50 MW) is approximately 0.5% of 2020 Connecticut net summer capacity.

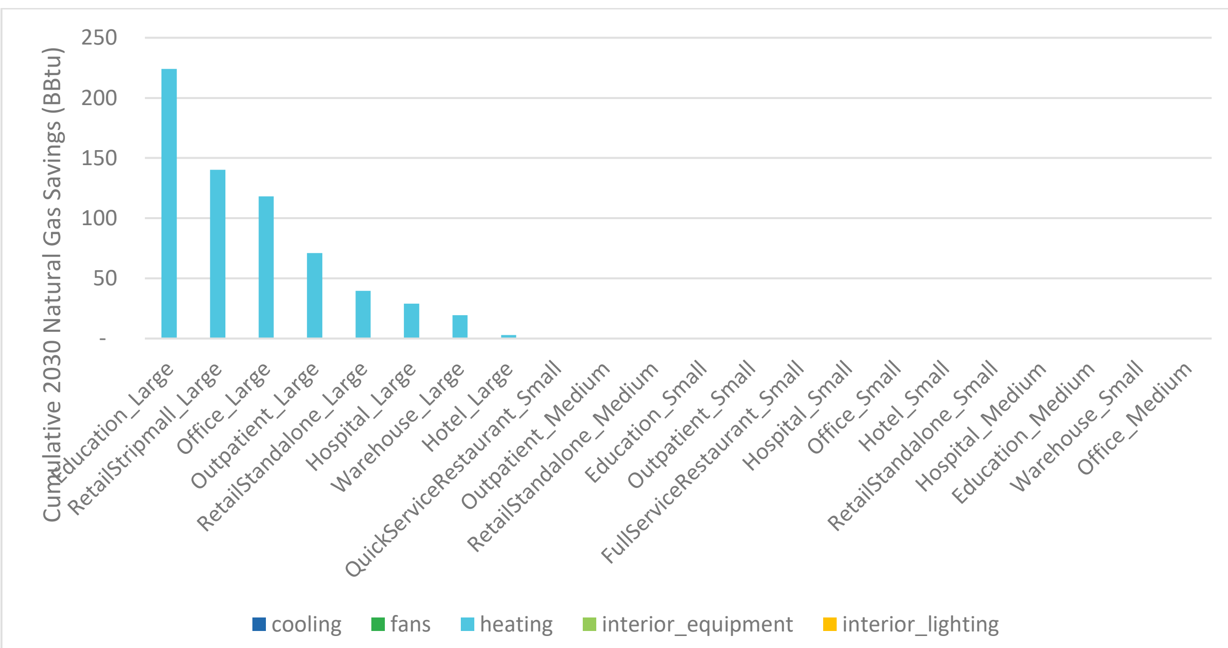


Figure 3: Economic Potential, Cumulative 2030 Natural Gas Savings (BBtu) by Building Type and End-Use, NLC Replacement Scenario, Connecticut

For reference, the maximum value on the y-axis in Figure 3

Figure 2 (250 BBtu) is approximately 0.5% of 2020 Connecticut commercial natural gas sales.

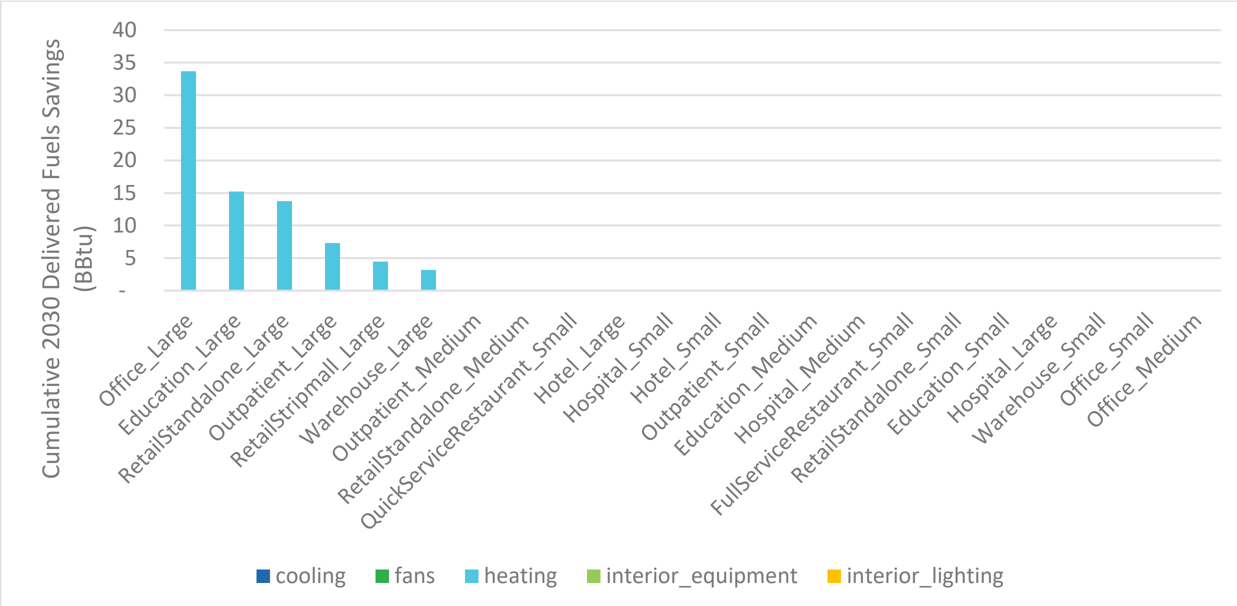


Figure 4: Economic Potential, Cumulative 2030 Delivered Fuels Savings (BBtu) by Building Type and End-Use, NLC Replacement Scenario, Connecticut

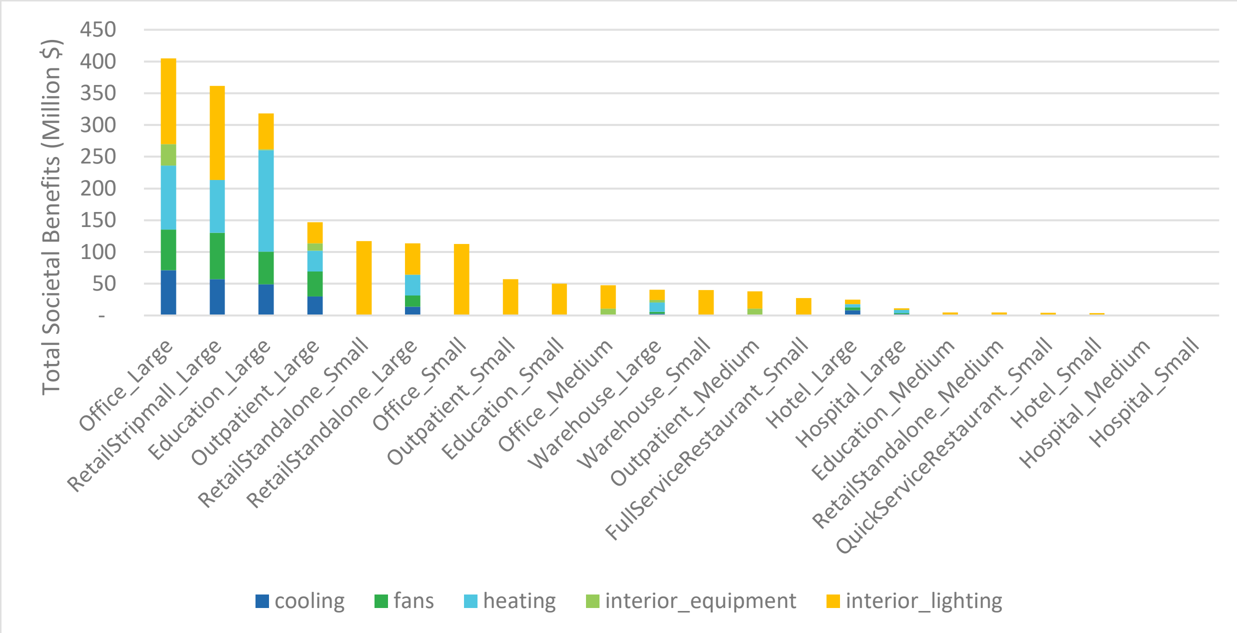


Figure 5: Economic Potential, Total Societal Benefits by Building Type and End-Use, NLC Replacement Scenario, Connecticut

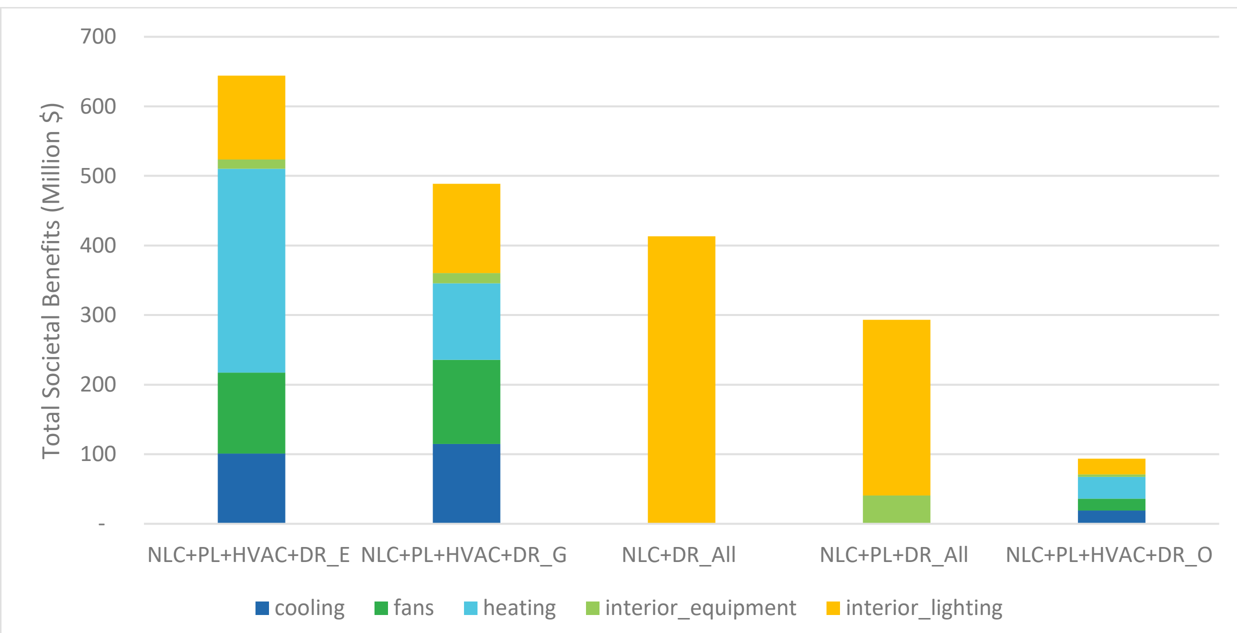


Figure 6: Economic Potential, Total Societal Benefits by Measure and End-Use, NLC Replacement Scenario, Connecticut

ARIZONA DETAILED RESULTS

Table 10 through Table 13 below present the results of the SCT and UCT by analysis scenario, measure, building type, and building size for Arizona.

Table 10: Measure Level Screening, Societal Cost Test BCR, NLC Replacement Scenario, Arizona

Building Type_Size	NLC_All	NLC+PL_All	NLC+HVAC_E	NLC+HVAC_G	NLC+HVAC_O	NLC+PL+HVAC_E	NLC+PL+HVAC_G	NLC+PL+HVAC_O	NLC+DR_All	NLC+PL+DR_All	NLC+HVAC+DR_E	NLC+HVAC+DR_G	NLC+HVAC+DR_O	NLC+PL+HVAC+DR_E	NLC+PL+HVAC+DR_G	NLC+PL+HVAC+DR_O
Education_Large	0.3	0.3	1.8	1.5	1.4	1.8	1.5	1.4	0.3	0.3	1.8	1.5	1.5	1.8	1.5	1.4
Education_Medium	0.3	0.3	---	---	---	---	---	---	0.3	0.3	---	---	---	---	---	---
Education_Small	0.6	---	---	---	---	---	---	---	0.7	---	---	---	---	---	---	---
FullServiceRestaurant_Small	0.9	---	---	---	---	---	---	---	1.0	---	---	---	---	---	---	---
Hospital_Large	0.5	0.4	1.7	1.8	2.8	1.6	1.7	2.7	0.6	0.5	1.7	1.9	2.9	1.6	1.8	2.7
Hospital_Medium	0.5	0.4	---	---	---	---	---	---	0.6	0.5	---	---	---	---	---	---
Hospital_Small	0.9	---	---	---	---	---	---	---	1.1	---	---	---	---	---	---	---
Hotel_Large	0.2	0.2	1.5	1.9	1.1	1.5	1.9	1.1	0.2	0.2	1.5	1.9	1.1	1.5	1.9	1.1
Hotel_Medium	0.2	0.2	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Hotel_Small	0.4	---	---	---	---	---	---	---	0.5	---	---	---	---	---	---	---
Office_Large	0.3	0.3	1.3	1.3	1.3	1.0	0.9	0.9	0.4	0.3	1.3	1.3	1.4	1.0	1.0	1.0
Office_Medium	0.3	0.3	---	---	---	---	---	---	0.4	0.3	---	---	---	---	---	---
Office_Small	0.6	---	---	---	---	---	---	---	0.7	---	---	---	---	---	---	---
Outpatient_Large	0.4	0.3	2.1	2.0	2.4	1.5	1.4	1.4	0.4	0.3	2.1	2.1	2.5	1.5	1.4	1.5
Outpatient_Medium	0.4	0.3	---	---	---	---	---	---	0.4	0.3	---	---	---	---	---	---
Outpatient_Small	0.7	---	---	---	---	---	---	---	0.9	---	---	---	---	---	---	---
QuickServiceRestaurant_Small	1.2	---	---	---	---	---	---	---	1.3	---	---	---	---	---	---	---
RetailStandalone_Large	0.6	0.6	1.6	1.6	1.7	1.6	1.6	1.7	0.7	0.7	1.7	1.6	1.8	1.7	1.6	1.8
RetailStandalone_Medium	0.6	0.6	---	---	---	---	---	---	0.7	0.7	---	---	---	---	---	---
RetailStandalone_Small	1.1	---	---	---	---	---	---	---	1.3	---	---	---	---	---	---	---
RetailStripmall_Large	0.9	0.9	2.4	2.4	---	2.4	2.4	---	1.0	1.0	2.5	2.5	---	2.5	2.5	---
RetailStripmall_Medium	0.9	0.9	---	---	---	---	---	---	1.0	1.0	---	---	---	---	---	---
RetailStripmall_Small	1.6	---	---	---	---	---	---	---	1.8	---	---	---	---	---	---	---
Warehouse_Large	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.2	0.5	0.4	0.4	0.4	0.4	0.4
Warehouse_Medium	0.2	0.2	---	---	---	---	---	---	0.3	0.2	---	---	---	---	---	---
Warehouse_Small	0.4	---	---	---	---	---	---	---	0.5	---	---	---	---	---	---	---

Table 11: Measure Level Screening, Societal Cost Test BCR, Controls-Ready Replacement Scenario, Arizona

