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A Review of Technical Reference Manuals in U.S. and Canada

Networked and Luminaire-Level Lighting Control Measure Prevalence and Best Practices

May 2025

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ACKNOWLEDGEMENTS:

We gratefully acknowledge the contributions of the following individuals who shared their insights and expertise as peer reviewers.

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DEFINITIONS

Deemed [Algorithm, Calculation, Energy Savings, Value]: pre-determined, standardized estimates or methodologies used to establish energy savings associated with specific energy efficiency measures. The savings represent population-wide average values based on historical data, engineering algorithms, and/or measurement studies rather than direct measurement and calculation for an individual project.

Luminaire Level Lighting Control (LLLC): a subset of Networked Lighting Controls (NLCs), lighting systems with sensing for occupancy and daylight embedded on every networked luminaire. The DLC's official definition for LLLC, for the purpose of product qualification, is: The capability to have a networked occupancy sensor and ambient light sensor installed for each luminaire or kit, and directly integrated or embedded into the form factor during the luminaire or kit manufacturing process. In addition to these required integrated components, LLLC systems must have control persistence capability as described in this document. To demonstrate commercial availability of the integrated component options, at least one family, luminaire or kit with integrated control must be verified by the DLC. Manufacturers may choose whether or not to list this information publicly on the QPL.

Midstream: a type of energy efficiency program in which a customer or trade ally receives an instant incentive/rebate at the point of purchase, typically through a wholesale electrical or mechanical distributor. The distributor confirms and collects limited project data such as customer information and product details and is reimbursed for the incentive when application and product information is reported to the energy efficiency program.

Networked Lighting Control (NLC): the combination of sensors, network interfaces, and controllers that effect lighting changes in luminaires, retrofit kits, or lamps.

Prescriptive: a type of energy efficiency program in which a customer or trade ally submits a post-project application to claim a standardized incentive. The extent of the project data collected on a prescriptive application varies considerably from one program to the next and may include customer information, product details, installation conditions, operating hours, building type, and baseline equipment type.

EXECUTIVE SUMMARY

To save more energy and reduce carbon emissions, the DesignLights Consortium (DLC) has been advocating for adoption of prescriptive incentives for Networked Lighting Controls (NLCs) and Luminaire-Level Lighting Controls (LLLC) in commercial and industrial settings by requiring listed LED lighting to be controllable and helping members find more ways to incentivize and prioritize their installation. This report, commissioned and led by the DLC, provides a comprehensive analysis of Technical Reference Manuals (TRMs) across the United States and Canada, with a focus on standardized NLC and LLLC measures. TRMs are critical resources for energy efficiency programs, providing standardized methodologies for estimating energy savings and cost-effectiveness. The study evaluates TRM availability, age, key assumptions, and best practices. It identifies opportunities for including and improving NLC and LLLC measures within TRMs, which will encourage installation and energy savings.

KEY FINDINGS:

- **TRM availability is limited.** TRMs exist in 36 jurisdictions, but 25 lack publicly available TRMs. Among the existing TRMs, 26 (72%) have been updated within the past two years.
- **NLC and LLLC measures have a low prevalence.** 58% of TRMs include at least one NLC measure, but only 28% (ten total) distinguish LLLC as a separate measure. Distinguishing NLC and LLLC measures creates a significant opportunity to expand adoption.
- **TRM assumptions vary.** Control Savings Factors (CSFs), operating hours, and measure life assumptions vary widely, affecting energy savings estimates and incentive structures.
- **NLC-HVAC Integration measures are missing.** No TRMs currently include NLC-HVAC integration measures, despite research[1] indicating significant energy savings potential.

RECOMMENDATIONS FOR UTILITY AND ENERGY EFFICIENCY PROGRAMS AND REGULATORS:

1. **Standardize TRM Methodologies.** Adopt uniform approaches for NLC and LLLC measures to improve consistency in energy savings estimates. Use the TRM workpaper in Appendix C as a guide.
2. **Expand NLC and LLLC Inclusion.** Prioritize TRM updates to explicitly define and incorporate these measures in the 26 jurisdictions identified with improvement opportunities.
3. **Regularly Update TRMs.** Implement review cycles every 1-2 years to align with advancements in technology and market conditions.

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[1] Nock et al. “2030 Goals Require Long Term Efficiency Plans that Specify Networked Lighting Controls.” *Proceedings of the ACEEE 2024 Summer Study*. Available at https://www.aceee.org/sites/default/files/proceedings/ssb24/pdfs/2030_Goals_Require_Long_Term_Efficiency_Plans_that_Specify_Networked_Lighting_Controls.pdf.

4. **Leverage Best Practices.** Learn from leading TRMs, such as the Illinois TRM's structured approach to operating hours and LLLC differentiation.
5. **Enhance Collaboration.** Facilitate engagement among utilities, regulators, and industry stakeholders to refine TRM methodologies and share best practices.

CONCLUSION

To maximize the impact of energy efficiency programs, TRMs must be continuously updated and standardized to reflect emerging lighting technologies and control strategies. The recommendations outlined in this report provide a roadmap for improving the consistency, transparency, and effectiveness of NLC and LLLC measures within TRMs, ensuring these resources remain valuable tools for achieving energy efficiency goals. Simultaneously, the adoption of NLC and LLLC measures can be scaled up more rapidly. DLC Member utilities and energy efficiency programs are invited to utilize this research and the key assumptions and algorithms contained in the work paper (appendix C) to propose or update measures for NLCs and LLLCs in their own TRMs.

INTRODUCTION

This report provides a comprehensive and analytical summary of networked and luminaire-level lighting control (NLC and LLLC) measures within Technical Reference Manuals (TRMs) across the United States and Canada. TRMs are an essential resource used in planning, evaluating, and implementing energy efficiency programs. They establish standardized methodologies, assumptions, and calculations to determine energy savings, ensuring regulatory compliance and cost-effectiveness. The goal of this report is to empower those who create, update, and influence TRMs to more effectively support networked and luminaire-level lighting controls.

This study explores the prevalence of TRMs, the extent to which interior NLC and LLLC measures are incorporated, and the significant variations in key assumptions across different jurisdictions. Additionally, this report aims to identify best practices, areas for improvement, and potential standardization opportunities to enhance TRM consistency and effectiveness in achieving energy efficiency goals. By addressing both the current state and future developments of TRMs, this report aims to serve as a guiding resource for DLC members and stakeholders.

In this report, references to TRMs include all forms of standardized technical and engineering guides used in the determination of energy efficiency savings. Some jurisdictions refer to these resources using different names, such as the Connecticut Program Savings Document (PSD), Michigan Energy Measures Database (MEMD), or the Northwest Regional Technical Forum (RTF) measure library.

TRM OVERVIEW

TRMs serve as essential technical documents that provide standardized approaches to quantifying *deemed* energy savings methodologies associated with a variety of energy efficiency measures. These manuals play a crucial role in defining the parameters and calculations used to estimate energy and demand savings, cost-effectiveness, and the overall impact of efficiency programs. The values defined within TRMs are intended to generalize a large population of projects, informed by studies and evaluations.

A TRM is a collection of discrete energy efficiency technologies and practices, referred to as *measures.* Measures are organized by customer sector (residential, commercial, industrial, among others) and technology end-use (HVAC, lighting, etc.). Examples of TRM measures include commercial LED lighting, residential thermostats, and industrial air compressors.

As depicted in Figure 1, TRMs are required for most *prescriptive* and *midstream* programs when deemed calculations are used to establish energy savings. Under these programs, a standardized incentive amount is published in advance, making project decisions easier for customers and trade allies. When projects are completed, an energy efficiency program relies on TRM algorithms to quantify average or typical energy savings.

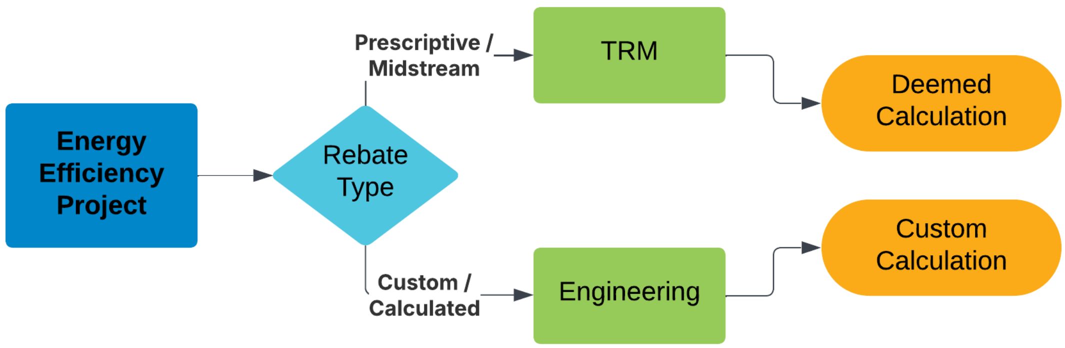

Figure 1. Diagram of Energy Savings Calculation Pathways[2]

Prescriptive and midstream programs are designed to be straightforward and easy to administer, making them accessible to a broad range of customers. Unlike custom programs, which require detailed engineering analysis and prior approval for unique projects, prescriptive and midstream programs follow a predefined list of measures with fixed incentives, simplifying participation and ensuring consistent results. Due to their simplicity and predictability, prescriptive and midstream programs typically lead to increased customer participation. Accordingly, a measure within a TRM is a must-have resource for programs that wish to reach scale for a particular technology.

TRM structure and level of detail can vary significantly by jurisdiction, reflecting differences in regulatory requirements, energy policies, and program goals. The core elements contained within each TRM measure typically include:

- **Eligibility Criteria:** Detailed specifications regarding customer classification, applicable project conditions, and product qualification requirements.
- **Default Conditions:** Standardized baseline energy consumption definitions, efficiency benchmarks, and assumptions related to operating conditions and load profiles.
- **Energy Savings Calculations:** Established engineering algorithms and/or predefined energy savings values, allowing for consistent estimation across various efficiency measures. Savings values may be annual energy (kWh or therms per year), lifetime energy (total kWh or therms over the measure's lifespan), demand (kW), or peak demand (kW saved during peak times).
- **Cost-Effectiveness Metrics:** Inputs such as incremental measure costs, expected operational lifespan, operation and maintenance (O&M) costs, and non-energy benefits, which are used to screen measure cost-effectiveness.
- **Supporting Documentation:** References to peer-reviewed studies, regulatory filings, and other TRMs that provide justification for assumptions and calculations.

[2] This diagram represents typical pathways for savings calculations, but exceptions do exist. For example, some programs offer a prescriptive rebate and calculate the savings using a custom process on the back end.

Most jurisdictions have a defined process for updating TRMs, which may include some or all of the following steps: 1) submission of new measures or measure revisions; 2) research and measure development; 3) review by regulators, evaluators, and stakeholders; 4) approval or rejection; 5) implementation.

The majority of TRMs are available as text-based documents (PDFs or Word files), while a few jurisdictions employ spreadsheet formats (e.g., MI, HI, AB) or interactive online “eTRM” databases (e.g., CA, NB (Canada)). Online TRMs allow for easier access, enable integration with utility data platforms, and can be continuously updated.

TRM AVAILABILITY

A jurisdictional review identified TRMs in **36 states and provinces**, whereas 25 jurisdictions either lack publicly available TRMs or do not have TRMs in place. The distribution of TRMs is categorized as follows:

- **State/provincewide TRMs (26):** Available in twenty-six states/provinces, these resources are typically managed by public utility commissions, energy efficiency boards, technical advisory groups, or designated third-party entities. State/provincewide TRMs may be used by multiple utilities within a state or province, or by a single statewide or provincewide energy efficiency program.
- **Regional TRMs (2 regions, 6 states):** Found in certain areas, such as the Northwest (Regional Technical Forum) and Mid-Atlantic regions, these TRMs use collaborative approaches to development involving multiple states. There are two regional TRMs currently being used by six states.
- **Utility-Specific TRMs (4):** Some individual utilities have developed their own TRM or similar engineering resources to guide their respective energy efficiency initiatives. The research identified four utility-specific TRMs[3], though it is likely that more exist since these resources are often not available publicly. The utility-specific resources identified by this research were part of docketed proceedings, which made them public.

Figure 2 provides a summary of the TRM availability across the U.S. and Canada. Some of the jurisdictions shown as “None or Unknown” may have a TRM-like resource that is unpublished or proprietary. Understanding the distribution of TRMs and their accessibility is crucial for ensuring transparency and encouraging uniformity in energy efficiency calculations. All TRM resources identified by this research are cataloged in Appendix A: Database of TRMs.

[3] Dominion Energy Virginia, Entergy New Orleans, Public Service Company of Colorado (Xcel Energy), Tennessee Valley Authority

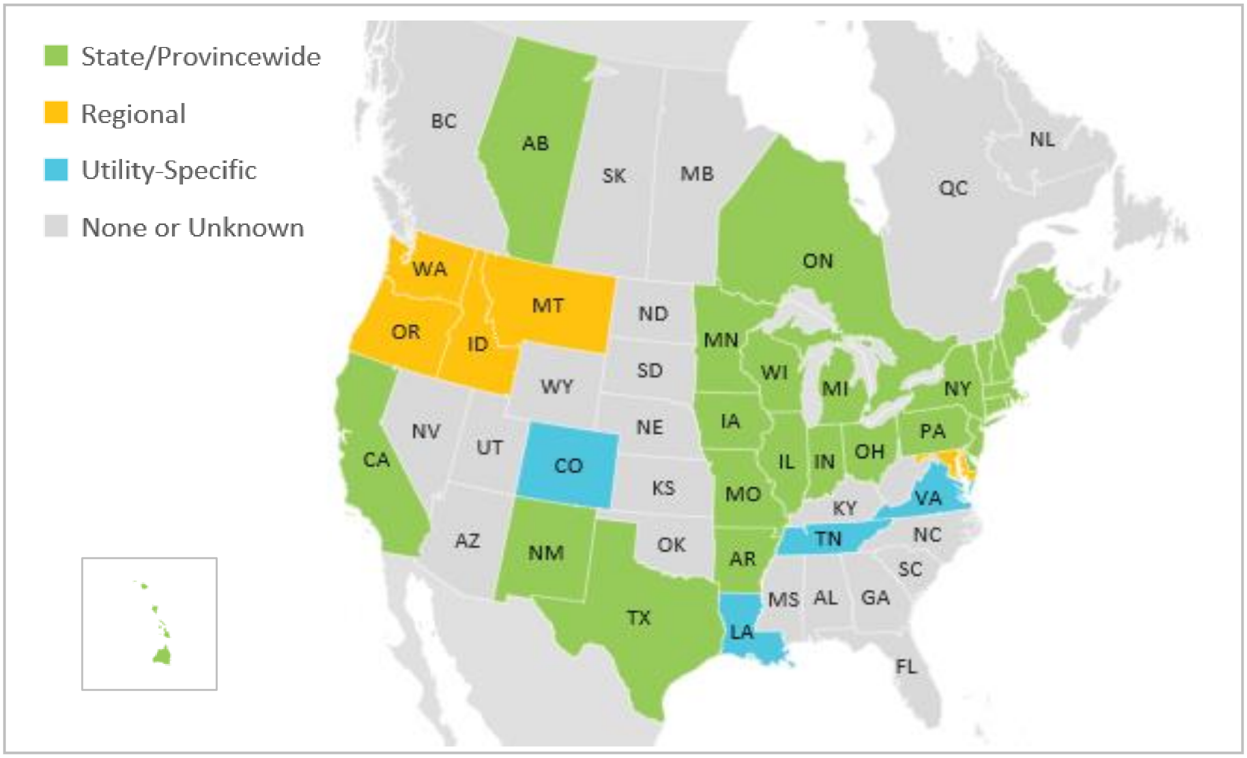

Figure 2. Availability of TRM Resources in U.S. and Canada

TRM AGE

The timeframe between TRM updates varies significantly across jurisdictions, with many being revised within the past year while others haven't been updated in 7+ years. Keeping TRMs up to date is essential to ensure that the assumptions, methodologies, and technologies they reference remain accurate and relevant. Outdated TRMs can lead to inaccurate energy savings estimates, misallocated incentives, and reduced effectiveness of energy efficiency programs. Regular updates allow TRMs to incorporate advancements in technology, current product costs, changes in energy codes, and new research findings, ensuring that programs remain effective and aligned with the latest industry standards.

The range of TRM ages identified by this research are shown in Figure 3. Most states and provinces (26 out of 36) are using a TRM that has been updated within the past two years. There are 8 jurisdictions using a TRM that is older than three years. TRM assumptions being used in these areas should be handled carefully for accuracy and relevancy.

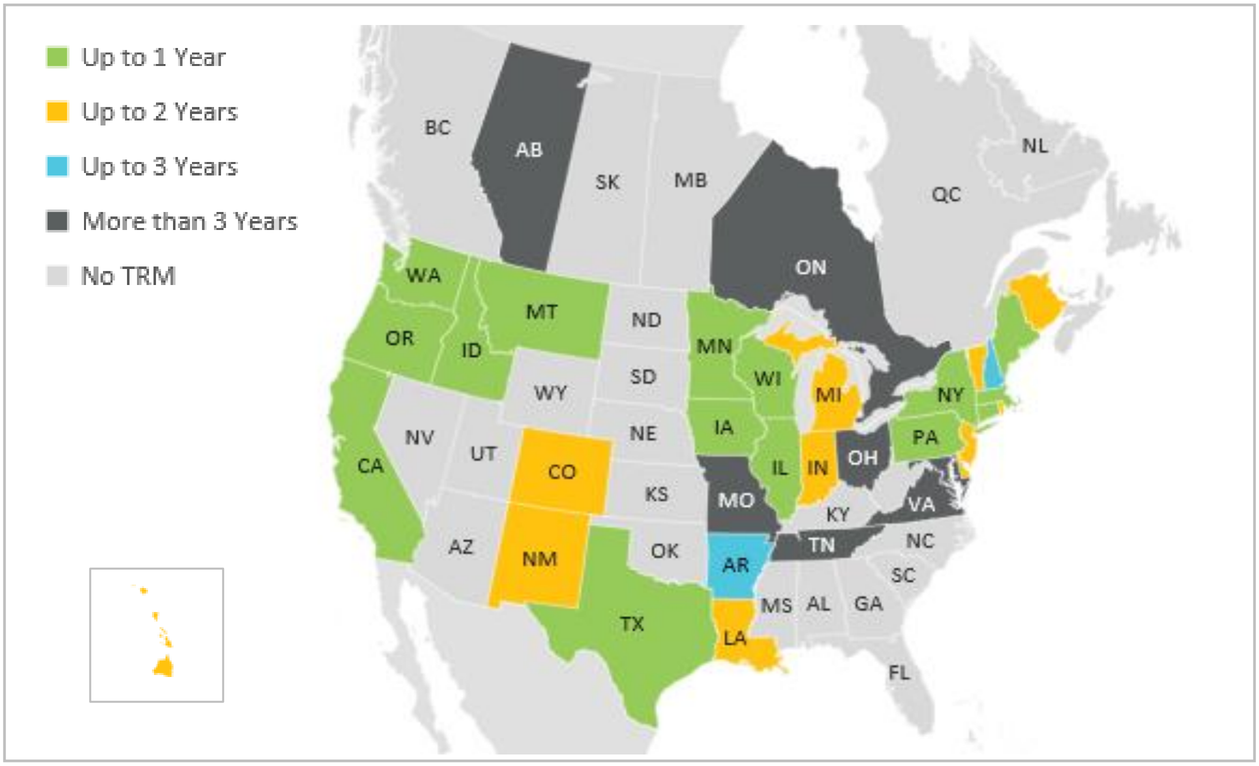

Figure 3. Age of TRM Resources in U.S. and Canada, as of March 1, 2025[4]

NETWORKED LIGHTING CONTROL MEASURES

Networked Lighting Controls (NLC) refer to advanced lighting control systems that combine sensors, network interfaces, and controllers to affect lighting changes in luminaires, retrofit kits, or lamps. These systems integrate multiple control strategies such as occupancy sensing, daylight harvesting, high-end trim, and scheduling to provide enhanced energy savings, automation, and performance tracking.

Luminaire-Level Lighting Controls (LLLC) are a subset of NLCs that use embedded sensors and controls within individual luminaires, enabling more granular control, easier installation, and increased flexibility.

There are a variety of ways that interior NLC and LLLC measures are represented in TRMs. Some TRMs use a single NLC measure that encompasses all systems with and without LLLC. Programs using a single TRM measure typically offer a single incentive amount covering all NLC system types, including LLLC. Other TRMs have two distinct measures for NLC (without LLLC) and LLLC. Programs relying on a dual measure TRM can offer distinct incentives, and claim distinct savings, for systems with and without LLLC. The approaches are depicted in Figure 4.

[4] Some TRMs may have more recent updates that are not yet finalized or publicly available.

It is worth noting that some jurisdictions have discontinued incentives for LED luminaires for reasons such as market saturation or state regulations. In most cases, NLC and LLLC measures should remain viable in these jurisdictions since the savings are controls-only with an LED luminaire baseline.

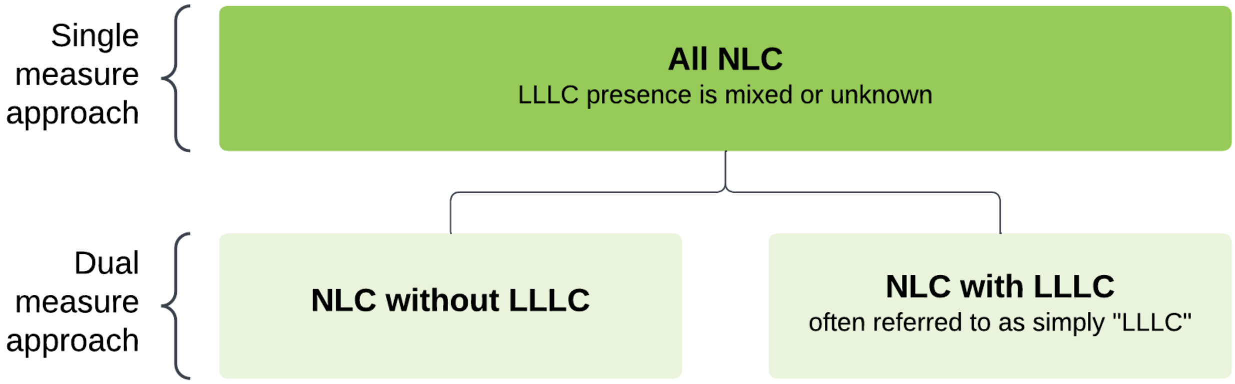

Figure 4. NLC and LLLC Measure Approaches in TRMs

The study found that more than half (58%) of TRMs include some form of an NLC measure. Within this group, 10 TRMs (28%) employ a dual measure approach with LLLC as an explicit and distinct measure. **These findings indicate that nearly three-quarters (72%) of TRMs have an opportunity to include or expand NLC and LLLC measures**.

- **21 of 36 TRMs (58%)** included at least one NLC measure.
- **10 TRMs (28%)** explicitly defined LLLC as a distinct measure.

The inclusion of NLC and LLLC measures within TRMs is critical for driving the adoption of networked lighting systems that contribute to significant energy savings. A distinct LLLC measure, in particular, is an important tool for reaching scale. LLLC products are well suited for midstream programs, where incentives and savings are applied on a per-unit basis. Table 1 and Figure 5 below show the 26 states where an opportunity exists to add or expand NLC and/or LLLC offerings within established TRMs.

Table 1. States and Provinces with Opportunities to Improve NLC and LLLC TRM Measures[5]

Country	State/Province	Applicability	TRM Age	Add NLC	Add LLLC
Canada	Alberta	Provincewide	> 4 Years	●	●
Canada	New Brunswick	Provincewide	1-2 Years	●	●
Canada	Ontario	Provincewide	> 4 Years		●
U.S.	Arkansas	Statewide	3-4 Years	●	●
U.S.	California	Statewide	< 1 Year	●	●
U.S.	Colorado	Utility-Specific	1-2 Years		●
U.S.	Delaware	Statewide	1-2 Years		●
U.S.	District of Columbia	Regional	> 4 Years		●
U.S.	Hawaii	Statewide	1-2 Years	●	●
U.S.	Louisiana	Utility-Specific	1-2 Years	●	●
U.S.	Maine	Statewide	< 1 Year	●	●
U.S.	Maryland	Regional	> 4 Years		●
U.S.	Massachusetts	Statewide	< 1 Year		●
U.S.	Michigan	Statewide	1-2 Years		●
U.S.	Missouri	Statewide	> 4 Years	●	●
U.S.	New Hampshire	Statewide	3-4 Years	●	●
U.S.	New Mexico	Statewide	1-2 Years	●	●
U.S.	New York	Statewide	< 1 Year		●
U.S.	Ohio	Statewide	> 4 Years	●	●
U.S.	Pennsylvania	Statewide	< 1 Year		●
U.S.	Rhode Island	Statewide	1-2 Years	●	●
U.S.	Tennessee	Utility-Specific	> 4 Years	●	●
U.S.	Texas	Statewide	< 1 Year		●
U.S.	Vermont	Statewide	1-2 Years	●	●
U.S.	Virginia	Utility-Specific	> 4 Years	●	●
U.S.	Wisconsin	Statewide	< 1 Year		●

[5] For many jurisdictions shown in this table, incentives for NLC and/or LLLC measures may be available through custom programs.