Building Type_Size	CR+NLC_All	CR+NLC+PL_All	CR+NLC+HVAC_E	CR+NLC+HVAC_G	CR+NLC+HVAC_O	CR+NLC+PL+HVAC_E	CR+NLC+PL+HVAC_G	CR+NLC+PL+HVAC_O	CR+NLC+DR_All	CR+NLC+PL+DR_All	CR+NLC+HVAC+DR_E	CR+NLC+HVAC+DR_G	CR+NLC+HVAC+DR_O	CR+NLC+PL+HVAC+DR_E	CR+NLC+PL+HVAC+DR_G	CR+NLC+PL+HVAC+DR_O
Education_Large	0.2	0.2	1.6	1.3	1.2	1.5	1.3	1.2	0.3	0.3	1.6	1.3	1.2	1.6	1.3	1.2
Education_Medium	0.2	0.2	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Education_Small	0.3	---	---	---	---	---	---	---	0.4	---	---	---	---	---	---	---
FullServiceRestaurant_Small	0.5	---	---	---	---	---	---	---	0.6	---	---	---	---	---	---	---
Hospital_Large	0.4	0.3	1.4	1.6	2.2	1.4	1.5	2.1	0.4	0.4	1.5	1.6	2.3	1.4	1.5	2.2
Hospital_Medium	0.3	0.3	---	---	---	---	---	---	0.4	0.4	---	---	---	---	---	---
Hospital_Small	0.5	---	---	---	---	---	---	---	0.6	---	---	---	---	---	---	---
Hotel_Large	0.2	0.2	1.3	1.7	0.8	1.3	1.7	0.8	0.2	0.2	1.3	1.7	0.9	1.3	1.7	0.9
Hotel_Medium	0.1	0.1	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Hotel_Small	0.2	---	---	---	---	---	---	---	0.3	---	---	---	---	---	---	---
Office_Large	0.2	0.2	1.1	1.1	1.1	0.9	0.8	0.8	0.3	0.3	1.2	1.1	1.1	0.9	0.9	0.9
Office_Medium	0.2	0.2	---	---	---	---	---	---	0.3	0.2	---	---	---	---	---	---
Office_Small	0.3	---	---	---	---	---	---	---	0.4	---	---	---	---	---	---	---
Outpatient_Large	0.3	0.2	1.8	1.8	2.1	1.3	1.3	1.3	0.3	0.3	1.9	1.8	2.1	1.4	1.3	1.3
Outpatient_Medium	0.3	0.2	---	---	---	---	---	---	0.3	0.3	---	---	---	---	---	---
Outpatient_Small	0.4	---	---	---	---	---	---	---	0.5	---	---	---	---	---	---	---
QuickServiceRestaurant_Small	0.7	---	---	---	---	---	---	---	0.8	---	---	---	---	---	---	---
RetailStandalone_Large	0.5	0.5	1.4	1.3	1.4	1.4	1.3	1.4	0.5	0.5	1.4	1.4	1.5	1.4	1.4	1.5
RetailStandalone_Medium	0.4	0.4	---	---	---	---	---	---	0.5	0.5	---	---	---	---	---	---
RetailStandalone_Small	0.6	---	---	---	---	---	---	---	0.7	---	---	---	---	---	---	---
RetailStripmall_Large	0.7	0.7	2.1	2.1	---	2.1	2.1	---	0.8	0.8	2.2	2.1	---	2.2	2.1	---
RetailStripmall_Medium	0.6	0.6	---	---	---	---	---	---	0.7	0.7	---	---	---	---	---	---
RetailStripmall_Small	0.9	---	---	---	---	---	---	---	1.1	---	---	---	---	---	---	---
Warehouse_Large	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.4	0.4	0.4	0.4	0.3	0.3
Warehouse_Medium	0.2	0.2	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Warehouse_Small	0.2	---	---	---	---	---	---	---	0.3	---	---	---	---	---	---	---

Table 12: Measure Level Screening, Utility Cost Test BCR, NLC Replacement Scenario, Arizona

Building Type_Size	NLC_All	NLC+PL_All	NLC+HVAC_E	NLC+HVAC_G	NLC+HVAC_O	NLC+PL+HVAC_E	NLC+PL+HVAC_G	NLC+PL+HVAC_O	NLC+DR_All	NLC+PL+DR_All	NLC+HVAC+DR_E	NLC+HVAC+DR_G	NLC+HVAC+DR_O	NLC+PL+HVAC+DR_E	NLC+PL+HVAC+DR_G	NLC+PL+HVAC+DR_O
Education_Large	0.2	0.2	1.6	1.3	1.1	1.6	1.3	1.1	0.3	0.3	1.6	1.3	1.1	1.6	1.3	1.1
Education_Medium	0.2	0.2	---	---	---	---	---	---	0.3	0.3	---	---	---	---	---	---
Education_Small	0.5	---	---	---	---	---	---	---	0.6	---	---	---	---	---	---	---
FullServiceRestaurant_Small	0.8	---	---	---	---	---	---	---	0.9	---	---	---	---	---	---	---
Hospital_Large	0.4	0.4	1.5	1.6	0.9	1.4	1.5	0.9	0.5	0.5	1.5	1.6	1.0	1.4	1.5	1.0
Hospital_Medium	0.4	0.4	---	---	---	---	---	---	0.5	0.5	---	---	---	---	---	---
Hospital_Small	0.8	---	---	---	---	---	---	---	1.0	---	---	---	---	---	---	---
Hotel_Large	0.2	0.2	1.3	1.7	0.7	1.3	1.7	0.7	0.2	0.2	1.3	1.7	0.7	1.3	1.7	0.7
Hotel_Medium	0.2	0.2	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Hotel_Small	0.4	---	---	---	---	---	---	---	0.4	---	---	---	---	---	---	---
Office_Large	0.3	0.2	1.1	1.1	0.9	0.9	0.8	0.7	0.3	0.3	1.2	1.2	1.0	0.9	0.9	0.7
Office_Medium	0.3	0.2	---	---	---	---	---	---	0.3	0.3	---	---	---	---	---	---
Office_Small	0.5	---	---	---	---	---	---	---	0.7	---	---	---	---	---	---	---
Outpatient_Large	0.3	0.2	1.9	1.8	1.9	1.3	1.2	1.1	0.4	0.3	1.9	1.8	2.0	1.3	1.2	1.2
Outpatient_Medium	0.3	0.2	---	---	---	---	---	---	0.4	0.3	---	---	---	---	---	---
Outpatient_Small	0.6	---	---	---	---	---	---	---	0.8	---	---	---	---	---	---	---
QuickServiceRestaurant_Small	1.0	---	---	---	---	---	---	---	1.2	---	---	---	---	---	---	---
RetailStandalone_Large	0.5	0.5	1.4	1.4	1.2	1.4	1.4	1.2	0.6	0.6	1.5	1.4	1.3	1.5	1.4	1.3
RetailStandalone_Medium	0.5	0.5	---	---	---	---	---	---	0.6	0.6	---	---	---	---	---	---
RetailStandalone_Small	1.0	---	---	---	---	---	---	---	1.2	---	---	---	---	---	---	---
RetailStripmall_Large	0.7	0.7	2.1	2.1	---	2.1	2.1	---	0.9	0.9	2.2	2.2	---	2.2	2.2	---
RetailStripmall_Medium	0.7	0.7	---	---	---	---	---	---	0.9	0.9	---	---	---	---	---	---
RetailStripmall_Small	1.4	---	---	---	---	---	---	---	1.6	---	---	---	---	---	---	---
Warehouse_Large	0.2	0.2	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.4	0.4	0.4	0.4	0.3	0.3
Warehouse_Medium	0.2	0.2	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Warehouse_Small	0.4	---	---	---	---	---	---	---	0.5	---	---	---	---	---	---	---

Table 13: Measure Level Screening, Utility Cost Test BCR, Controls-Ready Replacement Scenario, Arizona

Building Type_Size	CR+NLC_All	CR+NLC+PL_All	CR+NLC+HVAC_E	CR+NLC+HVAC_G	CR+NLC+HVAC_O	CR+NLC+PL+HVAC_E	CR+NLC+PL+HVAC_G	CR+NLC+PL+HVAC_O	CR+NLC+DR_All	CR+NLC+PL+DR_All	CR+NLC+HVAC+DR_E	CR+NLC+HVAC+DR_G	CR+NLC+HVAC+DR_O	CR+NLC+PL+HVAC+DR_E	CR+NLC+PL+HVAC+DR_G	CR+NLC+PL+HVAC+DR_O
Education_Large	0.2	0.2	1.4	1.1	0.9	1.4	1.1	0.9	0.2	0.2	1.4	1.2	0.9	1.4	1.1	0.9
Education_Medium	0.2	0.2	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Education_Small	0.3	---	---	---	---	---	---	---	0.3	---	---	---	---	---	---	---
FullServiceRestaurant_Small	0.4	---	---	---	---	---	---	---	0.5	---	---	---	---	---	---	---
Hospital_Large	0.3	0.3	1.3	1.4	0.7	1.2	1.3	0.7	0.4	0.4	1.3	1.4	0.8	1.2	1.3	0.8
Hospital_Medium	0.3	0.3	---	---	---	---	---	---	0.4	0.4	---	---	---	---	---	---
Hospital_Small	0.4	---	---	---	---	---	---	---	0.5	---	---	---	---	---	---	---
Hotel_Large	0.1	0.1	1.1	1.5	0.5	1.1	1.5	0.5	0.2	0.2	1.1	1.5	0.5	1.1	1.5	0.5
Hotel_Medium	0.1	0.1	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Hotel_Small	0.2	---	---	---	---	---	---	---	0.2	---	---	---	---	---	---	---
Office_Large	0.2	0.2	1.0	0.9	0.8	0.8	0.7	0.6	0.3	0.2	1.0	1.0	0.8	0.8	0.8	0.6
Office_Medium	0.2	0.2	---	---	---	---	---	---	0.3	0.2	---	---	---	---	---	---
Office_Small	0.3	---	---	---	---	---	---	---	0.4	---	---	---	---	---	---	---
Outpatient_Large	0.2	0.2	1.6	1.5	1.6	1.2	1.1	1.0	0.3	0.2	1.7	1.6	1.7	1.2	1.1	1.1
Outpatient_Medium	0.2	0.2	---	---	---	---	---	---	0.3	0.2	---	---	---	---	---	---
Outpatient_Small	0.3	---	---	---	---	---	---	---	0.4	---	---	---	---	---	---	---
QuickServiceRestaurant_Small	0.6	---	---	---	---	---	---	---	0.7	---	---	---	---	---	---	---
RetailStandalone_Large	0.4	0.4	1.2	1.2	1.0	1.2	1.2	1.0	0.5	0.5	1.3	1.2	1.0	1.3	1.2	1.0
RetailStandalone_Medium	0.4	0.4	---	---	---	---	---	---	0.4	0.4	---	---	---	---	---	---
RetailStandalone_Small	0.6	---	---	---	---	---	---	---	0.7	---	---	---	---	---	---	---
RetailStripmall_Large	0.6	0.6	1.8	1.8	---	1.8	1.8	---	0.7	0.7	1.9	1.9	---	1.9	1.9	---
RetailStripmall_Medium	0.6	0.6	---	---	---	---	---	---	0.6	0.6	---	---	---	---	---	---
RetailStripmall_Small	0.8	---	---	---	---	---	---	---	0.9	---	---	---	---	---	---	---
Warehouse_Large	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Warehouse_Medium	0.1	0.1	---	---	---	---	---	---	0.2	0.2	---	---	---	---	---	---
Warehouse_Small	0.2	---	---	---	---	---	---	---	0.3	---	---	---	---	---	---	---

In Arizona, the NLC and NLC+PL measures fail in almost all building types owing to primarily lower avoided costs and benefits in the SCT. However, most NLC Replacement scenario measure permutations with HVAC integration pass the SCT in all building types. While some additional NLC+HVAC measures fail the UCT, most permutations remain cost-effective. As in the Connecticut data a notable exception is the Warehouse building type where many measures fail cost-effectiveness owing to low lighting and HVAC end-use energy intensities in the underlying ComStock data.

As an illustrative comparison of the upper boundary of the incentive costs to capture the NLC potential relative to what representative programs—those programs that include the promotion of NLC measures—are currently paying to achieve savings in the C&I sector,

Table 14 below shows the full incremental cost by NLC measure per unit savings and the planned 2023 incentives per unit savings for representative commercial efficiency programs filed in Arizona. To facilitate comparison, savings from electric energy, natural gas, and delivered fuels are aggregated into savings in site MMBtus. This implies that offering incentives in Arizona that cover the full incremental costs of NLC measures would result in incentive dollars per site MMBtu savings at levels:

- With HVAC integration: more than 300% higher than the average cost of representative existing programs *(as shown in the "% Change" column, Rows 3 to 8 and 11 to 16)*,
- Without HVAC integration: 1200 to 1900% more expensive than representative existing programs, *(as shown in Rows 1, 2, 9, and 10).*

These large increases relative to representative Arizona programs are driven by the very low dollars per unit savings offered by those programs.

Table 14: Estimated Incremental Cost per Site MMBtu vs. Arizona Program Incentives

Row	Measure	*Incremental* Cost ($) / Site MMBtu Saved	AZ Program Incentive ($) / Site MMBtu Saved	% Change
1	NLC_All	$320	$24*	1222%
2	NLC+DR_All	$320		1222%
3	NLC+HVAC_E	$117		381%
4	NLC+HVAC_G	$105		335%
5	NLC+HVAC_O	$114		369%
6	NLC+HVAC+DR_E	$117		381%
7	NLC+HVAC+DR_G	$105		335%
8	NLC+HVAC+DR_O	$114		369%
9	NLC+PL_All	$483		1895%
10	NLC+PL+DR_All	$483		1895%
11	NLC+PL+HVAC_E	$134		453%
12	NLC+PL+HVAC_G	$122		402%
13	NLC+PL+HVAC_O	$143		488%
14	NLC+PL+HVAC+DR_E	$134		453%
15	NLC+PL+HVAC+DR_G	$122		402%
16	NLC+PL+HVAC+DR_O	$143		488%

*Source: APS 2022a. Assumes savings and incentive budgets from the "New Construction and Major Renovation" program.

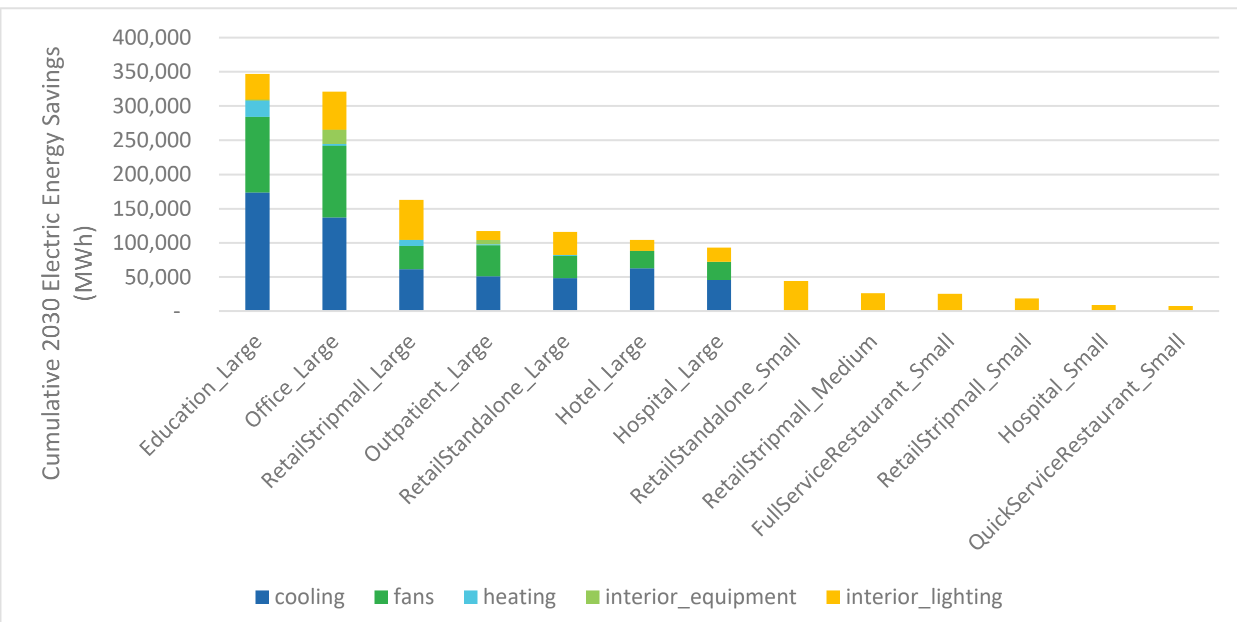


Figure 7 through Figure 12

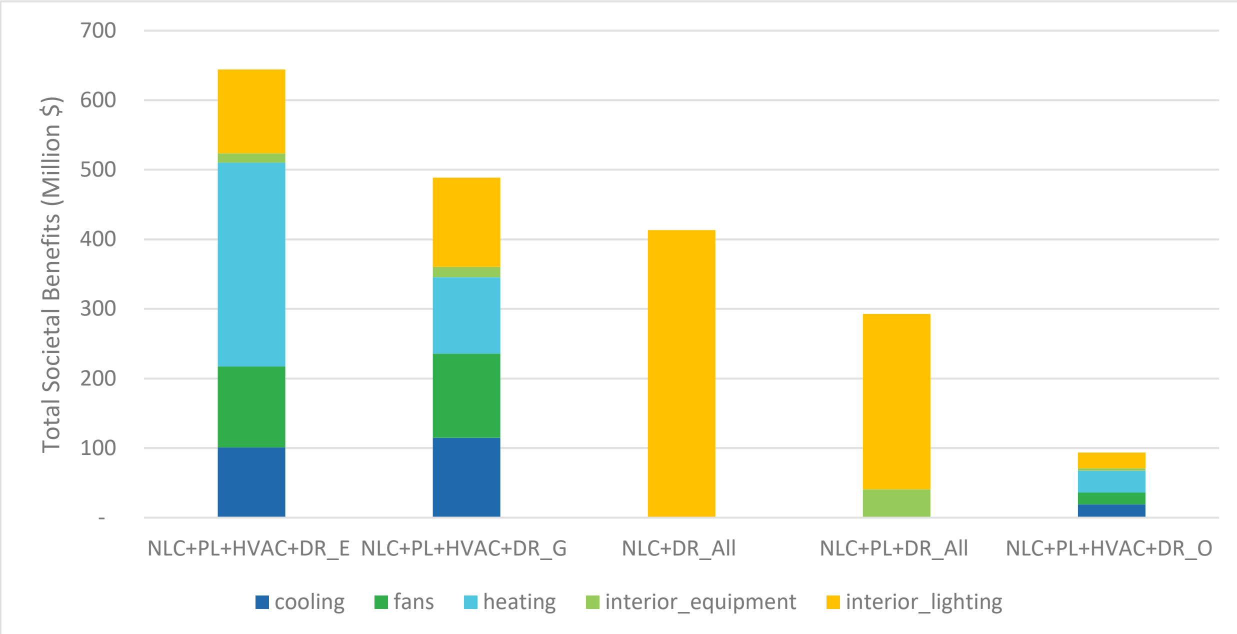


Figure 6 below present the electric savings, demand savings, natural gas savings, other fuel savings, and societal benefits and costs associated with the economic potential for the NLC Replacement scenario in Arizona.