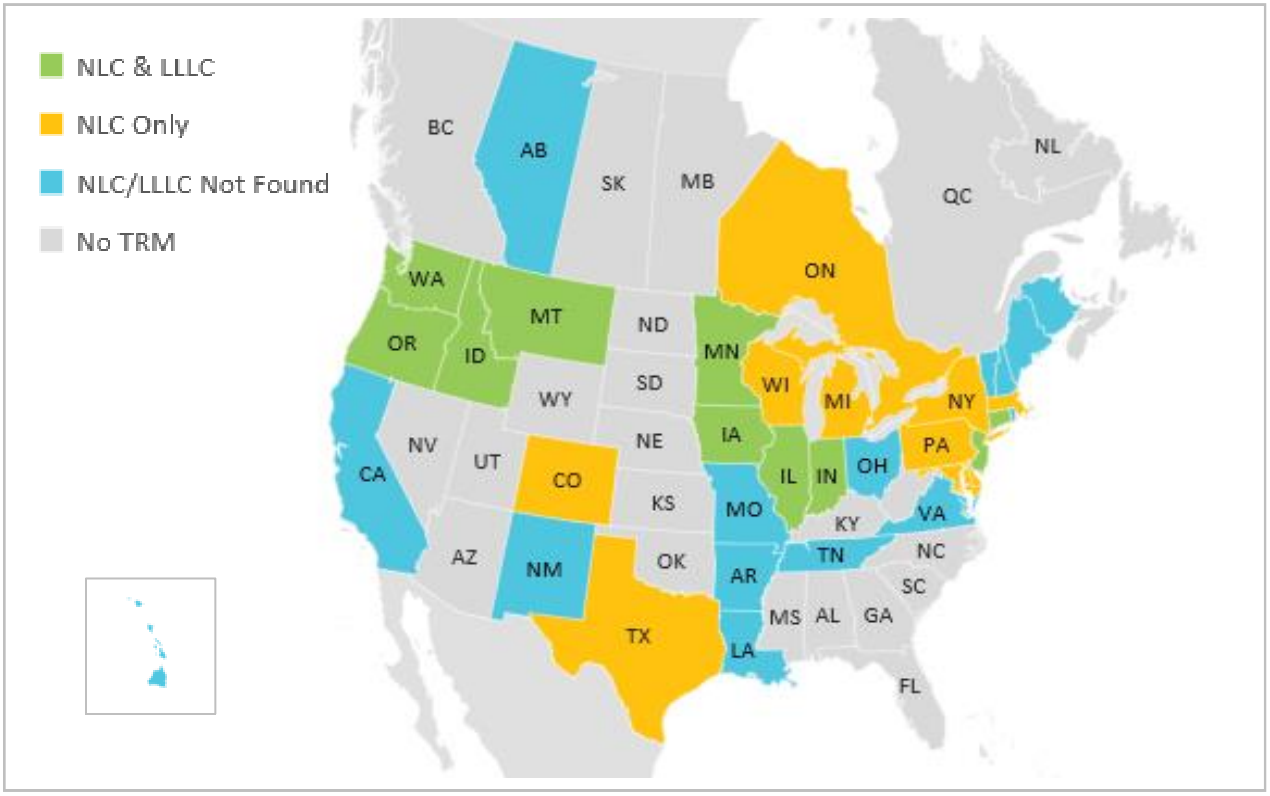

Figure 5. Presence of NLC and LLLC TRM Measures in U.S. and Canada

The jurisdictional scan did not identify any TRMs that included a measure for networked lighting controls integrated with a heating, ventilation, and air-conditioning (HVAC) system. Previous DLC research has shown significant energy savings potential when occupancy data from an NLC system is used to inform and optimize HVAC operations.[6] To assist DLC members who wish to pursue this measure, DLC has created an NLC-HVAC Integration Toolkit, available at https://designlights.org/lighting-hvac-integration/. While a measure for NLC-HVAC integration was not identified in any TRMs, the research did identify a system program manual for Xcel Energy, created by Lawrence Berkeley National Laboratory (LBNL).[7] Excerpts from this manual are included in Appendix D.

[6] Nock et al. "2030 Goals Require Long Term Efficiency Plans that Specify Networked Lighting Controls." *Proceedings of the ACEEE 2024 Summer Study*. Available at https://www.aceee.org/sites/default/files/proceedings/ssb24/pdfs/2030_Goals_Require_Long_Term_Efficiency_Plans_that_Specify_Networked_Lighting_Controls.pdf.

[7] "LEDs with Advanced Lighting Controls and Occupancy Sensor-based Demand Control Ventilation." Lawrence Berkeley National Laboratory, 2022. Available at https://buildings.lbl.gov/sites/default/files/2023-10/BW_Phase_2_Program_Manual.pdf.

KEY TRM ASSUMPTIONS FOR LIGHTING CONTROLS

When calculating energy savings for lighting controls, there are four critical variables that must be defined when calculating energy savings. These variables are:

- Controlled watts
- Control savings factor
- Operating hours
- Measure life

Each of these variables is discussed in the following sections of this report, including findings from the TRM research. The role of each variable in the calculation of energy savings is shown below in the Figure 6 equations.

$$Annual\ Savings\ (kWh) = \frac{Controlled\ Watts * Control\ Savings\ Factor\ (\%) * Operating\ Hours}{1000}$$

$$\boldsymbol{Lifetime\ Savings\ (kWh) = Annual\ Savings * Measure\ Life\ (years)}$$

Figure 6. Basic Equations for Lighting Control Annual and Lifetime Savings

Many TRMs include additional variables that are used to refine the savings estimate, such as an adjustment for the presence of pre-existing controls and factors to account for waste heat. The presence of pre-existing controls is important to consider, since a program can only claim the incremental savings beyond the baseline. While this report does not address these additional variables, they are included in the TRM workpaper in Appendix C. Incremental measure cost is included in the report, since it is a critical value in determining the cost effectiveness of a measure.

CONTROLLED WATTS

The amount of load (watts) controlled by a lighting system is a key variable used in the calculation of lighting control energy savings. This information can be provided as a reported value for the actual load of the controlled lighting, such as on custom projects and in some prescriptive programs. Alternatively, controlled watts can be a deemed value, such as in some prescriptive and nearly all midstream programs.

Of the 21 TRMs that have an NLC and/or LLLC measure, 16 (76%) rely on a reported value for controlled watts. This information must be provided by a customer or contractor on an incentive application. The other five TRMs use deemed values for controlled watts to represent the typical or average amount of controlled lighting load. A deemed value is often necessary for midstream programs since installation conditions are not typically reported at the time of sale.

Deemed controlled watts can be applied on a per-square foot basis (often for NLC) or per-luminaire basis (often for LLLC). If the value is per-square foot, then the project size in square feet must also be defined or reported. These deemed values vary by building type, since the type and amount of lighting will depend on the space. Table 2 presents the deemed controlled watts values for office building types. Recommendations for NLC and LLLC controlled watts are presented in Appendix C: TRM Workpaper.

Table 2. Deemed Values for Controlled Watts

State/Province	Control Type	Controlled Watts Input	Controlled Watts	Controlled Watts Unit
IL, IN, IA, MI	NLC-All	Deemed	0.61	per ft^2
IL, IN, IA	NLC-No LLLC	Deemed	0.61	per ft^2
IL, IN, IA	LLLC < 10,000 lumens	Deemed	31	per Luminaire
IL, IN, IA	LLLC >= 10,000 lumens	Deemed	118	per Luminaire
ON (Canada)	NLC-All	Deemed	0.79[8]	per ft^2

CONTROL SAVINGS FACTOR

Control Savings Factor (CSF) is a variable used to estimate the percentage reduction in energy consumption that results from implementing lighting control measures. It accounts for lighting being turned off and/or dimmed by different control strategies, such as occupancy sensors, daylight harvesting, and high-end trim. CSF is used in TRM savings algorithms to standardize the expected savings for various lighting control technologies, ensuring consistency across energy efficiency programs. CSF is sometimes referred to as control savings fraction, savings factor, or other similar terms.

Figure 7 shows the range of CSF assumptions across all TRMs identified in the study. While this report focuses on NLC and LLLC measures, non-networked control measures are included for reference.

[8] Ontario assigns different controlled watts values depending on the building type. The value presented here represents office buildings.

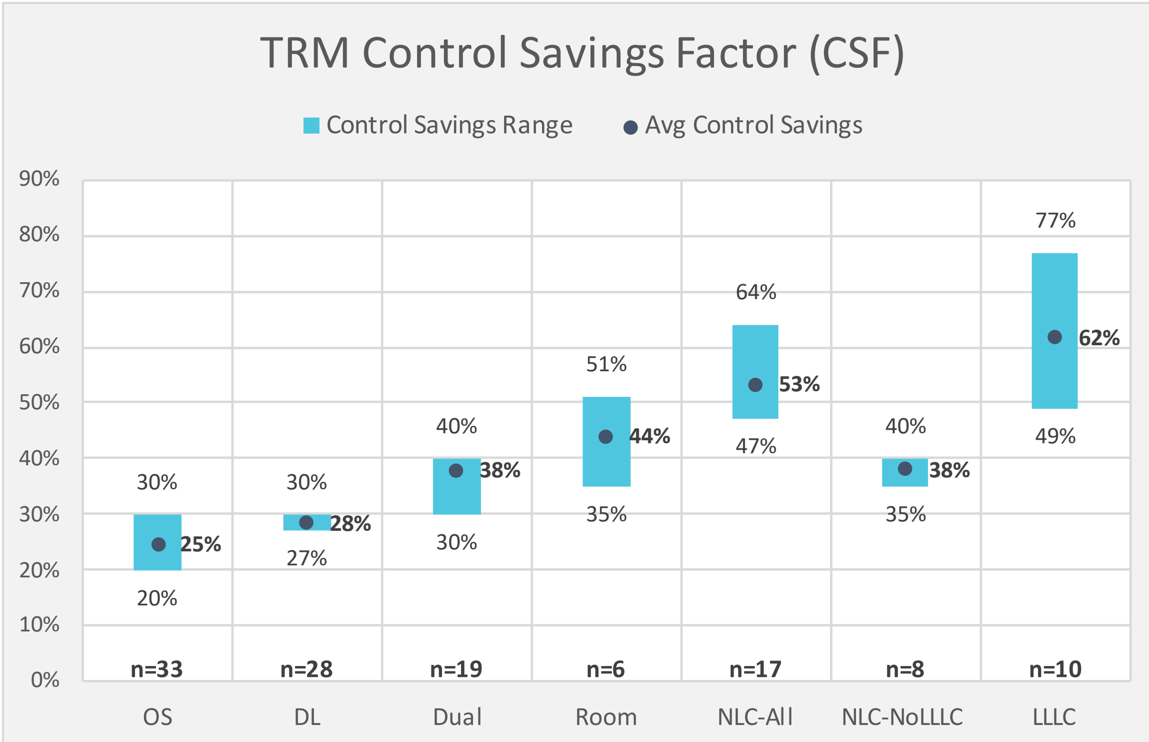

Figure 7. Control Savings Factor by Control Measure Type

The CSF findings for <u>non-networked measures</u> include:

- **Occupancy sensors (OS)** and **daylight sensors (DL**) are the most common control measures, appearing in 33 and 28 TRMs, respectively. The average CSF used for these control types is 25% for OS and 28% for DL.
- **Dual occupancy/daylight sensors (Dual)** demonstrate a higher energy savings potential than single-measure approaches, with an average CSF of 38%. 19 TRMs include this measure.
- Six TRMs include **room-based systems (Room)**, which have multiple control strategies but networking may be non-existent or limited to a single room. These systems have an average CSF of 44%.