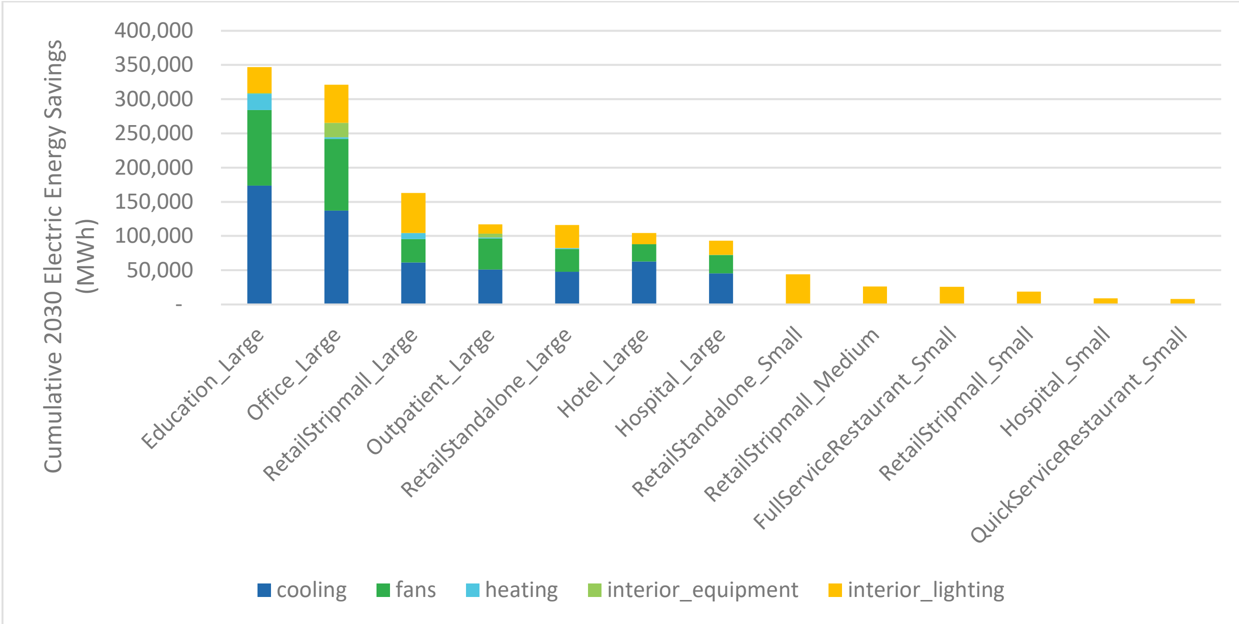


Figure 7: Economic Potential, Cumulative 2030 Electric Savings (MWh) by Building Type and End-Use, NLC Replacement Scenario, Arizona

For reference, the maximum value on the y-axis in

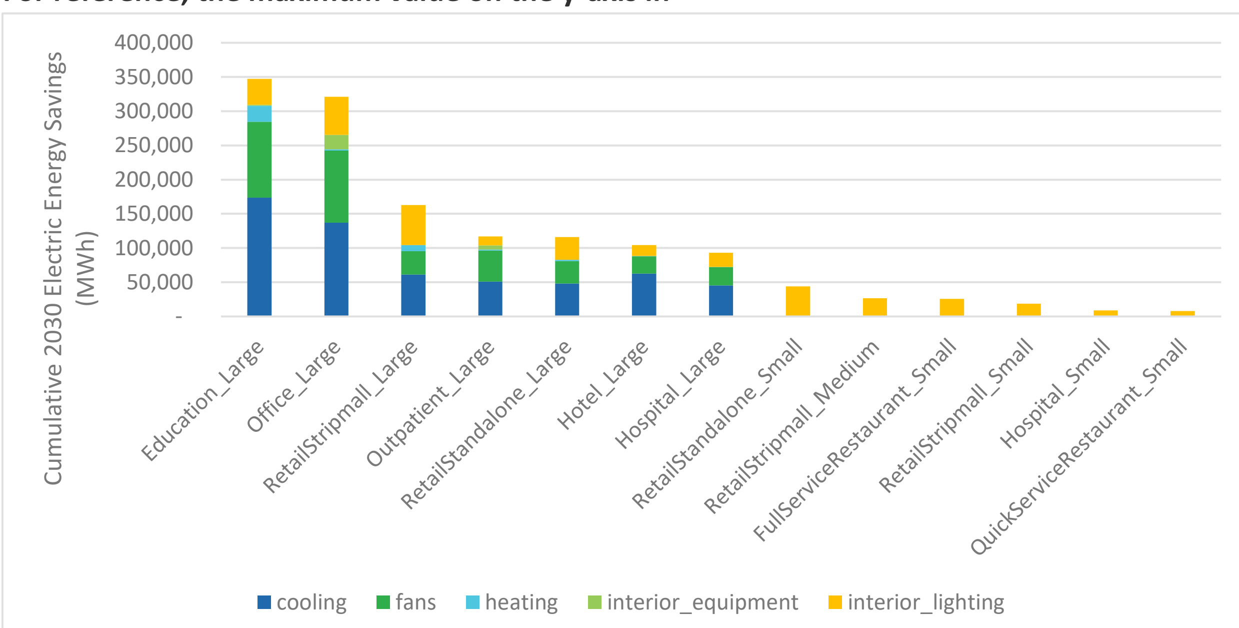


Figure 7 (400,000 MWh) is approximately 1.4% of 2020 Arizona commercial electric sales.

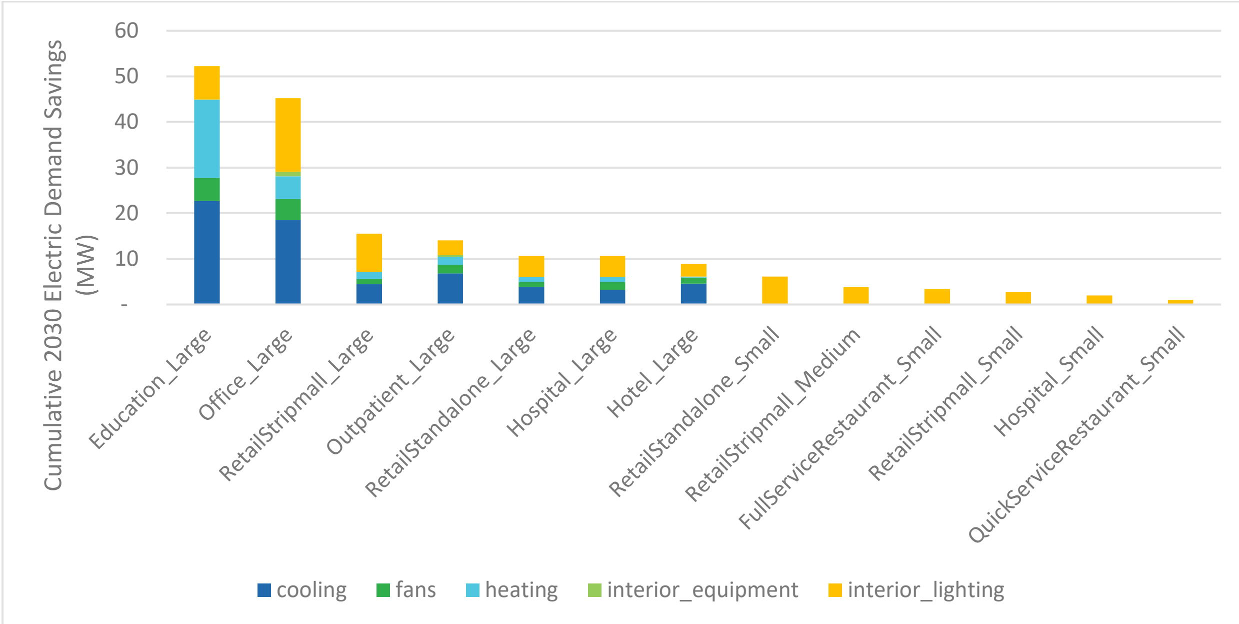


Figure 8: Economic Potential, Cumulative 2030 Electric Summer Peak Demand Savings (MW) by Building Type and End-Use, NLC Replacement Scenario, Arizona

For reference, the maximum value on the y-axis in

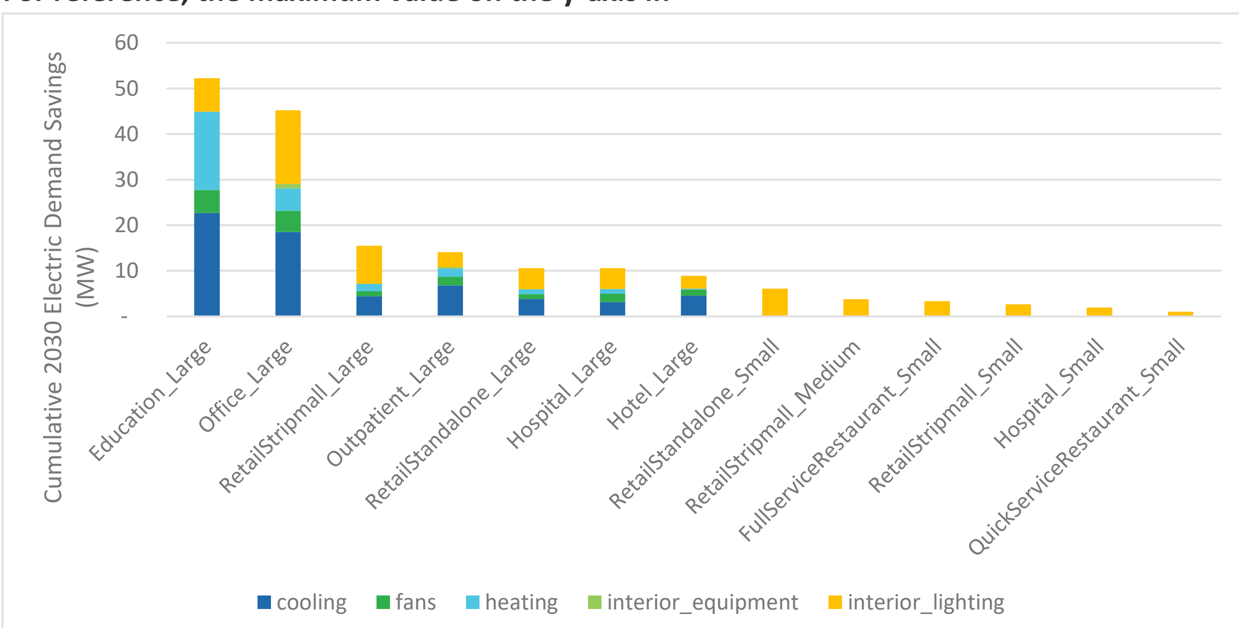


Figure 8 (60 MW) is approximately 0.2% of 2020 Arizona net summer capacity.

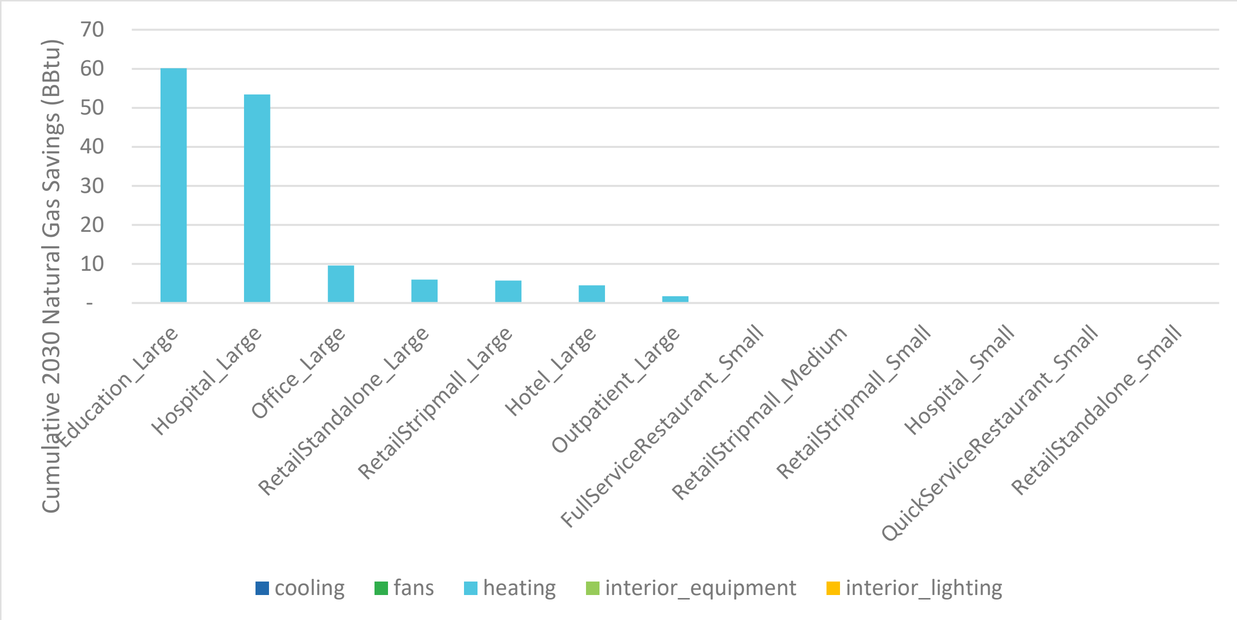


Figure 9: Economic Potential, Cumulative 2030 Natural Gas Savings (BBtu) by Building Type and End-Use, NLC Replacement Scenario, Arizona

For reference, the maximum value on the y-axis in

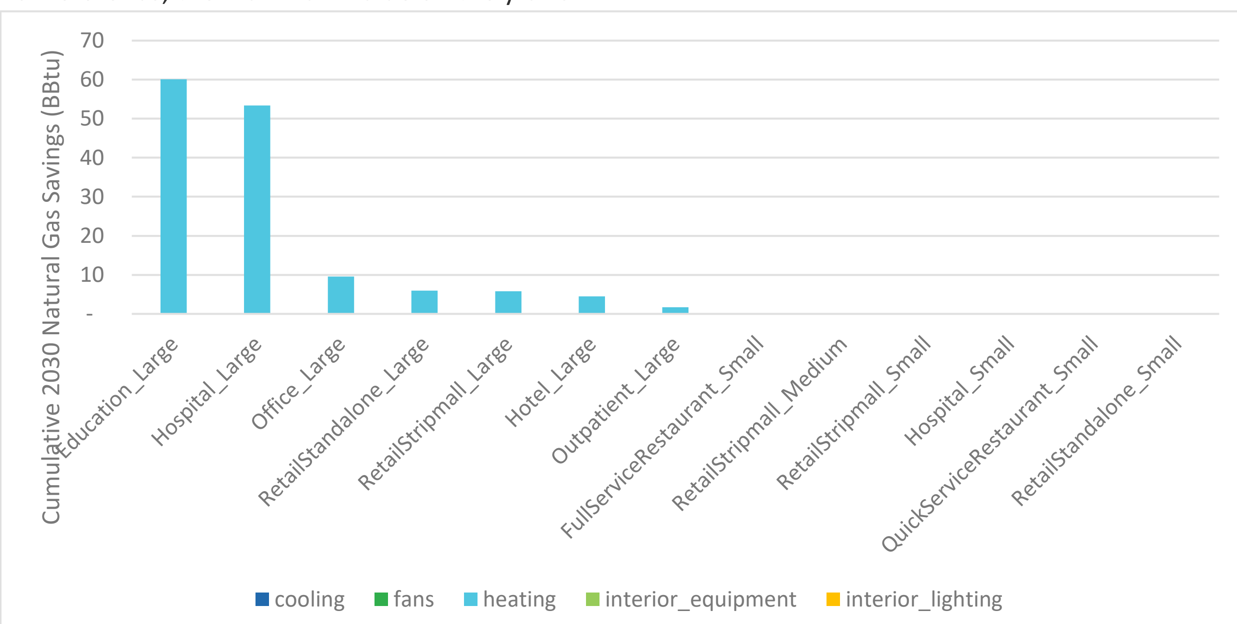


Figure 9

Figure 2 (70 BBtu) is approximately 0.2% of 2020 Arizona commercial natural gas sales.

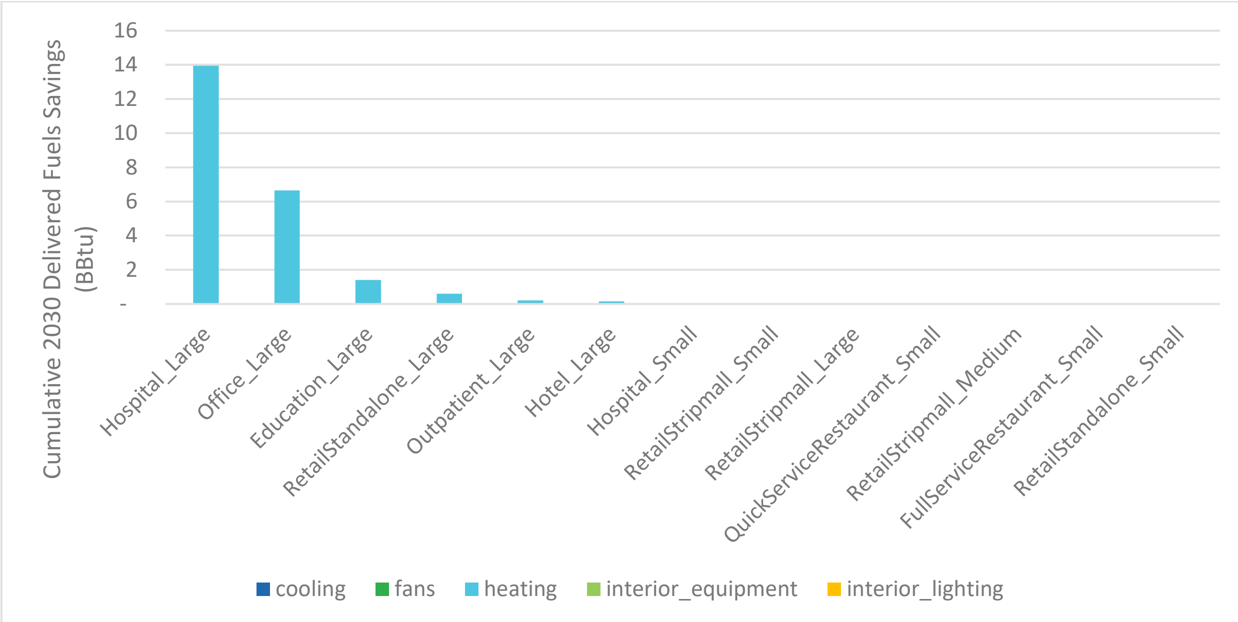


Figure 10: Economic Potential, Cumulative 2030 Delivered Fuels Savings (BBtu) by Building Type and End-Use, NLC Replacement Scenario, Arizona

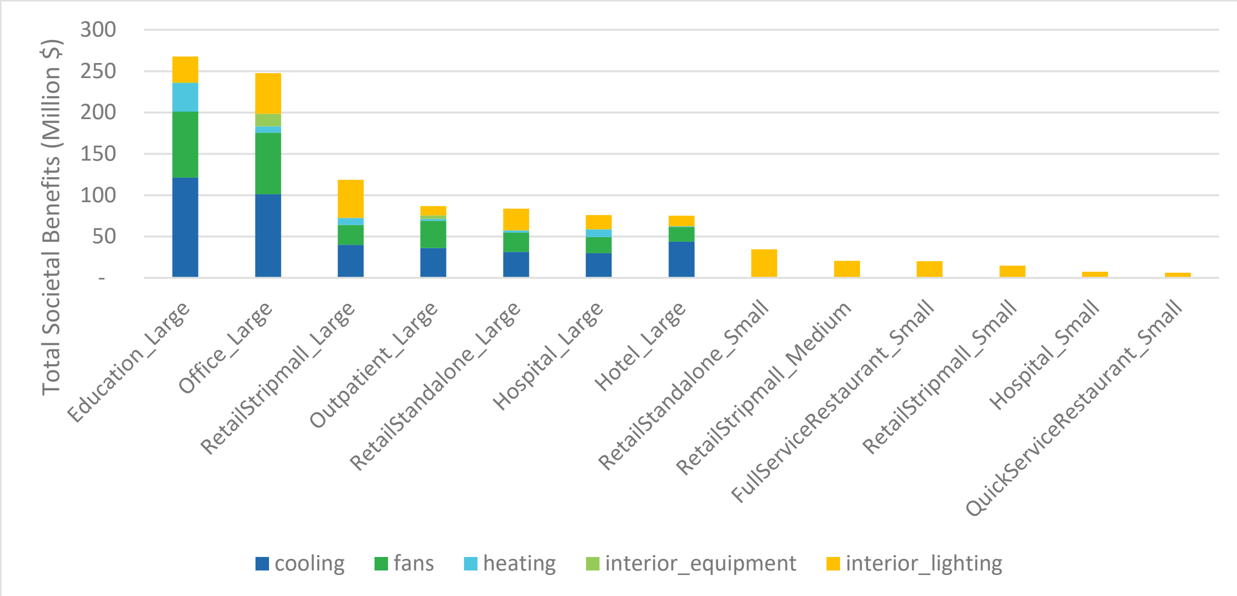


Figure 11: Economic Potential, Total Societal Benefits by Building Type and End-Use, NLC Replacement Scenario, Arizona

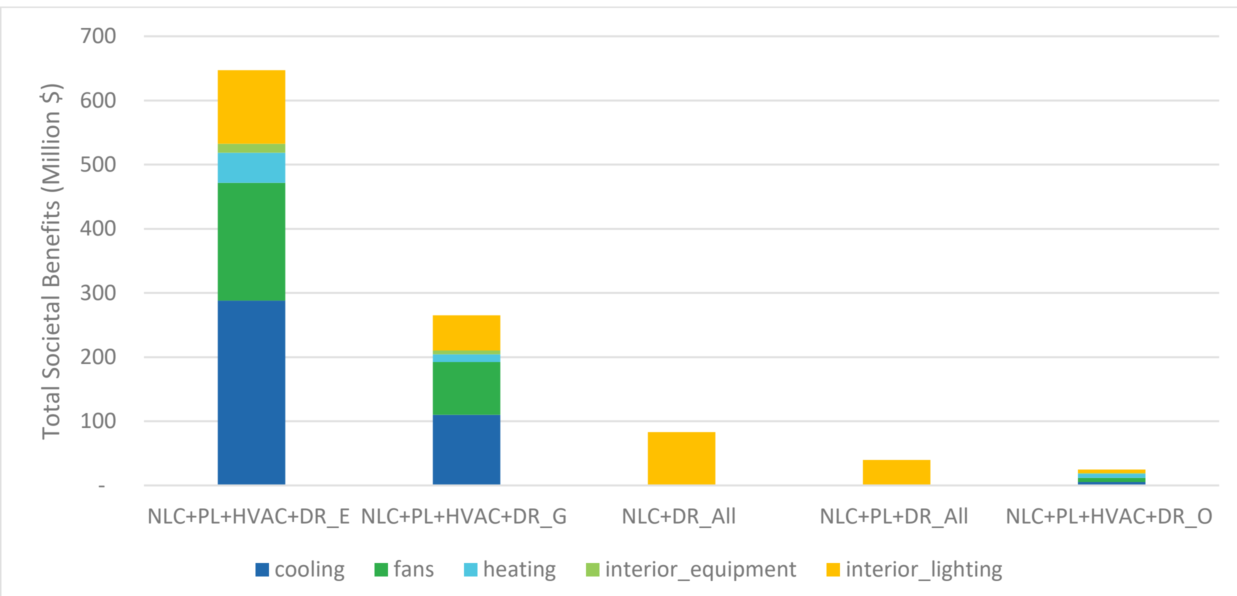


Figure 12: Economic Potential, Total Societal Benefits by Measure and End-Use, NLC Replacement Scenario, Arizona

DISCUSSION

KEY FINDINGS

This analysis finds significant cost-effective energy savings potential for NLC systems and demonstrates that most NLC systems pass the Societal Cost Test, even when assessing the incremental costs and lighting energy savings of the controls alone, in jurisdictions with favorable avoided costs. For the "NLC Replacement Scenario," in Arizona, measures assessing lighting savings alone only pass the cost-effectiveness screening in building types with the highest interior lighting end-use energy intensities such as retail and quick service restaurants. Further, integrating plug load controls with NLC systems almost universally fails the cost-effectiveness hurdle; in most cases plug load integration even reduces the cost-effectiveness of the measure owing to high costs of equipment and configuration, versus modest energy savings. While plug loads are a significant portion of the total electric energy use as modeled in ComStock, much of this load may not be appropriate for automatic control. Some equipment may already have dedicated retrofit plug load controls (e.g., vending machine controls), and some equipment may already have power management features that reduce idle energy use to very low levels. While integrated plug load control may eliminate these loads, they represent low savings opportunities relative to the costs of equipment and labor to achieve integration.

When NLCs are integrated with HVAC systems to enable cost-efficient control of heating, cooling, and ventilation loads, NLC measures are generally cost-effective from the societal perspective in both jurisdictions assessed. These HVAC savings effectively "unlock" the significant technical potential for lighting end-use energy savings which is otherwise not cost-effective. Potential savings are highest in large offices, retail, and health facilities and other buildings with high energy-use intensity.

The findings from Investigation of "Controls-Ready Replacement" scenario are similar to those of the "NLC Replacement" scenario, but savings are realized later in the analysis period. In spite of increased equipment and labor costs and delayed realization of savings, most Controls-Ready Replacement measures pass the Societal Cost Test where similar NLC Replacement measures are also cost-effective.

For both scenarios, this analysis demonstrates that the incentive costs to achieve the identified potential for NLC+HVAC integration measures are not significantly higher than the average incentives per unit savings currently paid by representative energy efficiency programs in CT but are far higher than incentives paid in AZ. In any case, it is clear that business-as-usual incentive levels and program designs are not effectively capturing that potential. Other barriers, in addition to appropriate financial support, stand in the way of widespread NLC adoption.

CHALLENGES

While the economic savings potential of NLCs is large, tapping this potential will require effectively addressing technical, program design, and policy barriers.

Technical Barriers

Integrating NLCs with HVAC and plug loads is still a somewhat nascent practice often requiring site-specific solutions (U.S. DOE 2022). The interoperability of NLCs and other building systems requires specialized knowledge of building operations, technologies, and communication protocols. Successful integration often requires ad hoc development of sequencing to enable the HVAC system to operate efficiently in response to sensor data from lighting systems. Finally, systems must be commissioned to ensure that integration has been successful. In summary, there is not currently a "plug-and-play" solution for integration of lighting and other building systems. On the contrary, integration projects are currently rare, accomplished by highly specialized master system integrators in very large buildings where large energy savings can justify customized work.

For reductions in energy usage and peak demand, the effort to acquire a given amount varies widely. If a large reduction is available from a single building, then a large investment in customized software and hardware may be justified. If only a small reduction is available, then no customization can be supported. Nevertheless, this small reduction may be valuable in aggregate, provided that it is acquired using inexpensive one-size-fits-all software and hardware. At one end of the spectrum, the building automation system of a single 500,000 ft^2 building can be customized to deliver significant reductions in peak demand. At the other end of the spectrum, a single iPhone charger can attain significance in aggregate, when one plug-and-play design is applied to millions of devices (Coren 2023).

There is evidence that the integration market is rapidly evolving and solutions to these barriers are on the horizon. For example, a guidance document recently developed by Slipstream serves as an effective primer to pursuing NLC and building systems integration (Slipstream 2021) and recent research by DLC has identified existing barriers to systems interoperability and highlighted key areas for continued research to bridge these gaps (DLC 2020). Further, efforts to standardize communication protocols are underway and equipment manufacturers are increasingly testing system interoperability.

Program Design Barriers

As noted above, NLC systems have yet to achieve significant adoption in the market. Certain aspects of current energy efficiency program design and strategy may be contributing to this disparity. Programs typically achieve the majority of electric savings from non-NLC lighting systems through simple lamp and fixture replacements and retrofit kits. In many jurisdictions, the majority of lighting savings are achieved through "midstream" or "downstream" programs. With the midstream approach, programs reduce the cost of efficient equipment at the distributor level to ideally achieve cost parity with standard efficiency options. Downstream programs pay rebates directly to end-use customers for purchasing and installing efficient equipment. While these programs do promote NLC lighting equipment, these approaches are not conducive to achieving integration with other building systems. Moreover, even though net-to-gross factors for C&I lighting continue to fall, efficiency programs may be inclined to maximize promotion of these measures in the near term while program claimable savings remain high enough to justify maintaining these measures in program portfolios. In other words, less expensive non-NLC lighting fixtures will compete with NLCs in the near term as these are less costly and easier to implement via mass-market approaches, even if they yield lower net savings per rebated fixture. Effective support of NLC systems and integration will require higher touch program implementation through custom and turnkey programs coupled with effective technical assistance services and trade ally and customer education.

In addition, current prescriptive incentives for LED luminaires with NLCs in the two states analyzed (and more broadly) do not cover enough of the incremental cost to effectively promote the technology. The prescriptive incentives currently offered by CT and AZ for select lighting products are summarized in

Table 1 below.