The CSF findings for <u>networked measures</u> include:

- Measures for all types of **NLC systems (NLC-All)** are represented in 17 TRMs with an average CSF of 53%. However, this average is skewed by a few TRMs that use a much higher CSF. Most TRMs use a CSF of 49% based on the DLC/NEEA *Energy Savings from Networked Lighting Control (NLC) Systems with and without LLLC* report from 2020.[9]

[9] Wen et al. "Energy Savings from Networked Lighting Control (NLC) Systems with and without LLLC." DLC/NEEA, 2020. See Table 2, average value for "All NLCs." Available at https://designlights.org/resources/reports/report-energy-savings-from-networked-lighting-control-nlc-systems-with-and-without-lllc/.

- Eight TRMs include a measure for **NLC systems without LLLC (NLC-NoLLLC)**. The average CSF for these measures is considerably lower at 38%. Again, many TRMs reference the DLC/NEEA report that quantified an average savings value of 35% for NLC systems without LLLC.[10]
- **LLLC measures (LLLC)** are represented in 10 TRMs with an average CSF of 62%. This measure has the widest range of CSF assumptions, with the lowest at 49% (NJ, CT) and the highest assumed value at 77% (MN).

Detailed CSF values can be found in Appendix B: Database of NLC and LLLC Measures. Recommendations for NLC and LLLC control savings factors are presented in Appendix C: TRM Workpaper.

OPERATING HOURS

Operating hours refer to the number of hours per year that a lighting system is in use, before accounting for any reductions due to controls. TRMs define default operating hour values for different building types and sometimes even space types. These default values are critical for deemed savings estimates in incentive programs and are often based on measured data from state or regional studies. Typically, the default operating hours are applied across all lighting measures within a single TRM. Many energy efficiency programs use the default operating hours only if the actual hours are not reported or known.

Figure 8 below shows the average and range of annual operating hours for office buildings. There is very little variation across control types since the default operating hours are applied uniformly to all lighting control measures. A notable exception to this practice is the Illinois TRM, which provides a table of operating hours specifically for NLC and LLLC measures.[11] Illinois assigns higher annual operating hours to NLC and LLLC measures, based on the findings from the DLC/NEEA report. For example, the default annual operating hours for mid-rise office buildings in the Illinois TRM are 3,266, but for NLC and LLLC measures the assumed operating hours increases 4,453.

Detailed values for operating hours can be found in Appendix B: Database of NLC and LLLC Measures. Recommendations for NLC and LLLC operating hours are presented in Appendix C: TRM Workpaper.

[10] Ibid, average value for "NLCs w/o LLLC."
[11] Illinois TRM v13.0, Volume 2, Page 755

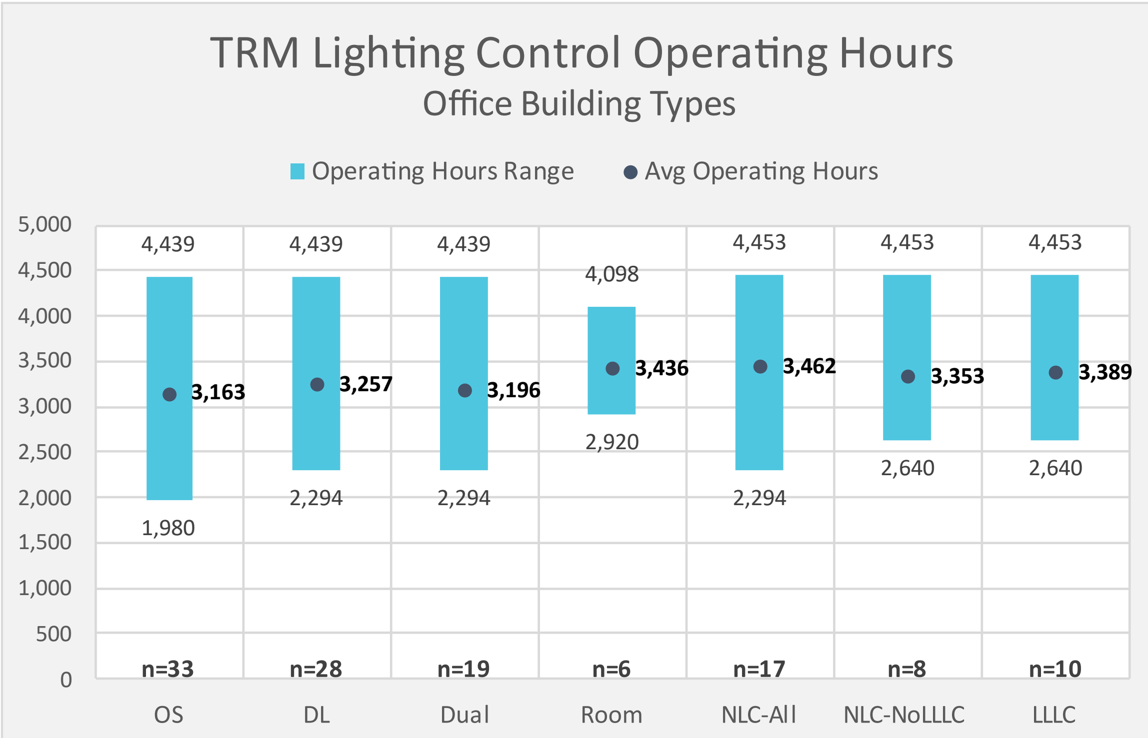

Figure 8. Operating Hours by Control Measure Type for Office Buildings

MEASURE LIFE

Measure life, also known as Effective Useful Life (EUL), represents the expected lifespan of energy savings before a measure fails, is disabled, or requires significant maintenance. Measure life is typically shorter than a product's functional life since there are factors that may cause energy savings to cease before the product fails. For lighting controls, an example limiting factor would be a sensor that is overridden due to occupant dissatisfaction.

TRMs use estimates of measure life to calculate lifetime energy savings as depicted in Figure 6. Many energy efficiency programs have goals based on annual energy savings, rather than lifetime, meaning the measure life in a TRM does not get much focus. However, since measure life is also a critical input into cost-effectiveness and the determination of program net benefits, the measure life value is deserving of attention. Measures with longer lives can improve the overall cost effectiveness of a program and may impact funding allocations and regulatory compliance.

The study findings for measure life across TRMs are shown in Figure 9.

- **Non-networked controls (OS, DL, Dual, Room)** have an average EUL of roughly 10 years, with some outliers as high as 15 years.
- **NLC measures (NLC-All)** have an incrementally higher average EUL of 11.5 years.

- The highest average EUL values were found for **NLC systems without LLLC (NLC-NoLLLC)** at 14.1 years and **LLLC systems** at 13.1 years. LLLC measures are frequently tied to the luminaire measure life, leading to extended measure life estimates.

Detailed measure life values can be found in Appendix B: Database of NLC and LLLC Measures. Recommendations for NLC and LLLC measure life are presented in Appendix C: TRM Workpaper.

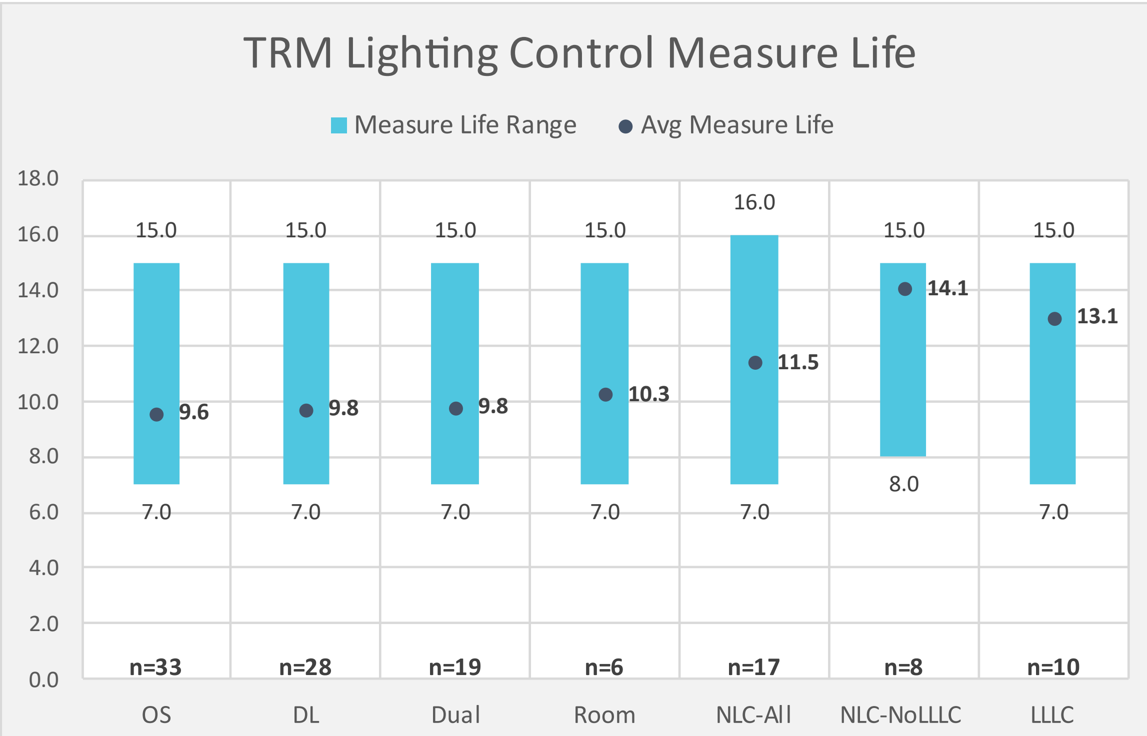

Figure 9. Measure Life by Control Measure Type

INCREMENTAL MEASURE COST

Incremental measure cost represents the difference between the cost of purchasing and installing a minimum efficiency or baseline piece of equipment and the cost of installing a high efficiency piece of equipment. For LLLC, the incremental cost represents the difference between an LED luminaire without LLLC functionality and an LED luminaire with LLLC functionality. For NLC, the incremental cost represents the difference between a lighting project without an NLC system and a lighting project with an NLC system.

Of the 21 states and provinces with NLC and/or LLLC measures in their TRM, only 8 include assumptions for the incremental cost associated with NLC and LLLC. Table 3 presents the costs associated with these eight states and provinces.

Table 3. Incremental Measure Costs for NLC and LLLC Measures

State/Province	Control Type	Cost	Unit
CO	NLC-All	\$0.72	per watt
DE	NLC-All	\$2.06	per ft^2
IL, IN, IA	LLLC	\$56.00	per luminaire
IL, IN, IA	NLC-All	\$0.40-\$0.86[12]	per ft^2
IL, IN, IA	NLC-NoLLLC	\$0.40-\$0.86[12]	per ft^2
MI	NLC-All	\$1.68	per ft^2
ON (Canada)	NLC-All	\$2.28	per ft^2
WI	NLC-All	\$0.57	per ft^2

KEY FINDINGS & RECOMMENDATIONS

This study identified several key insights regarding TRM availability, NLC/LLLC assumptions, and best practices:

- **TRM Coverage Variability:**
  TRM availability varies significantly by jurisdiction. While 26 states and provinces have updated TRMs within the past two years, 10 jurisdictions use TRMs that are more than three years old, raising concerns about outdated assumptions and methodologies as technology advances.

- **Gaps in NLC and LLLC Measures:**
  Many TRMs do not explicitly define NLC and LLLC measures, limiting the ability of programs to incentivize these advanced lighting control measures. Nearly 75% of TRMs have an opportunity to include or expand NLC and LLLC measures.

- **Inconsistencies in Key Assumptions:**
  There is wide variation in key TRM assumptions, including control savings factors, measure life, and operating hours. These inconsistencies lead to non-uniform savings calculations and a patchwork of incentive structures across different regions. Many stakeholders (including lighting and controls manufacturers, distributors, installers and end users) would benefit from the standardization of NLC and LLLC data requirements. In addition, greater consistency amongst North American TRMs can improve and streamline implementation and program tracking across jurisdictions.

- **Necessity for Regular Updates:**
  To maintain accuracy and relevance, TRMs should be updated regularly to reflect advancements in lighting control technologies, evolving energy codes, and the latest research findings.

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[12] The incremental cost varies depending on building size as follows: \$0.86 per ft^2 for buildings < 10,000 ft^2; \$0.59 per ft^2 for buildings between 10,000-100,000 ft^2; and \$0.40 per ft^2 for buildings > 100,000 ft^2.