Table 15: Connecticut and Arizona Lighting Incentive Summary[11]

Measure	Incentive	
	Connecticut (Energize CT 2023)	Arizona (APS 2023)
TLED, 2-ft (UL Type A, B, A/B)	$7/lamp	$3/lamp
TLED, 3-ft (UL Type A, B, A/B)	$7/lamp	$3/lamp
TLED, 4-ft (UL Type A, B, A/B)	$7/lamp	$3/lamp
TLED, 2-ft (UL Type C)	$9/lamp	$3/lamp
TLED, 3-ft (UL Type C)	$11/lamp	$3/lamp
TLED, 4-ft (UL Type C)	$13/lamp	$3/lamp
TLED, 8-ft	$7/lamp	$3/lamp
Interior Recessed Fixture, Troffer, LED 1x4-Fixture	$30/fixture	N/A
Interior Recessed Fixture, Troffer, LED 2x2-Fixture	$30/fixture	N/A
Interior Recessed Fixture, Troffer, LED 2x4-Fixture	$30/fixture	N/A
Interior Recessed Fixture, Troffer, LED 1x4-Fixture w/ Occ Sensor	$65/fixture	N/A
Interior Recessed Fixture, Troffer, LED 2x2-Fixture w/ Occ Sensor	$65/fixture	N/A
Interior Recessed Fixture, Troffer, LED 2x4-Fixture w/ Occ Sensor	$65/fixture	N/A
Interior Recessed Fixture, Troffer, LED 1x4-Fixture w/ LLLC	$70/fixture	N/A
Interior Recessed Fixture, Troffer, LED 2x2-Fixture w/ LLLC	$70/fixture	N/A
Interior Recessed Fixture, Troffer, LED 2x4-Fixture w/ LLLC	$70/fixture	N/A
Network Lighting Controls (Standalone)	$40/fixture	N/A
Demand response on lighting	N/A	$0.10/sq ft
Integrated lighting control	N/A	$0.10/sq ft

While programs in both states offer prescriptive rebates for NLC products, they also continue to offer lucrative incentives for TLED products and LED luminaires without controls. Considering that DLC SSL V5.1 qualified 4-ft TLEDs, the most common linear lamp size, can currently be purchased for less than

[11] This is not an exhaustive list of all available rebates but intended to provide an illustrative summary of relative rebates available for lighting equipment with and without advanced controls. For example, Connecticut also provides enhanced incentives for NLC systems paid per unit energy saved through its Existing Buildings program (see https://energizect.com/sites/default/files/2023-03/C0075%20Existing%20Building%20Cap%20Sheet%202023_FIN.pdf). The Arizona incentives reflect Arizona Public Service's programs.

$5, incentives of this magnitude either nearly cover or exceed the full costs of the equipment. In other words, this type of equipment is often being given away for free.

Further, in CT, rebates for fixtures with LLLC are just $40 higher than for fixtures without controls and only $5 higher than fixtures with integrated occupancy sensors. A 2021 NEEA study found that the incremental costs for an NLC system (utilizing LLLCs) was $90 per fixture—considerably higher than the $40 offered (NEEA 2021). Given the additional technical barriers previously discussed, it is clear that current efficiency programs are not adequately supporting NLCs before even considering integration with other building systems.

Policy Barriers

Several existing policy barriers inhibit the adoption of NLCs in the analysis states and nationwide. Both the primary cost tests employed and the values deemed in technical reference manuals (TRMs) can impede increased deployment of NLCs.

First, the primary cost tests vary by jurisdiction, both in terms of what test is used, what costs and benefits are included in those tests, and at what level of granularity those tests are applied (e.g., portfolio level, sector level, program level, measure level). Further, the established *values* of those benefits vary significantly by jurisdiction. For example, CT includes the wholesale energy and capacity price suppression effects of energy, but AZ does not. While such policy issues are not unique to NLC systems, they cause NLC systems to be deprioritized in program portfolios. Finally, the inclusion and value of any non-energy impacts (NEIs) in the primary cost tests varies considerably. This last point is of particular importance for NLC systems. Recent research has shown that NLC systems with Internet-of-Things ("IoT") capabilities can yield substantial positive NEIs. Several recent studies estimate that such non-energy benefits may dwarf resource benefits. For example, recent DLC-sponsored research indicates that including the net value of NEIs in NLC projects increased the return on investment by 2.3 times relative to considering the energy savings alone (DLC 2023). Similarly, a recent California study researching DR-enabling NLCs concluded that "the existing data strongly suggests that the value from NEBs is in many cases equal to or greater than cost savings derived from energy savings alone" (CEC 2019). Until these benefits are adequately recognized by regulators, NLC systems will continue to be undervalued.

Second, energy efficiency programs are often required to use assumptions documented in so-called technical reference manuals to calculate measure savings. The values of key parameters in TRMs vary considerably from jurisdiction to jurisdiction. As shown by previous research, measure lifetimes, savings factors, and peak demand coincidence factors for NLCs may all be undervalued in many TRMs (ASE, DLC 2019). While leading jurisdictions actively review and update their TRMs, factors used in many jurisdictions may not reflect current research. Further, most jurisdictions use a single value for energy savings that can be achieved as a percentage of baseline consumption for each lighting control type. As these values typically do not vary by building type, using them to estimate potential may obfuscate the relative scale of the opportunity among building types due to varying applicability of controls and occupancy patterns. Future research could investigate the building-type specific savings that could be achieved with NLCs, expanding preliminary research (DLC 2018; NEEA, DLC 2020) to include larger sample sets of various building types.

INVESTIGATION OF FLEXIBLE LOAD MANAGEMENT BENEFITS

This study included a research effort to assess the potential value stream associated with flexible load management enabled by NLCs. Recent efforts by the U.S. DOE and others have alluded to or attempted to quantify the potential for advanced demand response—beyond peak demand reduction—associated with NLC systems.

The U.S. DOE's recent technical report series on grid-interactive efficient buildings (GEBs) found that advanced sensors and controls as part of connected lighting systems may have the capability to perform frequency regulation grid services ("modulation"), but that they are not well-suited for this purpose due to capacity limitations imposed by the need to maintain occupant productivity, comfort, and safety (U.S. DOE 2019b). Further, recent simulation work demonstrated that connected lighting systems in medium office buildings could easily qualify to provide regulation services in the PJM RTO (Wang et. al. 2021). However, the authors also acknowledged that "[t]o meet the requirement of minimum regulation reserve of PJM, buildings need to be aggregated. Requesting and receiving service from numerous CLS in different buildings, of different types, may be challenging…"

Nonetheless, two recent studies had attempted to quantify this potential. A 2019 California Energy Commission study found that, while NLCs could deliver significant regulation services, "…the available revenue from [ISO] markets is always small relative to the system costs and overall energy cost savings. This suggests that the primary value proposition for demand response-enabled networked lighting controls comes from the site-level energy savings that will be realized…" (CEC 2019). A 2019 Brattle Group study investigating the national potential for load flexibility estimated that the benefits associated with frequency regulation were less than 2% of total estimated flexible load management benefits (Brattle Group 2019).[12]

As a final point of reference, ISO-NE's most recent market report shows that the total 2021 regulation market costs were $25 million (ISO-NE 2022). Even if NLCs in CT could provide the entirety of those regulation services, which is not feasible, they would still be small relative to the economic societal benefits already identified ($1.9 billion, see Table 3**Error! Reference source not found.**).

While connected lighting is likely to play a future role in flexible load management as more GEBs are constructed, the monetary benefits of providing grid services beyond peak demand reductions are small relative to the other benefit streams of NLCs. Given this conclusion, this analysis omits grid service benefits beyond peak demand reduction.

POLICY OPTIONS

This analysis supports several policy options that could be employed to maximize the NLC savings potential achieved in the coming years. These options are discussed briefly below.

Policy Option 1: Discontinue incentives for lighting equipment without integrated controls.
Due to the costs and technical limitations associated with retrofitting standard LED lamps and fixtures with NLCs, installation of such equipment represents significant stranded savings. As penetration of LED

[12] While these values are inclusive of NLCs, they reflect the total potential of all flexible load management technologies assessed in the study. However, they serve to illustrate the relative scale of the regulation market benefits.

lighting products has increased, program claimable savings have dropped due to increasing free-ridership.[13] Given these increasing Net to Gross (NTG) values, programs should consider discontinuing promotion of lighting systems without NLCs, in order to capture the higher net savings available from NLC lighting products. Recent program evaluations have highlighted the importance of promoting LED luminaires with advanced controls at the time of sale (CTEEB 2022, DNC 2021b), and ongoing evaluation work in CT suggests that promoting LED luminaires without controls via upstream programs may no longer be viable due to extremely low NTG values. However, for reasons previously discussed, efficiency programs that are still able to promote them may be resistant to discontinue promotion of non-NLC lamps and luminaires, even as NTG values fall.

Policy Option 2: Require that all incentivized lighting systems are "controls ready."
This analysis demonstrates that controls-ready fixtures are cost-effective *if* these fixtures are eventually retrofitted with NLCs and integrated with HVAC systems. Due to the costs and technical limitations associated with retrofitting standard LED lamps and fixtures with NLCs, installation of such equipment represents significant stranded savings. Requiring that efficiency programs incentivize only "controls ready" luminaires could future-proof equipment, leaving open the possibility of capturing these savings at a future date. Further, as system interoperability issues are resolved, integration solutions become more standardized, and market actors become more experienced with integration practices, costs of both controls-ready equipment and the equipment and labor costs associated with the eventual integration may fall over time.

Policy Option 3: Increase incentives for lighting systems with networked lighting controls.
The analysis demonstrates that NLCs, when integrated with HVAC systems, generally pass the Utility Cost Test even when offering incentives that cover 100 percent of the incremental equipment and labor costs relative to non-NLC light fixtures. While efficiency programs typically do provide increased incentives for LED luminaires with NLCs, current incentive levels are not effectively capturing the savings potential. This suggests that incentives can and should be increased to support the adoption of NLCs and building systems integration.

[13] Free riders are customers who would have installed the program measure or equipment even without the financial incentive or other support provided by the program.

REGULATORY PLANNING FOR A DIGITAL FUTURE

On the current path of NLC adoption as projected by the U.S. DOE (shown in light blue in

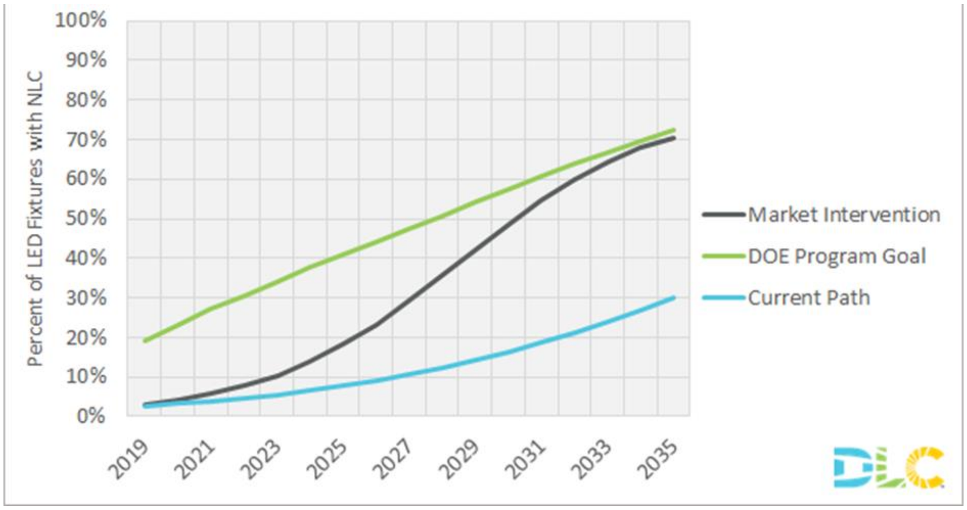
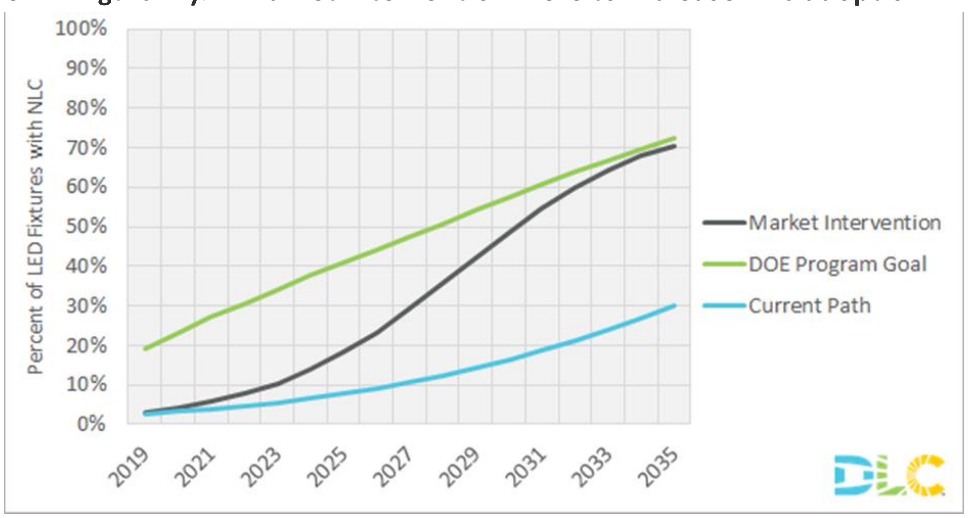


Figure 13), the lighting retrofit market is expected to saturate in NLC adoption by 2030 (shown in light green in Figure 14), because of higher penetration rates for NLC combined with less frequent lighting retrofits. Beyond that point of market saturation, the NLC market will only grow if new NLC equipment is installed in retrofit projects to control existing LED lighting (shown in dark green in Figure 14). If market intervention were to increase NLC adoption



(shown in black in

Figure 13) then NLC adoption would saturate even sooner than 2030 (not shown).

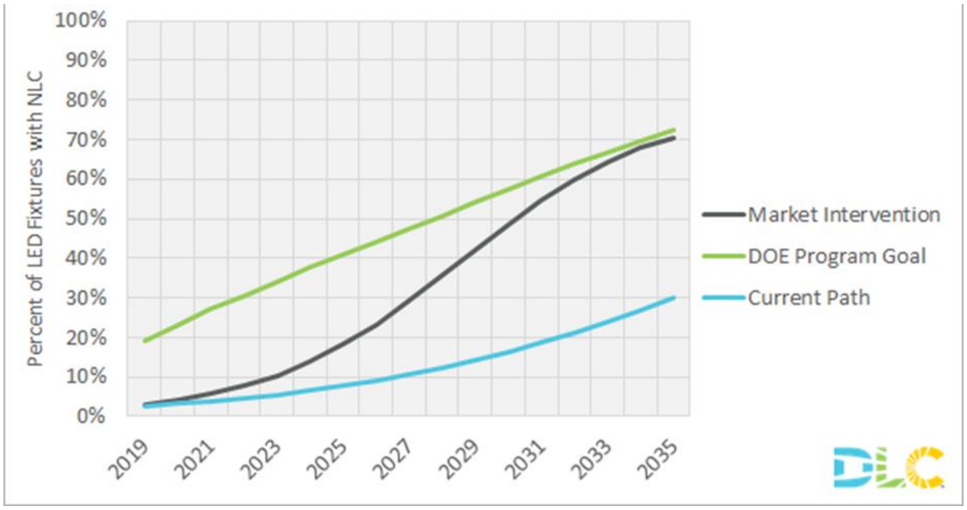


Figure 13: U.S. Non-Residential Indoor NLC Market Adoption

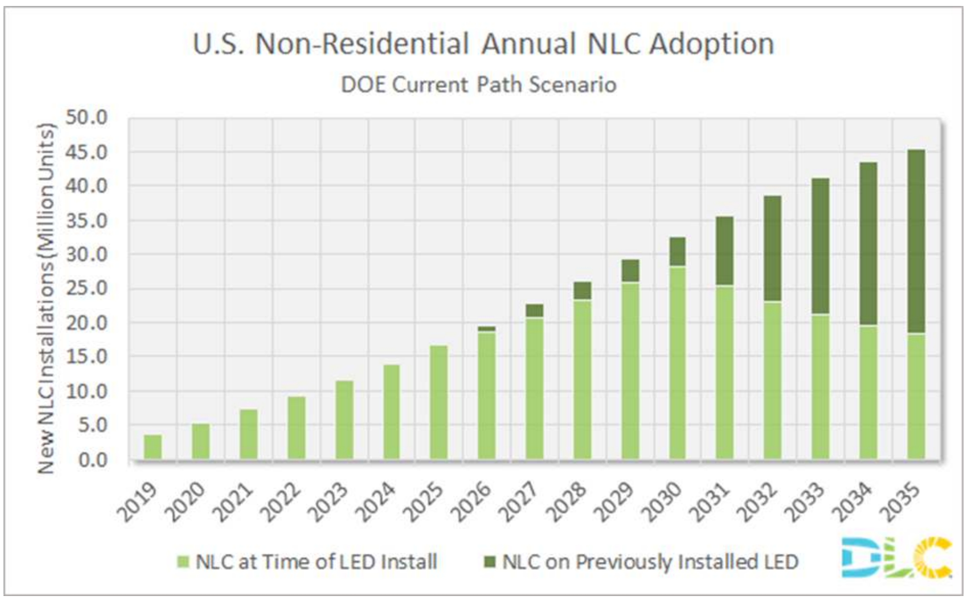


Figure 14: U.S. Non-Residential Annual NLC Adoption

Installing new NLC equipment in retrofit projects to control existing LED lighting will be far less costly and more feasible if drivers in the existing LED lighting are "controls ready," complying with the global D4i digital standard for driver communication. Projects to control noncompliant drivers will be considerably more expensive, due to extra material cost for analog NLC components, plus extra labor cost for the unpredictable customization needed to debug every analog project.

However, in the short term, in North America, analog 0-10V drivers are less expensive than digital D4i drivers. The price differential is mainly driven by volume, with analog drivers comprising most of the current market in North America.

If utilities invested in energy efficiency as a resource on the same 20-year timescale used for other investments in grid stability such as new generation and transmission, then investments in the next 5 years in controls-ready LED luminaires (with D4i drivers) would be seen as a vital foundation for investments over the following 5 to 10 years, to retrofit lighting controls onto those controls-ready LED luminaires. However, to the extent that energy efficiency is evaluated in terms of first-year energy savings and 3-year regulatory requirements, investments over the next 5 years in least-cost LED lamps and luminaires that are not controls-ready, will either lock out future savings from NLC retrofits, or necessitate premature and expensive replacement of still-functioning LED lamps and luminaires that are not controls-ready.

FUTURE WORK

This study estimates the savings potential for NLCs under a variety of scenarios, configurations, and geographies, but some of the data underpinning the assumptions and assumed applications are based on a limited number of case studies. As the market for NLCs and integration with other building systems continues to mature, these estimates could be refined in the future to consider not only updated estimates of savings and costs, but more granular assumptions of existing equipment saturations, historical program participation, and the feasibility of various NLC applications. For example, this study uses the broad assumption that all large buildings with a Specific incentive structures and program designs could be assessed to quantify the achievable potential associated with NLCs. Further, as new value streams emerge, particularly for grid-interactive buildings on a grid increasingly powered by intermittent resources, the conclusions of this study should be revisited.

CONCLUSION

This study demonstrates that the economic energy savings and demand reduction potential associated with NLCs in all jurisdictions assessed is substantial. However, capturing this potential will require addressing program and policy barriers to effectively support and prioritize NLCs over shorter term solutions. Further, continued support from state and utility programs, and market actors is necessary to reduce technical and cost barriers associated with effective NLC installation. Future efforts should focus on strategies and tactics to unlock this potential in the near term before the commercial lighting market is fully saturated with minimally-controlled equipment.

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APPENDIX A:
DETAILED METHODOLOGY AND ASSUMPTIONS

OVERVIEW OF APPROACH

This study uses a combination "top-down/bottom-up" methodology to estimate potential, whereby "top-down" estimates of forecasted energy sales disaggregated by building type and size category are considered with "bottom-up" measure level estimates of costs and savings for each applicable technology. This analysis approach involves several steps:

- Disaggregating estimated energy consumption by fuel, building type, and end use (e.g., interior lighting, cooling).
- Characterizing efficiency measures, including estimating costs, savings, lifetimes, and share of end-use level forecasted energy use applicable to each measure.
- Calculating the potential for each measure and building type combination to estimate the total technical potential.
- Screening each measure / building type combination for cost-effectiveness.
- Removing failing measures from the analysis and accounting for mutually exclusive measures to estimate the total economic potential.

Various measure-specific factors are applied to the forecasted building type and end use sales by year, to derive the potential for each measure for each year in the analysis period. This is shown below in the following central equation expressed in **Figure 15** below.

Measure savings	=	Building type / end use / year kWh sales	x	Applicability	x	Feasibility	x	Turnover	x	Savings factor	x	Penetration

Figure 15: General Potential Analysis Equation

Where:

Applicability is the fraction of the end use energy sales for each building type and year attributable to equipment that could be replaced by the high-efficiency measure.

Feasibility is the fraction of end use sales for which it is technically feasible to install the efficiency measure. Numbers less than 100 percent reflect engineering or other technical barriers that would preclude adoption of the measure.

Turnover is the percentage of existing equipment that will be naturally replaced each year due to failure, remodeling, or renovation.

Savings factor represents the percent savings of the high-efficiency technology, compared to the energy use from new baseline equipment.

Penetrations are the difference between the base case measure penetrations and the measure penetrations that are assumed for the potential. For the technical and economic potential, it is assumed that 100 percent penetration is captured for all measures.

The product of all of these factors is the total potential for each measure permutation. Costs are then derived from the "cost per energy unit saved" for each measure, applied to the total savings produced by the measure.

BUILDING STOCK AND END-USE CHARACTERIZATION

As previously noted, this study leverages the NREL's ComStock data to characterize end-use energy, equipment saturation, and key building characteristics by building type. As ComStock only models approximately 62% of the national total commercial floorspace as determined by the CBECS, floor space for building types that were not modeled in ComStock were mapped to ComStock-modeled building types based on estimated interior lighting end-use energy density and qualitative consideration of the primary building activity as presented in Table 2. Using this mapping, the floor space for non-ComStock-modeled building types was added to the totals for the appropriate ComStock-modeled building types and end-use consumption estimates by fuel were increased proportionally. As part of this process, due to differences in building size definitions, the "SmallOffice," "MediumOffice," and "LargeOffice" buildings types from ComStock were aggregated into a single "Office" building type. Similarly, the ComStock "PrimarySchool" and "SecondarySchool" building types were aggregated into an "Education" building and the ComStock "SmallHotel" and "LargeHotel" building types were aggregated into a "Hotel" building. All other building types were maintained directly from ComStock.

Next, energy consumption and square footage for the resulting set of aggregated ComStock buildings was disaggregated into small (<25,000 ft^2), medium (25,000-50,000 ft^2), and large (>50,000 ft^2) building size categories using data from CBECS 2018. This required first mapping the CBECS "primary building activity plus" (PBAPLUS) building types to the aggregated ComStock building types using the mapping presented in Table 16 below.

Table 16: CBECS PBAPLUS to Aggregated ComStock Building Type Mapping

CBECS PBAPLUS	Modeled in ComStock	Aggregated ComStock Building Type
College/university	No	Education
Convenience store (w/ or w/out gas station)	No	Hospital
Courthouse/probation office	No	Outpatient
Dormitory/fraternity/sorority	No	Office
Enclosed mall	No	RetailStripmall
Entertainment/culture	No	Education
Fire station/police station	No	Education
Grocery store/food market	No	Hospital
Laboratory	No	Outpatient
Library	No	Warehouse
Mixed-use office	No	Office
Nursing home/assisted living	No	Hospital
Other	No	Outpatient
Other classroom education	No	Education
Other food service	No	Education

CBECS PBAPLUS	Modeled in ComStock	Aggregated ComStock Building Type
Other lodging	No	Hotel
Other public assembly	No	Education
Other public order and safety	No	RetailStandalone
Other service	No	RetailStandalone
Post office/postal center	No	RetailStandalone
Preschool/daycare	No	Education
Recreation	No	Education
Refrigerated warehouse	No	Warehouse
Religious worship	No	Office
Social/meeting	No	Office
Vacant	No	Office
Vehicle service/repair shop	No	Outpatient
Vehicle storage/maintenance	No	Outpatient
Administrative/professional office	Yes	Office
Bank/other financial	Yes	Office
Clinic/other outpatient health	Yes	Outpatient
Distribution/shipping center	Yes	Warehouse
Elementary school	Yes	Education
Fast food	Yes	QuickServiceRestaurant
Government office	Yes	Office
High school	Yes	Education
Hospital/inpatient health	Yes	Hospital
Hotel/resort	Yes	Hotel
Medical office (diagnostic)	Yes	Outpatient
Medical office (non-diagnostic)	Yes	Office
Middle/junior high school	Yes	Education
Motel/inn/bed and breakfast	Yes	Hotel
Multi-grade school (any K-12)	Yes	Education
Non-refrigerated warehouse	Yes	Warehouse
Other office	Yes	Office
Other retail	Yes	RetailStandalone
Public rental storage units	Yes	Warehouse
Restaurant/cafeteria	Yes	FullServiceRestaurant
Retail store	Yes	RetailStandalone
Strip shopping mall	Yes	RetailStripmall

Using this mapping, the CBECS microdata was used to distribute the aggregated ComStock building types into size categories using the New England census division data for Connecticut and the Mountain census division data for Arizona.

Finally, adjustments to the ComStock interior lighting end-use energy consumption estimates were made to reflect changes in lighting energy intensity between 2018, the building stock vintage reflected by the ComStock data, and 2023, the first year of the analysis period. Leveraging data published in NREL 2023, lighting technology generation distributions were interpolated for 2023 by aggregated ComStock building type. These distributions were then applied by the average lighting power density by lighting generation to develop weighted average lighting power density estimates by aggregate ComStock building type. Calculating the ratio of the weighted average lighting power densities for 2023 and 2018 yielded multiplicative adjustment factors that were applied to the ComStock interior lighting end-use energy estimates to estimate 2023 consumption. The resulting adjustment factors are shown in Table 17 below.

Table 17: ComStock Interior Lighting End-Use Energy Adjustment Factors

Aggregated ComStock Building Type	Interior Lighting End-Use Energy Adjustment Factor
FullServiceRestaurant	74%
QuickServiceRestaurant	75%
RetailStripmall	81%
RetailStandalone	80%
Office	83%
Warehouse	81%
Hospital	79%
Outpatient	81%
Education	88%
Hotel	69%

The resulting square footage and end-use energy disaggregation by fuel are presented in Table 18: Connecticut Floorspace and End-Use Energy Disaggregation by Building Type & Size

Fuel	Floorspace	Electric	Electric	Electric	Electric	Electric	Natural Gas	Other Fuel
End Use	-	Interior Lighting	Cooling	Space Heating	Ventilation	Plug Loads	Space Heating	Space Heating
Unit	Million ft2	GWh	GWh	GWh	GWh	GWh	BBtu	BBtu
Education_Small	69	97	132	316	184	52	1,207	82
FullServiceRestaurant_Small	15	51	102	143	198	222	538	130
Hospital_Small	0	1	2	-	1	2	32	-
Hotel_Small	14	19	42	16	23	76	23	-
Office_Small	136	213	263	219	319	600	879	250
Outpatient_Small	79	153	223	107	361	566	976	101
QuickServiceRestaurant_Small	2	9	17	31	34	50	60	8
RetailStandalone_Small	69	214	160	215	232	106	755	263
RetailStripmall_Small	-	-	-	-	-	-	-	-
Warehouse_Small	67	67	16	47	22	189	226	37
Education_Medium	7	9	13	31	18	5	118	8
FullServiceRestaurant_Medium	-	-	-	-	-	-	-	-
Hospital_Medium	1	3	7	-	4	8	131	-
Hotel_Medium	-	-	-	-	-	-	-	-
Office_Medium	42	65	81	67	98	185	270	77
Outpatient_Medium	38	73	107	51	173	272	469	48
QuickServiceRestaurant_Medium	-	-	-	-	-	-	-	-
RetailStandalone_Medium	3	8	6	8	9	4	29	10
RetailStripmall_Medium	-	-	-	-	-	-	-	-
Warehouse_Medium	26	26	6	18	8	73	88	14
Education_Large	90	127	173	414	242	68	1,583	107
FullServiceRestaurant_Large	-	-	-	-	-	-	-	-
Hospital_Large	2	4	11	-	6	12	204	-
Hotel_Large	13	17	38	15	21	70	21	-
Office_Large	130	202	250	208	303	570	835	238
Outpatient_Large	41	78	114	55	185	290	501	52
QuickServiceRestaurant_Large	-	-	-	-	-	-	-	-
RetailStandalone_Large	26	79	59	79	86	39	279	97
RetailStripmall_Large	65	298	245	219	356	330	990	32
Warehouse_Large	40	40	10	28	13	115	137	22

Table 19 and Table 19 for Connecticut and Arizona, respectively.

Table 18: Connecticut Floorspace and End-Use Energy Disaggregation by Building Type & Size

Fuel	Floorspace	Electric	Electric	Electric	Electric	Electric	Natural Gas	Other Fuel
End Use	**-**	**Interior Lighting**	**Cooling**	**Space Heating**	**Ventilation**	**Plug Loads**	**Space Heating**	**Space Heating**
Unit	**Million ft2**	**GWh**	**GWh**	**GWh**	**GWh**	**GWh**	**BBtu**	**BBtu**
Education_Small	69	97	132	316	184	52	1,207	82
FullServiceRestaurant_Small	15	51	102	143	198	222	538	130
Hospital_Small	0	1	2	-	1	2	32	-
Hotel_Small	14	19	42	16	23	76	23	-
Office_Small	136	213	263	219	319	600	879	250
Outpatient_Small	79	153	223	107	361	566	976	101
QuickServiceRestaurant_Small	2	9	17	31	34	50	60	8
RetailStandalone_Small	69	214	160	215	232	106	755	263
RetailStripmall_Small	-	-	-	-	-	-	-	-
Warehouse_Small	67	67	16	47	22	189	226	37
Education_Medium	7	9	13	31	18	5	118	8
FullServiceRestaurant_Medium	-	-	-	-	-	-	-	-
Hospital_Medium	1	3	7	-	4	8	131	-
Hotel_Medium	-	-	-	-	-	-	-	-
Office_Medium	42	65	81	67	98	185	270	77
Outpatient_Medium	38	73	107	51	173	272	469	48
QuickServiceRestaurant_Medium	-	-	-	-	-	-	-	-
RetailStandalone_Medium	3	8	6	8	9	4	29	10
RetailStripmall_Medium	-	-	-	-	-	-	-	-
Warehouse_Medium	26	26	6	18	8	73	88	14
Education_Large	90	127	173	414	242	68	1,583	107
FullServiceRestaurant_Large	-	-	-	-	-	-	-	-
Hospital_Large	2	4	11	-	6	12	204	-
Hotel_Large	13	17	38	15	21	70	21	-
Office_Large	130	202	250	208	303	570	835	238
Outpatient_Large	41	78	114	55	185	290	501	52
QuickServiceRestaurant_Large	-	-	-	-	-	-	-	-
RetailStandalone_Large	26	79	59	79	86	39	279	97
RetailStripmall_Large	65	298	245	219	356	330	990	32
Warehouse_Large	40	40	10	28	13	115	137	22

Table 19: Arizona Floorspace and End-Use Energy Disaggregation by Building Type and Size

Fuel	Floorspace	Electric	Electric	Electric	Electric	Electric	Natural Gas	Other Fuel
End Use	-	Interior Lighting	Cooling	Space Heating	Ventilation	Plug Loads	Space Heating	Space Heating
Unit	Million ft2	GWh	GWh	GWh	GWh	GWh	BBtu	BBtu
Education_Small	76	103	483	66	308	64	167	4
FullServiceRestaurant_Small	26	81	423	45	386	353	91	16
Hospital_Small	13	35	94	4	55	97	111	29
Hotel_Small	8	14	54	0	22	42	4	0
Office_Small	163	256	845	13	648	786	59	41
Outpatient_Small	269	518	1,820	45	1,621	1,982	61	7
QuickServiceRestaurant_Small	7	26	120	14	117	160	12	-
RetailStandalone_Small	43	138	299	10	205	63	37	4
RetailStripmall_Small	17	74	159	24	88	78	15	-
Warehouse_Small	99	118	179	2	106	281	5	0
Education_Medium	47	64	298	41	190	39	103	2
FullServiceRestaurant_Medium	-	-	-	-	-	-	-	-
Hospital_Medium	18	47	127	5	74	130	149	39
Hotel_Medium	13	23	89	0	36	70	6	0
Office_Medium	57	89	293	4	225	273	20	14
Outpatient_Medium	29	55	194	5	173	211	6	1
QuickServiceRestaurant_Medium	-	-	-	-	-	-	-	-
RetailStandalone_Medium	9	29	64	2	44	14	8	1
RetailStripmall_Medium	23	104	222	33	124	109	21	-
Warehouse_Medium	36	43	66	1	39	104	2	0
Education_Large	193	262	1,225	168	783	162	425	10
FullServiceRestaurant_Large	-	-	-	-	-	-	-	-
Hospital_Large	46	118	321	13	187	329	377	99
Hotel_Large	65	116	443	2	179	350	32	1
Office_Large	187	293	968	14	742	900	68	47
Outpatient_Large	53	103	360	9	321	393	12	1
QuickServiceRestaurant_Large	-	-	-	-	-	-	-	-
RetailStandalone_Large	49	156	339	12	233	72	42	4
RetailStripmall_Large	45	202	433	64	241	213	41	-
Warehouse_Large	94	111	170	2	100	266	4	0

MARKETS MODELED AND MEASURE INPUTS

As previously described, this analysis explores two hypothetical scenarios. The NLC Replacement scenario assumes an LED luminaire with NLCs is installed at the time a lighting system replacement was already planned. The Controls-Ready Replacement scenario assumes that LED luminaires designed to accommodate the future addition of NLCs are installed at the time of planned replacement, then retrofitted with NLCs after five years. In both cases, the baseline measure is assumed to be an LED luminaire without networked lighting controls. Aside from the delayed realization of savings and higher incremental costs for the Controls-Ready Replacement scenario measures, the two scenarios use equivalent measure inputs.