Based on the findings of this research, the following recommendations should be considered by energy efficiency programs, public utility commissions, and other stakeholders:

1. **Develop Standardized Methodologies.** Establishing consistent frameworks for NLC and LLLC measures will enhance comparability across TRMs, improving program credibility and efficiency. Use the TRM workpaper in Appendix C to expedite the adoption of NLC and LLLC measures within TRMs and to improve consistency of measures across TRMs.
2. **Adopt Best Practices from Leading TRMs.** Many TRMs can serve as models for other jurisdictions, such as Illinois for its approach to operating hours, and multiple TRMs for their approach to distinct NLC & LLLC measures.
3. **Expand NLC and LLLC Measure Adoption.** Prioritize the inclusion and expansion of NLC and LLLC measures in the 26 states and provinces identified in Table 1. Consider including an NLC-HVAC integration measure based on the information in Appendix D.
4. **Improve Transparency and Update Frequency.** TRMs should be reviewed and updated every 1-2 years to ensure alignment with current technologies, policy changes, and market conditions.
5. **Enhance Stakeholder Collaboration.** Utilities, regulators, and industry experts should work together to refine TRM methodologies, leveraging shared knowledge and resources to create consistent, robust, and scalable energy efficiency programs.

CONCLUSION

TRMs play a crucial role in defining and guiding energy efficiency programs. While many TRMs already incorporate NLC and LLLC measures, significant opportunities exist to improve consistency, expand coverage, and refine key assumptions. Future efforts should prioritize standardization, periodic updates, and empirical data-driven refinement to enhance TRM accuracy and effectiveness. As new energy efficient technologies emerge, TRMs must evolve to provide the necessary guidance for successful implementation.

By implementing the recommendations outlined in this report, energy efficiency programs and their stakeholders can ensure that TRMs remain reliable, up-to-date, and instrumental in achieving sustainability goals. Simultaneously, the adoption of NLC and LLLC measures can be scaled up more rapidly.

APPENDIX A: DATABASE OF TRM RESOURCES

Country	State/ Province	**Resource Name** [links provided for public documents]	Version	Effective Date
Canada	AB	Energy Efficiency Alberta TRM [website, pdf]	v1	11/1/2020
Canada	NB	NB Power Technical Reference Manual [website, etrm]	v1.77.3	1/1/2024
Canada	ON	IESO Technical Reference Manual [website]		7/17/2020
U.S.	AR	Arkansas TRM [pdf]	v9.1	10/20/2022
U.S.	CA	California Electronic Technical Reference Manual [website]	2025	1/1/2025
U.S.	CO	Public Service Company of Colorado Technical Reference Manual [website, pdf]	2024-2026	1/1/2024
U.S.	CT	Connecticut's 2024 Program Savings Document [website, pdf]	2025	11/1/2024
U.S.	DE	Delaware Technical Reference Manual	v2.0	4/1/2023
U.S.	DC	Mid-Atlantic Technical Reference Manual[13] [website, pdf]	v10	5/1/2020
U.S.	HI	Hawai'i Energy Efficiency Program Technical Reference Manual [website, xlsx]	PY 2023	6/13/2023
U.S.	ID	Regional Technical Forum [website, xlsm]	v7.0	2/12/2025
U.S.	IL	Illinois Statewide Technical Reference Manual [website, pdf]	v13	1/1/2025
U.S.	IN	Indiana Technical Reference Manual Workbook [website, xlsx]	v1.0	8/21/2023
U.S.	IO	Iowa Energy Efficiency Statewide Technical Reference Manual [website, pdf]	v9.0	1/1/2025
U.S.	LA	New Orleans Technical Reference Manual [pdf]	v7	11/21/2023
U.S.	ME	Efficiency Maine Technical Reference Manual [website, pdf]	2025.1	7/1/2024
U.S.	MD	Mid-Atlantic Technical Reference Manual [website, pdf]	v10	5/1/2020
U.S.	MA	Massachusetts Technical Reference Manual [website, pdf]	2025-2027	10/31/2024
U.S.	MI	Michigan Energy Measures Database (MEMD) [website, xlsx]	2024	1/1/2024
U.S.	MN	State of Minnesota Technical Reference Manual [website, pdf]	v4.1	1/1/2025
U.S.	MO	Missouri Technical Reference Manual [website, pdf]		3/31/2017
U.S.	MT	Regional Technical Forum [website, xlsm]	v7.0	2/12/2025
U.S.	NH	New Hampshire Technical Reference Manual	2022	3/1/2022
U.S.	NJ	New Jersey 2023 Triennial Technical Reference Manual [pdf]	2023	5/22/2023
U.S.	NM	New Mexico Technical Resource Manual [website]	2023	3/24/2023
U.S.	NY	Technical Resource Manual [website, pdf]	v12.0	1/1/2025
U.S.	OH	State of Ohio Energy Efficiency Technical Reference Manual[14] [pdf]	2020	9/23/2019
U.S.	OR	Regional Technical Forum [website, xlsm]	v7.0	2/12/2025
U.S.	PA	Pennsylvania Technical Reference Manual [website, pdf]	2024	9/1/2024
U.S.	RI	Rhode Island Technical Reference Manual [pdf]	2024	10/1/2023
U.S.	TN	Tennessee Valley Authority TRM	v6	1/1/2017
U.S.	TX	Texas Technical Reference Manual [website, pdf]	v12.0	1/1/2025
U.S.	VT	Efficiency Vermont TRM [pdf]	2024	1/1/2024
U.S.	VA	Standard Tracking and Engineering Protocols Manual	v10.0	1/1/2020
U.S.	WA	Regional Technical Forum [website, xlsm]	v7.0	2/12/2025
U.S.	WI	Wisconsin Focus on Energy Technical Reference Manual [pdf]	2025	1/29/2025

[13] The DC Sustainable Energy Utility uses its own TRM, which is not available publicly and does not contain NLC/LLLC measures.

[14] The Efficiency Smart program in Ohio, available in select municipalities, uses its own TRM, which is not public and does not include NLC/LLLC measures.

APPENDIX B: DATABASE OF NLC AND LLLC MEASURES

Country	State/ Province	Measure ID	Control Type	Control Name in TRM	Remote or Luminaire Mounted	NC Eligible	Retrofit Eligible	Control Savings Factor	Measure Life	Operating Hours (Office)
Canada	Ontario	N/A	NLC-All	Networked Lighting Controls	Both	No	Yes	0.63	16	3610
U.S.	Colorado	14.1	NLC-All	Networked Lighting Controls (w & w/o LLLC)	Both	Yes	Yes	0.49	15	3266
U.S.	Connecticut	2.1.3	NLC-All	Networked lighting controls (NLC)	Both	Yes	Yes	0.49	7	4098
U.S.	Connecticut	2.1.3	LLLC	Luminaire-level lighting controls (LLLC) – Networked & Cx	Luminaire	Yes	Yes	0.49	7	4098
U.S.	District of Columbia	CI_LT_RF_NLC_0619 CI_LT_NC_NLC_0619	NLC-All	Networked Lighting Controls	Both	Yes	Yes	0.63	10	3009
U.S.	Delaware	CI_LT_RF_NLC_0619 CI_LT_NC_NLC_0619	NLC-All	Networked Lighting Controls	Both	Yes	Yes	0.63	10	3009
U.S.	Iowa	3.4.12	NLC-All	Interior Networked Lighting Controls (unknown or mixed LLLCs)	Both	Yes	Yes	0.49	15	2920
U.S.	Iowa	3.4.12	NLC-NoLLLC	Interior Networked Lighting Controls Only with No LLLCs	Remote	Yes	Yes	0.35	15	2920
U.S.	Iowa	3.4.12	LLLC	Interior Networked Luminaire-Level Lighting Controls	Luminaire	Yes	Yes	0.61	15	2920
U.S.	Idaho		NLC-NoLLLC	Networked Lighting Controls	Remote	No	Yes	0.40	15	2640
U.S.	Idaho		LLLC	Luminaire Level Lighting Control	Luminaire	No	Yes	0.65	15	2640
U.S.	Illinois	4.5.10	NLC-All	Interior Networked Lighting Controls (unknown or mixed LLLCs)	Both	No	Yes	0.49	15	4453
U.S.	Illinois	4.5.10	NLC-NoLLLC	Interior Networked Lighting Controls Only with No LLLCs	Remote	No	Yes	0.35	15	4453
U.S.	Illinois	4.5.10	LLLC	Interior Networked Luminaire-Level Lighting Controls	Luminaire	No	Yes	0.61	15	4453
U.S.	Indiana	4.5.10	NLC-All	Interior Networked Lighting Controls 10,000-100,000 sqft building	Both	No	Yes	0.49	15	4453

Country	State/ Province	Measure ID	Control Type	Control Name in TRM	Remote or Luminaire Mounted	NC Eligible	Retrofit Eligible	Control Savings Factor	Measure Life	Operating Hours (Office)
U.S.	Indiana	4.5.10	NLC-NoLLLC	Interior Networked Lighting Controls Only with No LLLCs	Remote	No	Yes	0.35	15	4453
U.S.	Indiana	4.5.10	LLLC	Interior Luminaire-Level Lighting Controls < 10,000 Lumens	Luminaire	No	Yes	0.61	15	4453
U.S.	Massachusetts	3.6	NLC-All	Networked Lighting Controls (NLC)	Both	Yes	Yes	0.49	10	4171
U.S.	Maryland	CI_LT_RF_NLC_0619 CI_LT_NC_NLC_0619	NLC-All	Networked Lighting Controls	Both	Yes	Yes	0.63	10	3009
U.S.	Michigan	N-CO-LI-000782-E-XX-XX-XX-XX-01	NLC-All	Networked Lighting Controls	Both	Yes	Yes	0.47	8	2669
U.S.	Minnesota	4.1	NLC-All	Networked lighting controls (NLC)	Both	Yes	Yes	0.64	8	4439
U.S.	Minnesota	4.1	NLC-NoLLLC	Networked lighting controls without LLLC	Remote	Yes	Yes	0.40	8	4439
U.S.	Minnesota	4.1	LLLC	Luminaire Level Lighting Control (LLLC)	Luminaire	Yes	Yes	0.77	11	4439
U.S.	Montana		NLC-NoLLLC	Networked Lighting Controls	Remote	No	Yes	0.40	15	2640
U.S.	Montana		LLLC	Luminaire Level Lighting Control	Luminaire	No	Yes	0.65	15	2640
U.S.	New Jersey	3.7.2	NLC-All	Networked lighting controls (NLC)	Both	Yes	Yes	0.49	8	2969
U.S.	New Jersey	3.7.2	LLLC	Luminaire-level lighting controls (LLLC) – Networked & Commissioned	Luminaire	Yes	Yes	0.49	8	2969
U.S.	New York		NLC-All	Networked Lighting Controls	Both	No	Yes	0.49	15	3013
U.S.	Oregon		NLC-NoLLLC	Networked Lighting Controls	Remote	No	Yes	0.40	15	2640
U.S.	Oregon		LLLC	Luminaire Level Lighting Control	Luminaire	No	Yes	0.65	15	2640
U.S.	Pennsylvania	3.1.1	NLC-All	Networked Lighting Controls	Both	No	Yes	0.49	8	2294
U.S.	Texas	2.1.2	NLC-All	Networked lighting control	Both	Yes	Yes	0.49	10	3737
U.S.	Washington		NLC-NoLLLC	Networked Lighting Controls	Remote	No	Yes	0.40	15	2640
U.S.	Washington		LLLC	Luminaire Level Lighting Control	Luminaire	No	Yes	0.65	15	2640
U.S.	Wisconsin	W0288	NLC-All	Networked Lighting Controls for New Construction	Both	Yes	No	0.56	15	3730

APPENDIX C: TRM WORKPAPER

The TRM workpaper is available on the MyDLC Dashboard under Member Resources and on the next page of this document.

TRM WORKPAPER

Networked and Luminaire Level Lighting Controls Measure Characterization

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ACKNOWLEDGEMENTS:

We gratefully acknowledge the contributions of the following individuals who shared their insights and expertise as peer reviewers.

Amy Dickerson, National Grid
Chris Wolgamott, Northwest Energy Efficiency Alliance
Sam Dent, VEIC

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
C&I	Commercial and Industrial
CSF	Control Savings Factor
DLC	DesignLights Consortium
EFG	Energy Futures Group
EUL	Effective Useful Life
IECC	International Energy Conservation Code
NEEA	Northwest Energy Efficiency Alliance
NLC	Networked Lighting Controls
NLC-All	Networked Lighting Controls with an unknown presence of LLLC
NLC-NoLLLC	Networked Lighting Controls without LLLC
LLLC	Luminaire-Level Lighting Controls
QPL	Qualified Products List
RTF	Regional Technical Forum
TRM	Technical Reference Manual

WORKPAPER PURPOSE AND OVERVIEW

This workpaper was developed by Energy Futures Group (EFG) on behalf of the DesignLights Consortium (DLC)and it's utility and energy efficiency program members. The purpose of this workpaper is to provide a guide for calculating the energy and demand savings associated with networked lighting controls (NLC) and luminaire-level lighting controls (LLLC). NLC and LLLC present substantial savings opportunities, yet these measures are not included in all program offerings or Technical Reference Manuals (TRMs). This workpaper provides a template for a state, province or utility to easily incorporate these measures within an existing TRM or similar engineering resource.