Measure applicability is presented in general terms in

Table 1 above. Interior lighting end-use savings were assumed to be applicable to 100% of lighting consumption. Applicability for HVAC integration (i.e., cooling, heating, and ventilation end-uses) is assumed to be 63% in buildings larger than 50,000 ft^2 consistent with the estimated fraction of floorspace in this building size with a BAS controlling heating and cooling nationally (U.S. EIA 2022). Plug load (i.e., interior equipment) end-use savings were assumed to be applicable to all interior equipment end-use energy consumption in office space types within the ComStock-modeled buildings. Using equipment power density estimates by space type and space type distributions by building type (NREL 2023), the applicability factors in Table 20 were developed. Note: the applicability factors used in the analysis also considered space heating fuel type, but that aspect of the analysis has been omitted from the discussion for clarity.

Table 20: Plug Load End-Use Applicability by Aggregated ComStock Building Type

Aggregated ComStock Building Type	Applicability
FullServiceRestaurant	0.00
Hospital	0.02
Hotel	0.00
Office	0.20
Outpatient	0.13
Education	0.06
QuickServiceRestaurant	0.00
RetailStandalone	0.00
Education	0.02
Hotel	0.02
RetailStripmall	0.00
Warehouse	0.19

Feasibility for lighting controls measures impacting the interior lighting end-use were adopted from PNNL 2020 and omit spaces with high sensitivity to occupant satisfaction or have emergency or life safety functions. The feasibility factors by building type (including the building type mapping from the source data) are presented in Table 21 below. Feasibility for all other impacted end-uses was assumed to be 100%.

Table 21: NLC Measure, Lighting End-Use, Feasibility by Building Type

Building Type_Size	DOE Prototype Building Model	Feasibility
Education_Small	Primary School	0.96
FullServiceRestaurant_Small	Restaurant - Sit down	0.91
Hospital_Small	Hospital	0.78
Hotel_Small	Small Hotel	0.28
Office_Small	Small office	0.81
Outpatient_Small	Outpatient	0.60

Building Type_Size	DOE Prototype Building Model	Feasibility
QuickServiceRestaurant_Small	Restaurant - Fast Food	0.88
RetailStandalone_Small	Standalone Retail	0.99
RetailStripmall_Small	Strip Mall	0.79
Warehouse_Small	Warehouse	0.99
Education_Medium	Primary School	0.96
FullServiceRestaurant_Medium	Restaurant - Sit down	0.91
Hospital_Medium	Hospital	0.78
Hotel_Medium	Small Hotel	0.28
Office_Medium	Medium office	0.86
Outpatient_Medium	Outpatient	0.60
QuickServiceRestaurant_Medium	Restaurant - Fast Food	0.88
RetailStandalone_Medium	Standalone Retail	0.99
RetailStripmall_Medium	Strip Mall	0.79
Warehouse_Medium	Warehouse	0.99
Education_Large	Secondary School	0.73
FullServiceRestaurant_Large	Restaurant - Sit down	0.91
Hospital_Large	Hospital	0.78
Hotel_Large	Large Hotel	0.55
Office_Large	Large office	0.90
Outpatient_Large	Outpatient	0.60
QuickServiceRestaurant_Large	Restaurant - Fast Food	0.88
RetailStandalone_Large	Standalone Retail	0.99
RetailStripmall_Large	Strip Mall	0.79
Warehouse_Large	Warehouse	0.99

The analysis assumes an existing lighting system turnover rate of 10 years, consistent with assumptions in ComStock (NREL 2023).

The assumed savings factors by measure are presented in Table 22 below.

Table 22: Savings Factors by Measure and End-Use

Measure ID	Interior Lighting	Plug Loads (PNNL 2022)	Heating, Ventilation, Cooling (PNNL 2022)
(CR+)NLC	See Table 23	-	-
(CR+)NLC+PL	See Table 23	25%	-
(CR+)NLC+HVAC	See Table 23	-	30%
(CR+)NLC+PL+HVAC	See Table 23	25%	30%
(CR+)NLC+DR	See Table 23	-	-
(CR+)NLC+PL+DR	See Table 23	25%	-

Measure ID	Interior Lighting	Plug Loads (PNNL 2022)	Heating, Ventilation, Cooling (PNNL 2022)
(CR+)NLC+HVAC+DR	See Table 23	-	30%
(CR+)NLC+PL+HVAC+DR	See Table 23	25%	30%

Because this study seeks to estimate the incremental savings opportunities from NLCs and not the savings associated with improved lighting efficacy, the analysis assumes that baseline interior lighting end-use energy consumption will be reduced at the time of turnover prior to consideration of the 49% savings for controls. Data from NREL 2023 is leveraged to estimate the reduced lighting loads if all lighting were upgraded to the distribution weighted average lighting power density of "gen3" to "gen8" lighting technologies at the time of turnover. The effective percent savings factors by building type are presented in Table 23 below.

Table 23: Effective Interior Lighting Savings Factors (All Measures) by Aggregated ComStock Building Type

Building Type	Interior Lighting (NEEA, DLC 2020)
FullServiceRestaurant	31%
QuickServiceRestaurant	32%
RetailStripmall	37%
RetailStandalone	37%
Office	39%
Warehouse	39%
Hospital	35%
Outpatient	38%
Education	43%
Hotel	26%

All measures assume a lifetime of 12.2 years (Energize CT 2022).

For the NLC Replacement scenario measures, incremental costs associated with the NLCs were adapted from NEEA 2021 assuming the "Clever" system, adopting the nomenclature from the source, for small buildings and "Smart" systems for medium and large buildings. For NLCs in the Controls-Ready Replacement scenario, an initial cost of $0.29 per ft^2 ($25 per fixture) is assumed to account for the incremental D4i Driver + Zhaga socket cost. The delayed retrofit equipment cost for the lighting controls assumes the difference in the incremental costs from NEEA 2021 and the aforementioned $0.29/$ft^2$ plus an assumed labor cost of $0.32/$ft^2$, $0.24/$ft^2$, and $0.19/$ft^2$ for small, medium, and large buildings, respectively, adapted from CEC 2019.

In both scenarios, HVAC and plug load integrations costs were adapted from PNNL 2022, but in the Controls-Ready Replacement scenario, the integration costs are discounted an additional five years to account for the assumed delay between light fixture installation and controls retrofit.

The resulting measure costs per unit energy savings are presented in Table 24 and Table 25 below.

Table 24: Connecticut Measure Costs Components per Unit Energy Savings

Building Type_Size	NLC Repl.: Lighting controls costs per kWh lighting savings	NLC Repl.: Plug load integration costs per kWh interior equip. savings	NLC Repl.: HVAC integration costs per kWh cooling savings	Controls-Ready Repl.: Lighting controls costs per kWh lighting end-use energy savings	Controls-Ready Repl.: Plug load integration costs per kWh interior equip. savings	Controls-Ready Repl.: HVAC integration costs per kWh cooling savings
Education_Small	$ 0.96	$ 2.61	$ 1.01	$ 1.50	$ 2.61	$ 1.01
FullServiceRestaurant_Small	$ 0.56	$ 2.61	$ 0.29	$ 0.87	$ 2.61	$ 0.29
Hospital_Small	$ 0.62	$ 2.61	$ 0.30	$ 0.97	$ 2.61	$ 0.30
Hotel_Small	$ 1.66	$ 2.61	$ 0.66	$ 2.61	$ 2.61	$ 0.66
Office_Small	$ 0.96	$ 2.61	$ 1.00	$ 1.50	$ 2.61	$ 1.00
Outpatient_Small	$ 0.80	$ 2.61	$ 0.69	$ 1.25	$ 2.61	$ 0.69
QuickServiceRestaurant_Small	$ 0.45	$ 2.61	$ 0.25	$ 0.70	$ 2.61	$ 0.25
RetailStandalone_Small	$ 0.50	$ 2.61	$ 0.84	$ 0.79	$ 2.61	$ 0.84
RetailStripmall_Small	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
Warehouse_Small	$ 1.47	$ 2.61	$ 8.15	$ 2.31	$ 2.61	$ 8.15
Education_Medium	$ 1.76	$ 2.61	$ 1.01	$ 2.18	$ 2.61	$ 1.01
FullServiceRestaurant_Medium	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
Hospital_Medium	$ 1.13	$ 2.61	$ 0.30	$ 1.40	$ 2.61	$ 0.30
Hotel_Medium	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
Office_Medium	$ 1.75	$ 2.61	$ 1.00	$ 2.18	$ 2.61	$ 1.00
Outpatient_Medium	$ 1.46	$ 2.61	$ 0.69	$ 1.81	$ 2.61	$ 0.69
QuickServiceRestaurant_Medium	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
RetailStandalone_Medium	$ 0.92	$ 2.61	$ 0.84	$ 1.14	$ 2.61	$ 0.84
RetailStripmall_Medium	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
Warehouse_Medium	$ 2.69	$ 2.61	$ 8.15	$ 3.34	$ 2.61	$ 8.15
Education_Large	$ 1.76	$ 2.61	$ 1.01	$ 2.10	$ 2.61	$ 1.01
FullServiceRestaurant_Large	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
Hospital_Large	$ 1.13	$ 2.61	$ 0.30	$ 1.35	$ 2.61	$ 0.30
Hotel_Large	$ 3.05	$ 2.61	$ 0.66	$ 3.65	$ 2.61	$ 0.66
Office_Large	$ 1.75	$ 2.61	$ 1.00	$ 2.10	$ 2.61	$ 1.00
Outpatient_Large	$ 1.46	$ 2.61	$ 0.69	$ 1.75	$ 2.61	$ 0.69
QuickServiceRestaurant_Large	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
RetailStandalone_Large	$ 0.92	$ 2.61	$ 0.84	$ 1.10	$ 2.61	$ 0.84
RetailStripmall_Large	$ 0.63	$ 2.61	$ 0.51	$ 0.75	$ 2.61	$ 0.51
Warehouse_Large	$ 2.69	$ 2.61	$ 8.15	$ 3.22	$ 2.61	$ 8.15

Table 25: Arizona Measure Costs Components per Unit Energy Savings

Building Type_Size	NLC Repl.: Lighting controls costs per kWh lighting savings	NLC Repl.: Plug load integration costs per kWh interior equip. savings	NLC Repl.: HVAC integration costs per kWh cooling savings	Controls-Ready Repl.: Lighting controls costs per kWh lighting end-use energy savings	Controls-Ready Repl.: Plug load integration costs per kWh interior equip. savings	Controls-Ready Repl.: HVAC integration costs per kWh cooling savings
Education_Small	$ 0.99	$ 2.61	$ 0.30	$ 1.68	$ 2.61	$ 0.30
FullServiceRestaurant_Small	$ 0.59	$ 2.61	$ 0.12	$ 1.01	$ 2.61	$ 0.12
Hospital_Small	$ 0.63	$ 2.61	$ 0.28	$ 1.08	$ 2.61	$ 0.28
Hotel_Small	$ 1.24	$ 2.61	$ 0.28	$ 2.11	$ 2.61	$ 0.28
Office_Small	$ 0.95	$ 2.61	$ 0.37	$ 1.62	$ 2.61	$ 0.37
Outpatient_Small	$ 0.80	$ 2.61	$ 0.29	$ 1.36	$ 2.61	$ 0.29
QuickServiceRestaurant_Small	$ 0.47	$ 2.61	$ 0.11	$ 0.80	$ 2.61	$ 0.11
RetailStandalone_Small	$ 0.48	$ 2.61	$ 0.28	$ 0.82	$ 2.61	$ 0.28
RetailStripmall_Small	$ 0.35	$ 2.61	$ 0.20	$ 0.59	$ 2.61	$ 0.20
Warehouse_Small	$ 1.24	$ 2.61	$ 1.07	$ 2.10	$ 2.61	$ 1.07
Education_Medium	$ 1.82	$ 2.61	$ 0.30	$ 2.38	$ 2.61	$ 0.30
FullServiceRestaurant_Medium	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
Hospital_Medium	$ 1.16	$ 2.61	$ 0.28	$ 1.53	$ 2.61	$ 0.28
Hotel_Medium	$ 2.28	$ 2.61	$ 0.28	$ 2.99	$ 2.61	$ 0.28
Office_Medium	$ 1.74	$ 2.61	$ 0.37	$ 2.29	$ 2.61	$ 0.37
Outpatient_Medium	$ 1.46	$ 2.61	$ 0.29	$ 1.92	$ 2.61	$ 0.29
QuickServiceRestaurant_Medium	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
RetailStandalone_Medium	$ 0.89	$ 2.61	$ 0.28	$ 1.16	$ 2.61	$ 0.28
RetailStripmall_Medium	$ 0.64	$ 2.61	$ 0.20	$ 0.84	$ 2.61	$ 0.20
Warehouse_Medium	$ 2.27	$ 2.61	$ 1.07	$ 2.98	$ 2.61	$ 1.07
Education_Large	$ 1.82	$ 2.61	$ 0.30	$ 2.30	$ 2.61	$ 0.30
FullServiceRestaurant_Large	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
Hospital_Large	$ 1.16	$ 2.61	$ 0.28	$ 1.47	$ 2.61	$ 0.28
Hotel_Large	$ 2.28	$ 2.61	$ 0.28	$ 2.89	$ 2.61	$ 0.28
Office_Large	$ 1.74	$ 2.61	$ 0.37	$ 2.21	$ 2.61	$ 0.37
Outpatient_Large	$ 1.46	$ 2.61	$ 0.29	$ 1.85	$ 2.61	$ 0.29
QuickServiceRestaurant_Large	$ -	$ 2.61	$ -	$ -	$ 2.61	$ -
RetailStandalone_Large	$ 0.89	$ 2.61	$ 0.28	$ 1.13	$ 2.61	$ 0.28
RetailStripmall_Large	$ 0.64	$ 2.61	$ 0.20	$ 0.81	$ 2.61	$ 0.20
Warehouse_Large	$ 2.27	$ 2.61	$ 1.07	$ 2.88	$ 2.61	$ 1.07

ECONOMIC POTENTIAL ANALYSIS

Cost-Effectiveness Test

To assess the economic potential, this study uses the Societal Cost Test (SCT) as the primary test. The Societal Cost Test (SCT) indicates whether the benefits of a measure will exceed its costs from the perspective of society as a whole. This test provides the most comprehensive picture of the total impacts of an efficiency measure. The test considers all costs incurred to acquire the measure, including all utility system and all non-utility system costs. This study uses a “winner-take-all” approach which assumes, in cases where two or more measures are mutually exclusive, the measure with the highest savings is assumed to be adopted in all cases.

Measure-level cost effectiveness was examined using both the SCT and the Utility Cost Test (UCT). The UCT indicates whether the benefits of a measure will exceed its costs from the perspective of only the utility system. The UCT considers all benefits and costs that impact the operation of the utility system and the provision of electric and gas services to customers. Note that the UCT applied in this study assumes a combined electric and gas utility test. Table 26 provides the costs and benefits assessed for the SCT and UCT.