For states, provinces or utilities that already incorporate these measures, this workpaper presents a recommended set of input value assumptions and sources that should be considered for future TRM updates. Program implementers, lighting controls manufacturers, and lighting market actors installing these products would all benefit from the standardization of NLC and LLLC data requirements. In addition, greater consistency amongst North American TRMs can improve and streamline implementation and program tracking across jurisdictions.

DLC Member utilities and energy efficiency programs (and their authorized implementation contractors and evaluators) are invited to utilize recommendations and values in this paper to populate their own workpapers to submit new NLC and LLLC savings measures to their state, province, or regional TRMs.

EFG conducted a detailed review of 36 known TRMs in use throughout North America. Our review revealed 21 states or provinces with TRMs that include NLC, LLLC, or both, as measures with energy and demand savings calculations. EFG reviewed each of these TRMs to identify the algorithms, input variables, and values assumed for NLC and LLLC savings calculations. Below we present the findings associated with this research, the range of values assumed for key variables in the current literature, and recommended values for adoption in any future TRM applications.

This workpaper is accompanied by the report, "A Review of Technical Reference Manuals in the U.S. and Canada: Networked and Luminaire-Level Lighting Control Measure Prevalence and Best Practices," prepared by Energy Futures Group for DesignLights Consortium. This report provides a comprehensive analysis of TRMs in North America, focusing on NLC and LLLC measures. Please contact the DLC with any questions or feedback on the workpaper or the report at info@designlights.org.

KEY VARIABLES FOR SAVINGS CALCULATIONS

This section provides a detailed summary of the key variables that are used for calculating savings for NLC and LLLC measures. Specifically, this section provides a definition of key variables, a summary of the values used by current TRMs for each variable, and the DLC recommended value and source.

CONTROL SAVINGS FACTOR

Control Savings Factor (CSF) is a variable used to estimate the percentage reduction in energy consumption that results from implementing lighting control measures. It accounts for lighting being turned off and/or dimmed by different control strategies, such as occupancy sensors, daylight harvesting, and high-end trim. CSF is used in TRMs to standardize the expected savings for various lighting control technologies, ensuring consistency across energy efficiency programs. CSF is sometimes referred to as control savings fraction, savings factor, or other similar terms.

SUMMARY OF CURRENT TRMS

NLC-All

Of the 21 states or provinces with TRMs that were identified as including algorithms for NLC or LLLC, 17 of them (81%) include CSFs for NLC generically or for NLC where the presence of LLLC is unknown (also referred to as '***NLC-All***'). The mean CSF among the 17 TRMs was 0.53 while the median was 0.49.

Table 1. Summary of NLC-All CSF Values

	NLC-All CSF Values	States or Provinces Covered
n	*17*	ON (Canada), CO, CT, DE, DC, IL, IN, IA, MD, MA, MI, MN, NJ, NY, PA, TX, WI
Min	0.47	
Max	0.64	
Mean	0.53	
Median	0.49	

Of the 17 TRMs that include NLC where the presence of LLLC is unknown:

- 10 exclusively define a CSF for NLC with an unknown LLLC presence.
- 4 define CSFs for LLLC, NLC without LLLC, and NLC with an unknown LLLC presence.

- 3 define CSFs for NLC with an unknown LLLC presence and for LLLC as a stand-alone measure. In each of these instances the CSF is the same for NLC with an unknown LLLC presence and for LLLC.

Two TRMs, covering a total of three states, include CSFs for different building types. In these instances, the 'Office' building type is used in the results presented in Table 1.

NLC-NoLLLC

Based on our review, there are currently eight states or provinces where the TRMs provide a CSF for NLC and specify that the CSF is for NLC without the inclusion of LLLC (also referred to as '***NLC-NoLLLC***'). Table 2 provides a summary of the CSF values from the eight TRMs that include a NLC-NoLLLC measure. As shown, there is a tight range of CSFs – the mean CSF is 0.38 and the median is 0.40. Four states – Idaho, Montana, Oregon, and Washington – all use the Northwest Power and Conservation Council's Regional Technical Forum (RTF) as the foundation for their savings calculations.

Table 2. Summary of NLC-NoLLLC CSF Values

	NLC-NoLLLC CSF Values	States or Provinces Covered
n	*8*	ID, IL, IN, IA, MN, MT, OR, WA
Min	0.35	
Max	0.40	
Mean	0.38	
Median	0.40	

Two TRMs, covering a total of five states, include CSFs for different building types. In these instances, the 'Office' building type is used in the results presented in Table 2.

LLLC

Our research identified 10 states or provinces where the current TRMs include LLLC as a measure with distinct savings assumptions. Table 3 presents a summary of the range of values currently used for LLLC CSF. As shown, the range of CSF values used for LLLC ranges from 0.49 to 0.77, with an average of 0.62 and a median of 0.63.

Table 3. Summary of LLLC CSF Values

	LLLC CSF Values	States or Provinces Covered
n	*10*	CT, IA, ID, IL, IN, MN, MT, NJ, OR, WA
Min	0.49	
Max	0.77	
Mean	0.62	
Median	0.63	

Two states – Connecticut and New Jersey – are using a CSF of 0.49 for both NLC and LLLC. The technologies are split into distinct lighting control types within these TRMs, but both NLC and LLLC use the same value. Again, it is worth pointing out that four states – Idaho, Montana, Oregon, and Washington – all use the Northwest Power and Conservation Council's RTF as the foundation for their savings calculations. The RTF recently updated the CSF for LLLC from 0.60 to 0.65.

Two TRMs, covering a total of five states, include CSFs for different building types. In these instances, the 'Office' building type is used in the results presented in Table 3.

Recommendations

We recommend that TRM administrators adopt two measures to cover NLC:

- NLC without LLLC (NLC-NoLLLC)
- LLLC

As detailed in Table 1, many TRMs currently offer a deemed CSF for NLC where the presence of LLLC is unknown. This is useful to the extent that a program is tracking the presence of NLC, but not LLLC. However, this value offers a CSF that is quite a bit higher than the CSF associated with NLC-NoLLLC (see Table 2). This results in the potential to overstate savings in a scenario where 1) NLC-NoLLLC are installed and 2) the only CSF available covers NLC where the presence of LLLC is unknown. Of course, this also results in the potential to understate savings in the case where 1) LLLC are installed and 2) the only CSF available covers NLC where the presence of LLLC is unknown.

For these reasons, we advocate that program administrators ensure they are tracking the presence of both NLC and LLLC as part of their program implementation. This will allow for more detailed granularity when applying CSFs and other factors, such as measure life, while reducing evaluation risks. Table 4 presents our recommended CFS values for NLC-NoLLLC and LLLC. These values are consistent with the findings from the 2020 NEEA and DLC report titled "*Energy Savings from Networked Lighting Control Systems With and Without Luminaire Level Lighting Controls*". This report, which recently had a clarifications memo published, is the primary source of NLC and LLLC CSF assumptions in the TRMs that we reviewed. Our research did not uncover a more recent set of primary research results on these values, and therefore we suggest that TRM administrators adopt these values for NLC and LLLC moving forward.

Table 4. Recommended CSF Values

Control Type	CSF
NLC-NoLLLC	0.35
LLLC	0.63

OPERATING HOURS

Operating hours refer to the number of hours per year that a lighting system is in use, before accounting for any reductions due to controls. TRMs define default operating hour values for different building types and sometimes even space types. These default values are critical for deemed savings estimates in incentive programs and are often based on measured data from state or regional studies. Typically, the default operating hours are applied across all lighting measures within a single TRM. Many energy efficiency programs use the default operating hours only if the actual hours are not reported or known.

Summary of Current TRMs

All of the TRMs included in our review specify unique operating hours based on the building type in which the lighting controls are installed. In most instances, the operating hours for different building types are used for all deemed savings calculations associated with lighting measures in the commercial and industrial (C&I) sector. The number of building types and the operating hours associated with them varies considerably from jurisdiction to jurisdiction. Figure 1 presents the range of operating hours for 'Office' building types in TRMs that include NLC and/or LLLC; this is a good example of the wide variation associated with operating hours across TRMs.

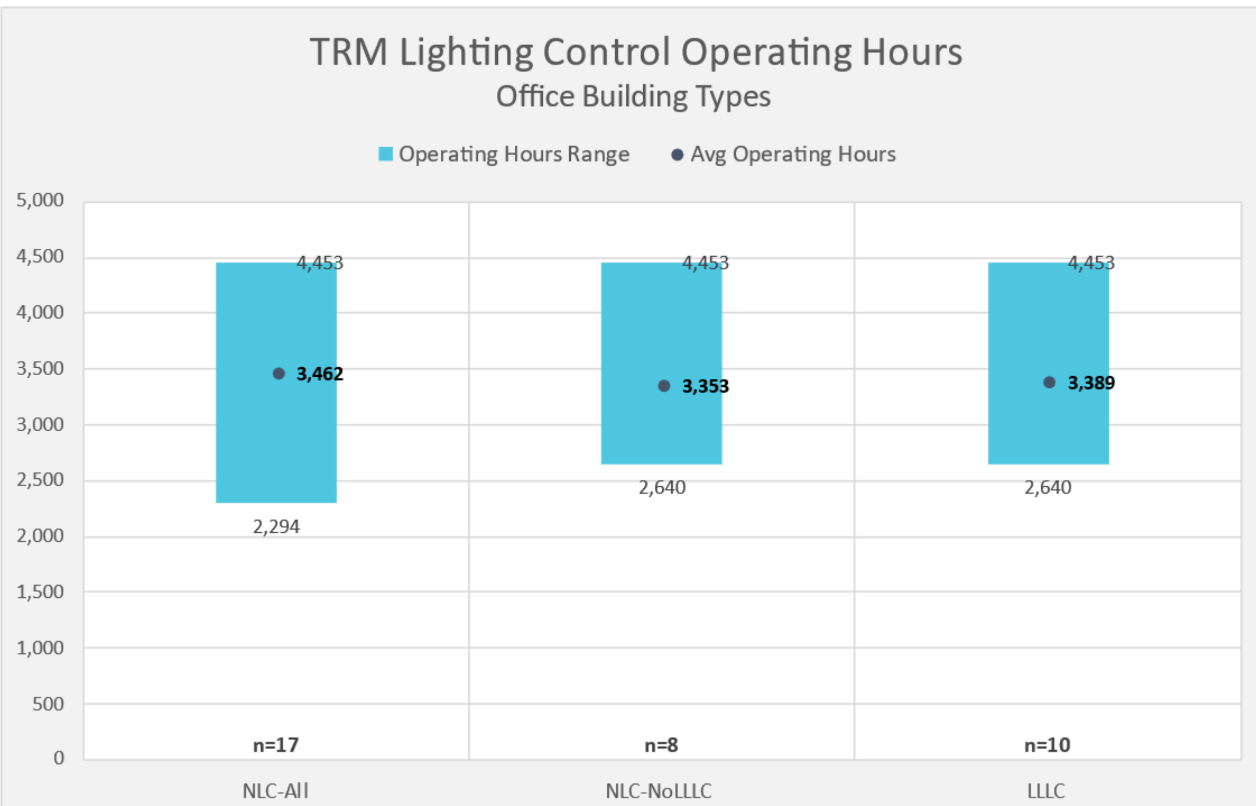

Figure 1. TRM Operating Hours for NLC and LLLC

Two TRMs (Illinois, and by extension Indiana which references the Illinois measure) use operating hours from the 2020 NEEA/DLC study that looked at savings from NLC with and without LLLC. That study found that the inferred operating hours calculated for buildings with NLC systems were higher than what most TRMs assumed for the majority of building types. The report notes that this could be due to buildings with longer operating hours being naturally inclined to implement NLC systems. The study appropriately points out that this suggests the current operating hours used by many TRMs could underestimate the impact of NLC and LLLC systems. Table 5 presents the values currently used in the Illinois TRM for NLC and LLLC, which originate from the 2020 NEEA/DLC study on savings for NLC with and without LLLC.