Table 26: Benefits and Costs by Cost Test

Monetized Benefits / Costs	Societal Cost Test	Utility Cost Test
Measure cost (incremental over baseline)	Cost	
Utility incentives		Cost
Electric energy & capacity (demand, transmission, distribution) savings	Benefit	Benefit
Natural gas savings or increased usage	Benefit, Cost	Benefit, Cost
Other end-use fuel savings or increased usage (non-natural gas)	Benefit	
Electric externalities	Benefit	
End-use fuel externalities	Benefit	

Discounting the Future Value of Money

Future costs and benefits were discounted to the present using a nominal discount rate of 3.0% for Connecticut (Eversource 2022) and 7.57% for Arizona (APS 2020). For discounting purposes, it is assumed that initial measure costs are incurred at the beginning of the year, whereas annual energy savings are incurred halfway through the year.

Avoided Energy Supply Costs

Avoided energy supply costs assess the economic value of energy savings (or the costs of increased consumption). The summarized avoided costs used in this study are presented by state in

Table 27 below. The Connecticut avoided costs are adapted from Synapse 2021. Avoided costs for Arizona were not publicly available; avoided cost were inferred from statewide retail rates from U.S. EIA 2023 and other secondary sources.

Table 27: Avoided Energy Supply Costs by State and Fuel (15-year levelized)

State	Electric Avoided Costs						Natural Gas Avoided Cost	Fuel Oil Avoided Cost	Propane Avoided Cost
	Summer Peak	Summer Off-Peak	Non-Summer Peak	Non-Summer Off-Peak	Summer Gener. Capacity	T&D Capacity			
	$/kWh	$/kWh	$/kWh	$/kWh	$/kW-yr	$/kW-yr	$/MMBtu	$/MMBtu	$/MMBtu
CT	$0.065	$0.057	$0.092	$0.088	$68.63	$130.89	$8.44	$25.51	-
AZ	$0.044	$0.038	$0.063	$0.060	$72.88	-	$6.45	-	$23.84

Avoided Emissions Costs

The summarized avoided CO_2 emissions costs used in this study are presented in Table 28 below. Emissions rates from U.S. EPA 2022 are used to convert costs from the source values to dollars per unit energy values. The Connecticut costs are adapted from Synapse 2021 and the Arizona costs are referenced from APS 2020.

Table 28: Avoided CO2 Emissions Costs by State and Fuel (15-year levelized)

State	Electric Non-Embedded Avoided CO_2 Emissions Costs				Natural Gas Avoided CO2 Emissions Cost	Fuel Oil Avoided CO2 Emissions Cost	Propane Avoided CO2 Emissions Cost
	Summer Peak	Summer Off-Peak	Non-Summer Peak	Non-Summer Off-Peak			
	$/kWh	$/kWh	$/kWh	$/kWh	$/MMBtu	$/MMBtu	$/MMBtu
CT	$0.042	$0.048	$0.040	$0.043	$6.71	$9.36	-
AZ	$0.008	$0.008	$0.008	$0.008	$1.05	-	$1.47

Electric Load Shapes

Electric energy load shapes are used to divide annual measure electric energy savings into the energy costing periods of the avoided costs. The load shapes are developed from NREL 2023 using the appropriate state aggregated timeseries data. The resulting load shapes are presented in Table 29 and Table 30 below. Load shape names ending in "DR" are specifically for lighting demand response savings; otherwise, load shapes are applied by building type and end-use.

Table 29: Connecticut Electric Load Shapes by ComStock Building Type and End-Use

Load Shape Name	Summer Peak	Summer Off-Peak	Non-Summer Peak	Non-Summer Off-Peak	Summer Gener. Capacity
smalloffice.interior_lighting.base	26%	7%	13%	54%	0.27
mediumoffice.interior_lighting.base	26%	7%	17%	50%	0.27
largeoffice.interior_lighting.base	26%	7%	16%	51%	0.27
smallhotel.interior_lighting.base	23%	10%	9%	57%	0.18
largehotel.interior_lighting.base	24%	10%	10%	57%	0.18
outpatient.interior_lighting.base	24%	9%	13%	54%	0.24
hospital.interior_lighting.base	24%	9%	11%	56%	0.24

Load Shape Name	Summer Peak	Summer Off-Peak	Non-Summer Peak	Non-Summer Off-Peak	Summer Gener. Capacity
quickservicerestaurant.interior_lighting.base	24%	10%	8%	58%	0.15
fullservicerestaurant.interior_lighting.base	24%	10%	8%	58%	0.15
retailstandalone.interior_lighting.base	23%	10%	10%	57%	0.15
retailstripmall.interior_lighting.base	23%	10%	9%	57%	0.15
primaryschool.interior_lighting.base	21%	8%	12%	60%	0.21
secondaryschool.interior_lighting.base	21%	8%	14%	58%	0.21
warehouse.interior_lighting.base	25%	8%	13%	54%	0.25
smalloffice.cooling.base	62%	21%	3%	15%	0.27
mediumoffice.cooling.base	59%	22%	3%	16%	0.27
largeoffice.cooling.base	41%	16%	6%	36%	0.27
smallhotel.cooling.base	44%	17%	5%	34%	0.18
largehotel.cooling.base	42%	16%	6%	36%	0.18
outpatient.cooling.base	54%	19%	5%	22%	0.24
hospital.cooling.base	55%	22%	3%	20%	0.24
quickservicerestaurant.cooling.base	57%	21%	3%	19%	0.15
fullservicerestaurant.cooling.base	58%	21%	2%	18%	0.15
retailstandalone.cooling.base	61%	24%	2%	13%	0.15
retailstripmall.cooling.base	61%	23%	2%	14%	0.15
primaryschool.cooling.base	62%	20%	3%	15%	0.21
secondaryschool.cooling.base	60%	19%	3%	18%	0.21
warehouse.cooling.base	68%	22%	1%	9%	0.25
smalloffice.heating.base	0%	0%	17%	82%	0.27
mediumoffice.heating.base	1%	0%	15%	84%	0.27
largeoffice.heating.base	0%	0%	14%	85%	0.27
smallhotel.heating.base	0%	0%	12%	88%	0.18
largehotel.heating.base	0%	0%	13%	87%	0.18
outpatient.heating.base	0%	0%	18%	81%	0.24
hospital.heating.base	0%	0%	0%	0%	0.24
quickservicerestaurant.heating.base	2%	1%	16%	82%	0.15
fullservicerestaurant.heating.base	1%	0%	16%	83%	0.15
retailstandalone.heating.base	0%	0%	19%	81%	0.15
retailstripmall.heating.base	1%	0%	20%	79%	0.15
primaryschool.heating.base	2%	1%	19%	79%	0.21
secondaryschool.heating.base	1%	0%	21%	78%	0.21
warehouse.heating.base	0%	0%	13%	87%	0.25
smalloffice.fans.base	25%	10%	10%	55%	0.27
mediumoffice.fans.base	24%	11%	10%	55%	0.27
largeoffice.fans.base	29%	12%	9%	50%	0.27
smallhotel.fans.base	34%	14%	7%	46%	0.18
largehotel.fans.base	31%	12%	8%	49%	0.18

Load Shape Name	Summer Peak	Summer Off-Peak	Non-Summer Peak	Non-Summer Off-Peak	Summer Gener. Capacity
outpatient.fans.base	25%	10%	10%	55%	0.24
hospital.fans.base	26%	10%	9%	55%	0.24
quickservicerestaurant.fans.base	24%	10%	10%	56%	0.15
fullservicerestaurant.fans.base	24%	10%	10%	56%	0.15
retailstandalone.fans.base	23%	11%	11%	55%	0.15
retailstripmall.fans.base	25%	10%	10%	55%	0.15
primaryschool.fans.base	25%	9%	11%	55%	0.21
secondaryschool.fans.base	25%	9%	13%	53%	0.21
warehouse.fans.base	26%	10%	10%	55%	0.25
smalloffice.interior_equipment.base	24%	10%	9%	57%	0.27
mediumoffice.interior_equipment.base	24%	9%	10%	57%	0.27
largeoffice.interior_equipment.base	24%	10%	10%	57%	0.27
smallhotel.interior_equipment.base	24%	10%	9%	58%	0.18
largehotel.interior_equipment.base	23%	10%	10%	57%	0.18
outpatient.interior_equipment.base	23%	10%	12%	54%	0.24
hospital.interior_equipment.base	23%	11%	10%	57%	0.24
quickservicerestaurant.interior_equipment.base	23%	10%	11%	55%	0.15
fullservicerestaurant.interior_equipment.base	23%	10%	10%	56%	0.15
retailstandalone.interior_equipment.base	24%	10%	7%	60%	0.15
retailstripmall.interior_equipment.base	23%	10%	9%	58%	0.15
primaryschool.interior_equipment.base	21%	7%	12%	60%	0.21
secondaryschool.interior_equipment.base	21%	7%	13%	59%	0.21
warehouse.interior_equipment.base	25%	8%	12%	55%	0.25
smalloffice.interior_lighting.DR	26%	7%	13%	54%	0.82
mediumoffice.interior_lighting.DR	26%	7%	17%	50%	0.82
largeoffice.interior_lighting.DR	26%	7%	16%	51%	0.82
smallhotel.interior_lighting.DR	23%	10%	9%	57%	0.82
largehotel.interior_lighting.DR	24%	10%	10%	57%	0.82
outpatient.interior_lighting.DR	24%	9%	13%	54%	0.82
hospital.interior_lighting.DR	24%	9%	11%	56%	0.82
quickservicerestaurant.interior_lighting.DR	24%	10%	8%	58%	0.82
fullservicerestaurant.interior_lighting.DR	24%	10%	8%	58%	0.82
retailstandalone.interior_lighting.DR	23%	10%	10%	57%	0.82
retailstripmall.interior_lighting.DR	23%	10%	9%	57%	0.82
primaryschool.interior_lighting.DR	21%	8%	12%	60%	0.82
secondaryschool.interior_lighting.DR	21%	8%	14%	58%	0.82
warehouse.interior_lighting.DR	25%	8%	13%	54%	0.82

Table 30: Arizona Electric Load Shapes by ComStock Building Type and End-Use

Load Shape Name	Summer Peak	Summer Off-Peak	Non-Summer Peak	Non-Summer Off-Peak	Summer Gener. Capacity
smalloffice.interior_lighting.base	26%	7%	9%	58%	0.27
mediumoffice.interior_lighting.base	25%	8%	11%	56%	0.27
largeoffice.interior_lighting.base	26%	7%	11%	56%	0.27
smallhotel.interior_lighting.base	23%	10%	10%	57%	0.18
largehotel.interior_lighting.base	23%	11%	7%	59%	0.18
outpatient.interior_lighting.base	24%	9%	9%	57%	0.24
hospital.interior_lighting.base	24%	9%	7%	60%	0.24
quickservicerestaurant.interior_lighting.base	24%	10%	5%	61%	0.15
fullservicerestaurant.interior_lighting.base	24%	10%	5%	61%	0.15
retailstandalone.interior_lighting.base	24%	10%	6%	60%	0.15
retailstripmall.interior_lighting.base	23%	10%	6%	61%	0.15
primaryschool.interior_lighting.base	21%	8%	10%	62%	0.21
secondaryschool.interior_lighting.base	21%	8%	12%	60%	0.21
warehouse.interior_lighting.base	25%	8%	9%	58%	0.25
smalloffice.cooling.base	46%	19%	2%	33%	0.27
mediumoffice.cooling.base	46%	20%	2%	32%	0.27
largeoffice.cooling.base	36%	15%	4%	44%	0.27
smallhotel.cooling.base	37%	16%	4%	43%	0.18
largehotel.cooling.base	38%	16%	4%	42%	0.18
outpatient.cooling.base	46%	19%	3%	33%	0.24
hospital.cooling.base	38%	16%	3%	42%	0.24
quickservicerestaurant.cooling.base	46%	19%	1%	33%	0.15
fullservicerestaurant.cooling.base	47%	20%	1%	31%	0.15
retailstandalone.cooling.base	46%	21%	2%	32%	0.15
retailstripmall.cooling.base	45%	19%	2%	35%	0.15
primaryschool.cooling.base	48%	19%	2%	31%	0.21
secondaryschool.cooling.base	48%	19%	2%	31%	0.21
warehouse.cooling.base	52%	21%	1%	26%	0.25
smalloffice.heating.base	0%	0%	35%	64%	0.27
mediumoffice.heating.base	0%	0%	41%	59%	0.27
largeoffice.heating.base	0%	0%	30%	70%	0.27
smallhotel.heating.base	0%	0%	29%	71%	0.18
largehotel.heating.base	5%	2%	24%	69%	0.18
outpatient.heating.base	1%	0%	39%	61%	0.24
hospital.heating.base	9%	2%	24%	65%	0.24
quickservicerestaurant.heating.base	1%	0%	31%	68%	0.15
fullservicerestaurant.heating.base	0%	0%	30%	69%	0.15
retailstandalone.heating.base	0%	0%	36%	64%	0.15
retailstripmall.heating.base	10%	4%	22%	64%	0.15

Load Shape Name	Summer Peak	Summer Off-Peak	Non-Summer Peak	Non-Summer Off-Peak	Summer Gener. Capacity
primaryschool.heating.base	3%	1%	34%	62%	0.21
secondaryschool.heating.base	1%	0%	34%	65%	0.21
warehouse.heating.base	0%	0%	29%	71%	0.25
smalloffice.fans.base	29%	12%	7%	52%	0.27
mediumoffice.fans.base	25%	11%	8%	56%	0.27
largeoffice.fans.base	28%	12%	7%	53%	0.27
smallhotel.fans.base	33%	14%	5%	47%	0.18
largehotel.fans.base	33%	14%	5%	48%	0.18
outpatient.fans.base	25%	10%	9%	56%	0.24
hospital.fans.base	28%	11%	7%	54%	0.24
quickservicerestaurant.fans.base	25%	10%	8%	57%	0.15
fullservicerestaurant.fans.base	24%	10%	8%	58%	0.15
retailstandalone.fans.base	27%	12%	7%	54%	0.15
retailstripmall.fans.base	27%	11%	7%	55%	0.15
primaryschool.fans.base	26%	10%	9%	55%	0.21
secondaryschool.fans.base	27%	10%	9%	54%	0.21
warehouse.fans.base	30%	12%	7%	52%	0.25
smalloffice.interior_equipment.base	24%	10%	8%	59%	0.27
mediumoffice.interior_equipment.base	24%	10%	9%	58%	0.27
largeoffice.interior_equipment.base	24%	10%	9%	58%	0.27
smallhotel.interior_equipment.base	24%	10%	9%	58%	0.18
largehotel.interior_equipment.base	23%	10%	8%	58%	0.18
outpatient.interior_equipment.base	23%	10%	10%	56%	0.24
hospital.interior_equipment.base	23%	10%	7%	60%	0.24
quickservicerestaurant.interior_equipment.base	23%	10%	8%	59%	0.15
fullservicerestaurant.interior_equipment.base	23%	10%	7%	60%	0.15
retailstandalone.interior_equipment.base	24%	10%	6%	61%	0.15
retailstripmall.interior_equipment.base	23%	10%	7%	60%	0.15
primaryschool.interior_equipment.base	21%	7%	9%	63%	0.21
secondaryschool.interior_equipment.base	21%	7%	10%	62%	0.21
warehouse.interior_equipment.base	25%	8%	8%	58%	0.25
smalloffice.interior_lighting.DR	26%	7%	9%	58%	0.82
mediumoffice.interior_lighting.DR	25%	8%	11%	56%	0.82
largeoffice.interior_lighting.DR	26%	7%	11%	56%	0.82
smallhotel.interior_lighting.DR	23%	10%	10%	57%	0.82
largehotel.interior_lighting.DR	23%	11%	7%	59%	0.82
outpatient.interior_lighting.DR	24%	9%	9%	57%	0.82
hospital.interior_lighting.DR	24%	9%	7%	60%	0.82
quickservicerestaurant.interior_lighting.DR	24%	10%	5%	61%	0.82
fullservicerestaurant.interior_lighting.DR	24%	10%	5%	61%	0.82

Load Shape Name	Summer Peak	Summer Off-Peak	Non-Summer Peak	Non-Summer Off-Peak	Summer Gener. Capacity
retailstandalone.interior_lighting.DR	24%	10%	6%	60%	0.82
retailstripmall.interior_lighting.DR	23%	10%	6%	61%	0.82
primaryschool.interior_lighting.DR	21%	8%	10%	62%	0.82
secondaryschool.interior_lighting.DR	21%	8%	12%	60%	0.82
warehouse.interior_lighting.DR	25%	8%	9%	58%	0.82