Table 5. Annual Operating Hours for NLC and LLLC, by Building Type, in Illinois TRM v13.0

General Building Type	Annual Hours of Use
Education	4,231
Manufacturing	5,365
Office	4,453
Retail	6,936
Warehouse	5,116
All Other	Use local operating hour assumptions associated with different building types for other C&I lighting measures

Recommendations

We recommend that TRM administrators use the values presented in Table 5 for each of the five building types with operating hours from the NEEA/DLC study.[1] The NEEA/DLC study included projects from all over the United States and Canada, ultimately covering 110 different buildings. As previously noted, the study found that buildings with NLC and LLLC systems are likely to have higher operating hours than the default values specified in most TRMs. The values in Table 5 represent these higher operating hours and will result in higher savings associated with NLC and LLLC systems.

For all building types outside of those listed in Table 5, we recommend that TRM administrators use the values that are currently defined in their existing TRM for other C&I lighting measures.

We recommend that TRM administrators consider documenting the difference between buildings with and without NLC and LLLC systems when updating operating hour assumptions. Any primary research that accounts for these differences should supersede the values recommended in Table 5.

CONTROLLED WATTS

The amount of load (watts) controlled by a lighting system is a key variable used in the calculation of lighting control energy savings. This information can be provided as a reported value for the actual load of the controlled lighting, such as on custom projects and in some prescriptive programs. Alternatively, controlled watts can be a deemed value, such as in some prescriptive and nearly all midstream programs.

[1] The inferred operating hours for “Assembly”, “Healthcare”, and “Restaurant” were excluded due to the reported small sample sizes in the NEEA/DLC study.

Summary of Current TRMs

Of the 21 states or provinces that have an NLC and/or LLLC measure in their TRM, 16 (76%) rely on a reported value for controlled watts. This information must be provided by a customer or contractor on an incentive application. The other five use deemed values for controlled watts to represent the typical or average amount of controlled lighting load. A deemed value is often necessary for midstream programs since installation conditions are not typically reported at the time of sale.

Deemed controlled watts can be applied on a per-square foot basis (often for NLC) or per-luminaire basis (often for LLLC). If the value is per-square foot, then the project size in square feet must also be defined or reported. Table 6 presents the deemed values used for controlled watts in each of the five TRMs where a deemed approach is incorporated for controlled watts. Four of the five TRMs – Illinois, Indiana, Iowa, and Michigan – are all based on the same assumptions. Ontario incorporates controlled watts by building type, and the value shown in Table 6 is an average across all building types.

Table 6. Deemed Values for Controlled Watts

State/Province	Control Type	Controlled Watts Input	Controlled Watts	Controlled Watts Unit
IL, IN, IA, MI	NLC-All	Deemed	0.61	per ft^2
IL, IN, IA	NLC-NoLLLC	Deemed	0.61	per ft^2
IL, IN, IA	LLLC < 10,000 lumens	Deemed	31	per Luminaire
IL, IN, IA	LLLC >= 10,000 lumens	Deemed	118	per Luminaire
ON (Canada)	NLC-All	Deemed	0.82	per ft^2

Recommendations

We recommend that the total wattage controlled by NLC and/or LLLC be collected from the customer and documented as part of the program implementation process whenever possible. These wattages should be used to calculate the savings associated with these systems. This will result in the most accurate savings possible for each NLC/LLLC application. Typically, reported values will be feasible on prescriptive and custom programs, but may not be practical to collect on midstream programs. Accordingly, we recommend that midstream LLLC programs rely on the reported wattage on the DLC qualified products list (QPL) for the luminaire(s) associated with the LLLC.

For luminaires with selectable wattage ranges, we recommend that the same wattage assumptions be used for both the luminaire and the luminaire controls. It is important to maintain consistency across the savings calculations used for both luminaires and controls, both of which should represent the installed conditions for luminaires with selectable wattages.

MEASURE LIFE

Measure life, also known as Effective Useful Life (EUL), represents the expected lifespan of energy savings before a measure fails, is disabled, or requires significant maintenance. Measure life is typically shorter than a product's functional life since there are factors that may cause energy savings to cease before the product fails. For lighting controls, an example limiting factor would be a sensor that is overridden due to occupant dissatisfaction.

Summary of Current TRMs

Our team reviewed the measure life associated with NLC and/or LLLC in each of the 21 states/provinces with TRMs covering these measures. Figure 2 presents the range of findings associated with the TRMs included in our analysis. As shown, the average measure life was 11.5 years for NLC-All, 14.1 years for NLC-NoLLLC, and 13.1 years for LLLC.

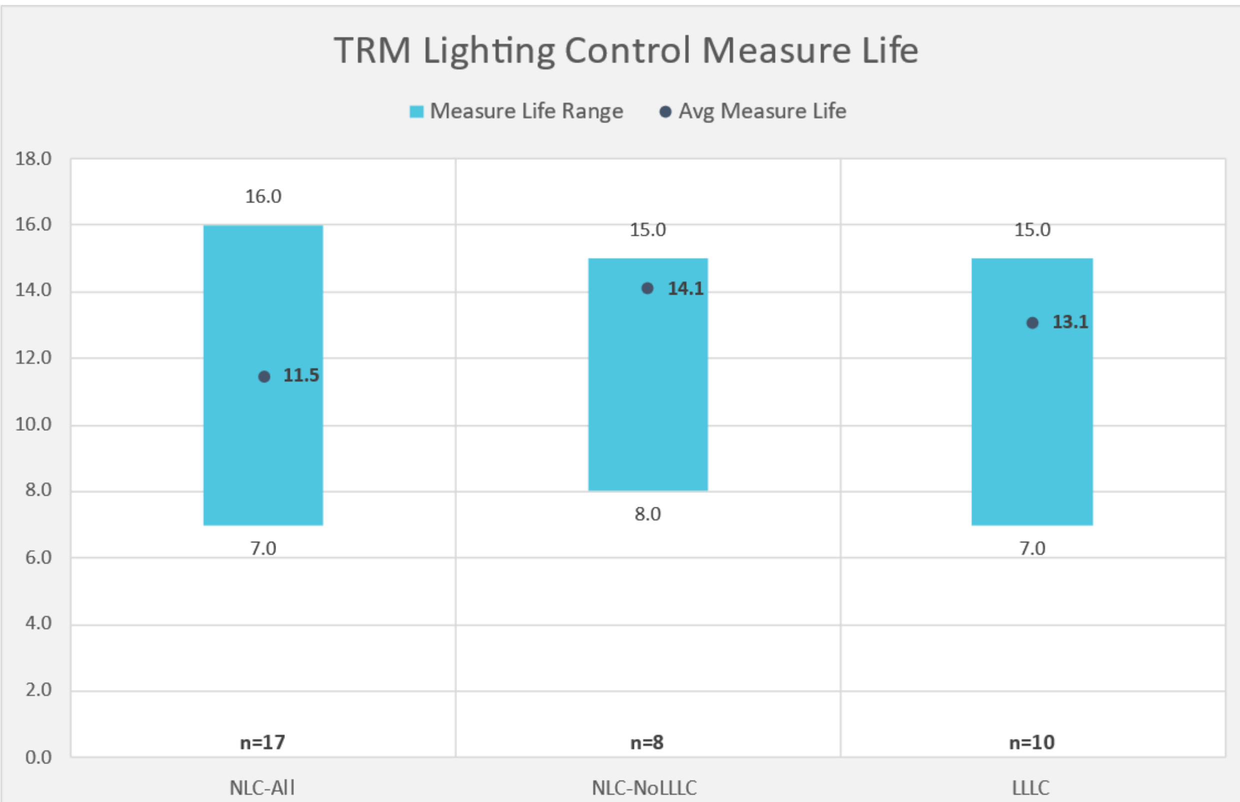

Figure 2. Measure Life

The Minnesota TRM prescribes a different measure life for NLC and LLLC – this was the only state in our review that includes both NLC and LLLC measures and offers different measure life values for the two technologies. The TRM notes that LLLC are integrated into luminaires and, as a result, the measure life for LLLC should be equivalent to that of the luminaire. Minnesota uses a measure life assumption of 11 years for LEDs, and this same value is applied to LLLC. The measure life for NLC-NoLLLC is 8 years and is consistent with the measure life of other non-LLLC lighting control technologies.

Recommendations

We recommend that TRM administrators take the following approach when determining measure lives for NLC-NoLLLC and for LLLC measures.

- For NLC-NoLLLC, use the measure life associated with other C&I lighting control measures.
- For LLLC, use the measure life associated with C&I LED luminaires.

Most TRMs that include both NLC-NoLLLC and LLLC measures use the same measure life for both. However, the logic associated with the Minnesota TRM is sound and reflects the reality that LLLC are an integrated component of LED luminaires, and the measures lives should be identical.

INCREMENTAL MEASURE COST

Incremental measure cost represents the difference between the cost of purchasing and installing a minimum efficiency or baseline piece of equipment and the cost of installing a high efficiency piece of equipment. For LLLC, the baseline is typically an LED luminaire without LLLC functionality, and the upgrade case is an LED luminaire with LLLC functionality. For NLC, the baseline is a lighting project without an NLC system[2], and the upgrade case is a lighting project with an NLC system. The baseline for a new construction project would be the minimum controls required by code.

Summary of Current TRMs

Of the 21 states and provinces with NLC and/or LLLC measures in their TRM, only 8 include assumptions for the incremental cost associated with NLC and LLLC. Table 7 presents the costs associated with these eight states and provinces. The incremental costs are reported in different units across different technologies and jurisdictions. Figure 3 presents the incremental costs from Table 7 only the per luminaire costs for LLLC have been converted to a per square foot estimate.[3] As shown, the incremental costs associated with these technologies have generally declined over time and that is reflected in the more recent TRM resources.

[2] The baseline scenario may include existing controls.

[3] This figure excludes Colorado which reports incremental costs in terms of dollars per watt. The LLLC incremental cost was converted from per luminaire to per square feet using an assumption of 100 square feet per LLLC luminaire. 'NLC-All' and 'NLC-NoLLLC' were merged in the figure as the incremental costs are the same for these two measures in each of the jurisdictions that cover both.

Table 7. Incremental Measure Costs for NLC and LLLC Measures

State/Province	Control Type	Cost	Unit
CO	NLC-All	$0.72	per watt
DE	NLC-All	$2.06	per ft^2
IL, IN, IA	LLLC	$56.00	per luminaire
IL, IN, IA	NLC-All	$0.40-$0.86[4]	per ft^2
IL, IN, IA	NLC-NoLLLC	$0.40-$0.86[Error! Bookmark not defined.]	per ft^2
MI	NLC-All	$1.68	per ft^2
ON (Canada)	NLC-All	$2.28	per ft^2
WI	NLC-All	$0.57	per ft^2

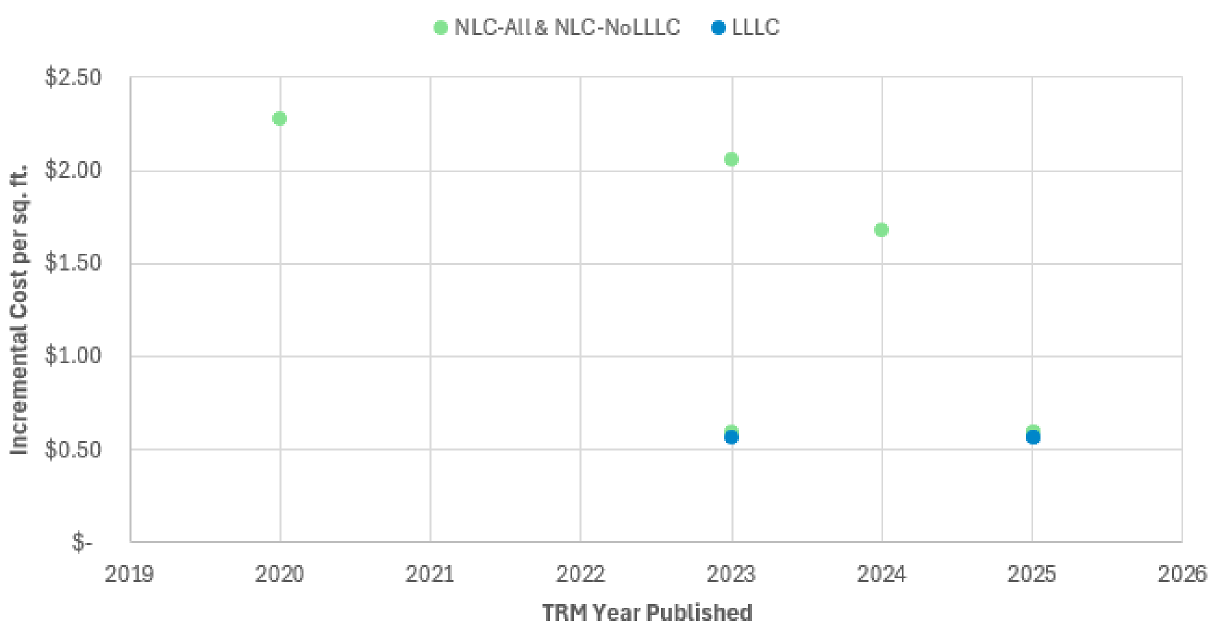

Figure 3. Incremental Cost per Square Foot

Recommendations

We recommend that TRM administrators use the values in Table 8 for incremental measure costs. The incremental cost for LLLC comes from a [2022 NEEA incremental cost study] and represents the average incremental cost of three different LLLC technologies. The 2022 study is an update to a 2020 NEEA incremental cost study that is referenced by half of the states/provinces listed in Table 7. The incremental cost we recommend for NLC-NoLLLC measures is $0.53 per square foot. This is based on the

[4] The incremental cost varies depending on building size as follows: $0.86 per ft^2 for buildings < 10,000 ft^2; $0.59 per ft^2 for buildings between 10,000-100,000 ft^2; and $0.40 per ft^2 for buildings > 100,000 ft^2.

same data from the 2022 NEEA study and assumes an LLLC luminaire typically covers 100 square feet.[5] We recommend using the incremental cost associated with LLLC as a proxy for NLC; this is due to the fact that the most recent incremental cost research associated with NLC-NoLLLC systems is a 2019 study from California. The 2022 NEEA study shows that the incremental costs for LLLC have come down in recent years, and as a result we believe the more recent LLLC data is more accurate than the 2019 study data on NLC-NoLLLC systems.

Table 8. Recommended Incremental Cost Values

Control Type	Cost	Unit
NLC-NoLLLC	$0.53	per ft^2
LLLC	$53.00	per luminaire

DRAFT TRM MEASURE CHARACTERIZATION

The sections below are intended to offer TRM administrators an easily accessible template for adopting and/or updating NLC and LLLC measure characterizations into their TRMs. Our intent is that the sections below can easily be incorporated into TRMs across the country with minimal need for customization.

TECHNOLOGY SUMMARY

For the purposes of this workpaper we are using the following definitions for NLC and LLLC.

Networked Lighting Controls (NLC) refer to advanced lighting control systems that combine sensors, network interfaces, and controllers to effect lighting changes in luminaires, retrofit kits, or lamps. These systems integrate multiple control strategies such as occupancy sensing, daylight harvesting, high-end trim, and scheduling to provide enhanced energy savings, automation, and performance tracking.

Luminaire-Level Lighting Controls (LLLC) are a subset of NLCs that use embedded sensors and controls within individual luminaires, enabling more granular control, easier installation, and increased flexibility.

BASE CASE DESCRIPTION

Retrofit

The baseline for any retrofit scenario is assumed to be the existing lighting system and can include manual or no controls or an existing control strategy that is being improved. Note, where an existing inefficient luminaire is replaced with an efficient luminaire control, use the luminaire measure to calculate savings from the wattage reduction first, then assume the efficient luminaire without control as the baseline for the control measure.

[5] The assumption of 100 square feet represents the midpoint of values reported by the Lighting Controls Association: https://lightingcontrolsassociation.org/2022/06/15/introduction-to-luminaire-level-lighting-controls/.

New Construction

In a new construction or lost opportunity scenario, the baseline should be based on the energy code that is in place for new construction in any given jurisdiction. For example, beginning with the 2012 International Energy Conservation Code (IECC), occupancy sensors are required in certain space types such as classrooms and private offices. The types of spaces included in this requirement have been expanded with recent iterations of the energy code and now include various office types, which are common space types for NLC and LLLC applications. Program administrators should use any local code requirements for lighting controls as the baseline condition in new construction applications.

UPGRADE CASE DESCRIPTION

The upgrade case is defined as any lighting that is controlled with either NLC or LLLC control strategies. These measures should be consistent with the definitions documented above. We recommend that eligible products be restricted to those listed in the DLC Qualified Products List (QPL) for Networked Lighting Controls.

Measure Life[1]

For NLC-NoLLLC measures, use the measure life associated with other C&I lighting control measures such as occupancy sensors. For LLLC, use the measure life associated with C&I LED luminaires.

Incremental Measure Cost[2]

If possible, the actual incremental cost of the measures shall be used. When not available, the following default values can be applied:

Table 9. Recommended Incremental Cost Values

Control Type	Cost	Unit
NLC-NoLLLC	\$0.53	per ft^2
LLLC	\$53.00	per luminaire

Energy and Demand Savings

Energy Savings

$$\Delta kWh = kW_{Controlled} \times Hours \times (CSF_{EE} - CSF_{Base}) \times IF_e$$

Where:

- $kW_{Controlled}$ is the number of kilowatts (kW) controlled by the NLC or LLLC system.

- Source and values: This information should be collected from the customer and documented as part of the program implementation process. The values will be variable as they should be customized for each project. We recommend that midstream LLLC programs rely on the reported wattage on the DLC QPL for the luminaire(s) associated with the LLLC.

- $Hours$ are the annual operating hours associated with the control system.
  - Source and values: Table 10 and current TRM assumptions for annual operating hours associated with other C&I lighting measures.

Table 10. Annual Operating Hours for NLC-NoLLLC and LLLC Measures[3]

General Building Type	Annual Hours of Use
Education	4,231
Manufacturing	5,365
Office	4,453
Retail	6,936
Warehouse	5,116
All Other	Use TRM specific operating hour assumptions associated with different building types for other C&I lighting measures

- CSF_{EE} is the Control Savings Factor (CSF) for the NLC-NoLLLC or LLLC measure.
  - Source and values: See Table 11

Table 11. CSF Values for NLC-NoLLLC and LLLC[4]

Control Type	CSF
NLC-NoLLLC	0.35
LLLC	0.63

- CSF_{Base} is the Control Savings Factor (CSF) for the lighting controls that existed before the new lighting controls were installed.

- Source and values: This value should be set to zero (0) in instances where there were no lighting controls in the baseline scenario or when the prior existence of lighting controls is unknown. If non-networked lighting controls were already in place, the CSF values associated with those controls should be used.[6] For example, in Illinois, the CSF_{Base} value would be set to 0.24 when an interior occupancy sensor was already in place, or 0.28 when an interior daylight sensor was already in place. A larger CSF_{Base} value will result in smaller savings associated with the upgrade technology.

- IF_e is the Interactive Energy Factor associated with NLC-NoLLLC and LLLC measures. This represents the secondary energy impacts associated with decreased waste heat (and subsequently reduced cooling loads) from efficient lighting strategies.
  - Source and values: This value should be based on the IF_e values identified for all other C&I lighting measures. This value should be greater than 1 for any building with cooling. If the TRM does not include values for lighting-HVAC interactive effects, this value should be set to 1.

Heating Penalty for Electrically Heated Buildings

$$\Delta kWh_{HeatPenalty} = kW_{Controlled} \times Hours \times (CSF_{EE} - CSF_{Base}) \times IF_{HeatPenalty}$$

Where:

- $IF_{HeatPenalty}$ is a factor that accounts for the increased electric heating impacts associated with lighting controls. Because these controls reduce waste heat from lighting, the building's heating system must compensate accordingly. This factor is only applicable to electrically heated buildings—the heating penalty for other buildings is described below. If the TRM does not include values for lighting-HVAC interactive effects, this value should be set to 0.

Total Electric Energy Savings

$$\Delta kWh_{Total} = \Delta kWh - \Delta kWh_{HeatPenalty}$$

Heating Penalty for Buildings Not Heated with Electricity

$$\Delta Therms = kW_{Controlled} \times Hours \times (CSF_{EE} - CSF_{Base}) \times IF_{Therms}$$

[6] The CSF values for multiple control types are not additive. Most TRMs include CSF values for 'dual' lighting controls, such as occupancy sensors and daylighting controls. In these instances the CSF for the 'dual' lighting control measure should be used; the individual CSF values from the two separate control strategies should not be added together to develop the baseline CSF.

Where:

- IF_{Therms} is a factor that accounts for the increased fossil fuel heating impacts associated with lighting controls. This factor, measured in therms, includes any fossil fuel heating sources (e.g., natural gas, fuel oil, coal, etc.). Because these controls reduce waste heat from lighting, they do result in an increased heating load. This is only applicable to non-electrically heated buildings. If the TRM does not include values for lighting-HVAC interactive effects, this value should be set to 0.

Peak Demand Savings

$$kW_{Summer} = kW_{Controlled} \times (CSF_{EE} - CSF_{Base}) \times CF_S \times IF_{d\_s}$$

$$kW_{Winter} = kW_{Controlled} \times (CSF_{EE} - CSF_{Base}) \times CF_W \times IF_{d\_w}$$

Where:

- CF_S is the summer peak coincidence factor by building type used for C&I lighting measures.
  - Source and values: This value should be based on the CF_S values identified for other C&I lighting measures. This is often broken out by building type.
- CF_W is the winter peak coincidence factor by building type used for C&I lighting measures.
  - Source and values: This value should be based on the CF_W values identified for other C&I lighting measures. This is often broken out by building type.
- IF_{d_s} is the Summer Interactive Demand Factor that represents the impact on the cooling system associated with decreased waste heat from efficient lighting.
  - Source and values: This value should be based on the IF_{d_s} values identified for all other C&I lighting measures. If the TRM does not include values for this input, then the value should be set to 1.
- IF_{d_w} is the Winter Interactive Demand Factor that represents the impact on the heating system associated with decreased waste heat from efficient lighting.
  - Source and values: This value should be based on the IF_{d_w} values identified for all other C&I lighting measures. If the TRM does not include values for this input, then the value should be set to 1.

SOURCES

[1] DesignLights Consortium (2025). Review of Technical Reference Manuals in the U.S. and Canada. Networked and Luminaire-Level Lighting Control Measure Prevalence and Best Practices.
[2] Ibid.
[3] Northwest Energy Efficiency Alliance, DesignLights Consortium (2020). Energy Savings from Network Lighting Control (NLC) Systems with and without LLLC. https://designlights.org/resources/reports/report-energy-savings-from-networked-lighting-control-nlc-systems-with-and-without-lllc/
[4] Ibid.

APPENDIX D: TRM REFERENCES FOR NLC-HVAC INTEGRATION

The following excerpts were pulled from a system program manual titled "LEDs with Advanced Lighting Controls and Occupancy Sensor-based Demand Control Ventilation," which was developed by Lawrence Berkeley National Laboratory (LBNL), in collaboration with Xcel Energy (Colorado and Minnesota). The manual is available online at https://buildings.lbl.gov/sites/default/files/2023-10/BW_Phase_2_Program_Manual.pdf.

OVERVIEW

The design and operating principle of this system package is that via installation of LED light fixtures with onboard sensors and controls (luminaire-level lighting controls, or LLLCs), the heating, ventilation, and air conditioning (HVAC) system zones may also be configured to appropriately regulate the volume of ventilation supply air, relying on the lighting controls occupancy sensor data in each zone. In doing so, this will save electric lighting energy by providing lighting only when and where it is needed, and ventilation supply air will similarly be provided in response to need.

This program manual contains detailed technical information for implementing an incentive program for LED lighting with luminaire-level controls (occupancy and daylight dimming) and paired with occupancy sensor-based demand controlled ventilation, or DCV.

ENERGY SAVINGS

Whole building and end-use energy usage were modeled with EnergyPlus-based simulations for the relevant climate zone. Based on annual energy simulations, the measure savings were derived for the LED lighting with advanced controls and DCV package.

Table 8. Simulation-based annual energy savings for measure in relative (%) and normalized energy and demand terms

	Whole Building Energy Savings		Lighting Electricity Savings		HVAC Electric Savings		Gas Energy Savings		Peak Demand Savings	
	EUI savings (kWh/ft² /yr)	% savings	EUI savings (kWh/ft² /yr)	% savings	EUI savings (kWh/ft² /yr)	% savings	EUI savings (kWh/ft² /yr)	% savings	W/ft² savings	% savings
Existing Building - Colorado	**1.94**	**13%**	**2.00**	**68%**	**0.10**	**8%**	**(0.15)**	**-3%**	**0.92**	**31%**
Existing Building - Minnesota	**2.28**	**12%**	**2.00**	**68%**	**0.08**	**7%**	**0.21**	**2%**	**0.83**	**26%**