CTX1931-4 ALC PSD Phase 1 Memo

Summary of Literature Review and Recommendations

Memo To: CT EA Team

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ABSTRACT

The objective of this study is to create entries for new residential and commercial Advanced Lighting Controls (ALC) measures to be incorporated into the 2022 Connecticut Program Savings Document (CT PSD). In Phase 1 of this study, these new measures were developed through a literature review, discussions with experts, and program administrator (PA) interviews. The primary source of information for the development of the new measures was the literature review. The team reviewed over 25 sources published between 2000 – 2021, including the following Technical Reference Manuals (TRMs): IL, MA, Mid-Atlantic, NH, NY, PA, RI, WI.

The three new measures developed as part of this study were:

1. Commercial Interior Lighting Controls (including networked lighting controls (NLC), luminaire-level lighting controls (LLLC), the combination of high-end trim with daylight dimming or occupancy sensors, dual occupancy and daylight controls, high-end trim, daylight dimming, and occupancy sensors),
2. Residential Connected LED Lighting, and
3. Residential Occupancy Sensors.

The new measure write-ups follow the format for direct insertion in the PSD and include description of the measures, savings methodologies with descriptions of the inputs and nomenclature, definitions for all the control technologies, and corresponding measure references and notes.

NLCs and LLLCs are defined according to the DesignLights Consortium (DLC) NLC definition. DLC certification is not a requirement for this control type, but it is recommended that the programs consider eligibility requirements that ensure quality product is installed. The commercial measures developed for Phase 1 of this study are applicable to all CT programs, including Energy Opportunities (EO), Midstream, and SBDI. The developed commercial measure is specifically for interior lighting controls and does not apply to exterior lighting, such as parking lot or street lighting.

The team developed savings methodologies for each of the measures and selected control technologies based on the review of other TRMs. The key factors to determine the measure energy and demand savings are the controls savings factors, which were selected through the literature review. The team identified three sources, which they felt had the best available information based on primary data for the corresponding controls technologies. Table 1 summarizes the savings factors for each measure/control type and the corresponding source.

Table 1. New measure write-ups selected commercial and residential savings factors

Measure	Controls Technology	Savings Factor	Source
Commercial Interior Lighting Controls	Networked Lighting Controls (NLC)	49%	DLC and NEEA, 2020
	Luminaire-Level Lighting Controls (LLLC)	49%	DLC and NEEA, 2020
	Dual Occupancy and Daylight Sensors	38%	Williams, et al., 2012

Measure	Controls Technology	Savings Factor	Source
	Combination of High-End Trim and Daylight Dimming	35%	Calculated based on High-End Trim and Daylight Dimming savings factors from Williams, et al., 2012
	Combination of High-End Trim and Occupancy Sensors	33%	Calculated based on High-End Trim and Occupancy Sensor savings factors from Williams, et al., 2012
	High-End Trim	27%	DLC and NEEA, 2020
	Daylight Dimming	28%	Williams, et al., 2012
	Occupancy Sensors	24%	Williams, et al., 2012
Residential Connected LED Lighting	Connected LED Lighting	29%	Navigant, 2019
Residential Occupancy Sensors	Occupancy Sensors	17%	Navigant, 2019

DNV believes the results of the Phase 1 research are sufficient to immediately add these new measures to CT's PSD. In Phase 2 researchers will refine the measures' factors based primary on research.

The sections below provide more details on the new measure savings methodology, the selection of the savings factors, and the topics that will be investigated in Phase 2. The three new ALC measures are included as Appendix A of this memo report.

NEW MEASURE SAVINGS METHODOLOGY

The team developed the energy and demand savings methodologies and inputs based on the 2021 CT PSD commercial and residential standard lighting measures and the TRMs reviewed as part of the literature review.

The energy savings methodology formulas below are included in the commercial and residential measure write-ups:

$$Energy\ Savings = Control\ Savings + Cooling\ Savings$$

$$Control\ Savings = Controlled\ kW \times Operating\ Hours\ Before\ Controls\ Were\ Installed \times (Savings\ Factor\ for\ Installed\ Control - Savings\ Factor\ for\ Baseline\ Control, if\ any)$$

$$Cooling\ Savings = Control\ Savings \times Cooling\ HVAC\ Interactivity$$

The control savings are determined based on the difference between installed and baseline savings factors, which are selected based on the installed and existing control technologies. If there are no existing controls, the baseline savings factor is 0%. In the calculation of residential energy savings, the baseline is assumed to be manual controls with a savings factor of 0%. The use of savings factors to determine the energy savings was selected based on discussion with PAs and experts and the review of other TRMs.

The HVAC interactivity for the commercial measure is calculated based on the controlled area of the facility and uses the same references as the 2021 CT PSD standard commercial lighting measure. The commercial measure write-up also includes a heating penalty, which is calculated with a factor based on the calculated energy savings (annual oil/natural gas savings = -0.000162279 MMBtu per annual kWh saved). The residential measures' HVAC interactivity is a fixed value based on the same references as the 2021 CT PSD standard residential lighting measure and does not include a heating penalty, as the impact on space heating energy consumption is assumed to be insignificant.

The demand savings methodology formulas below are included in the commercial and residential measure write-ups:

$$Summer\ Peak\ Demand\ Savings = Controlled\ kW \times Cooling\ HVAC\ Interactivity \times CF\ for\ Occupancy\ Sensors \times (Savings\ Factor\ for\ Installed\ Control - Savings\ Factor\ for\ Baseline\ Control, if\ any)$$

$$Winter\ Peak\ Demand\ Savings = Controlled\ kW \times CF\ for\ Occupancy\ Sensors \times (Savings\ Factor\ for\ Installed\ Control - Savings\ Factor\ for\ Baseline\ Control, if\ any)$$

The demand savings calculations use the same savings factors that are included in the energy savings calculation. The applicability of the savings factors to calculate both energy and demand savings is the standard assumption for the reviewed TRMs (IL, MA, Mid-Atlantic, NH, NY, PA, RI, WI) across all control types; the two exceptions were the MA and IL TRMs.

The summer peak demand savings calculation includes HVAC interactivity, which uses the same references as the CT PSD standard lighting measures. Similar to the 2021 CT PSD standard lighting measures, the winter peak demand savings does not include a heating penalty for facilities with electric heat.

The coincidence factors (CFs) used in the calculation of demand savings are from the CT PSD. The commercial interior lighting controls measure utilizes the CT PSD CFs for occupancy sensors. The occupancy sensor CFs vary by facility type, ranging from 2.4 – 28% for the summer. The residential controls measures utilize the CT PSD CFs for residential lighting. The CT PSD defines the peak periods as follows:

- **Seasonal Peak Hours:** Hours in which the actual, real-time hourly load Monday through Friday on non-holidays, during the months of June, July, August, December, and January, as determined by ISO-NE, is equal to or greater than 90% of the most recent 50/50 system peak load forecast, as determined by ISO-NE, for the applicable summer or winter season.
- **On-Peak Hours:** Hours 1:00 to 5:00 p.m., Monday through Friday on non-holidays during the months of June, July, and August and from 5:00-7:00 p.m., Monday through Friday on non-holidays during the months of December and January.

The closest regionally reviewed TRM (MA TRM) defines the seasonal and on-peak hours similar to CT. The MA commercial lighting controls measure lists a CF of 13% for the summer peak and 15% for the winter peak for both occupancy sensors and daylighting dimming measures but calculates the controls peak demand savings using a CF of 1.0. The NY TRM does not define the peak period in the TRM and calculates the peak demand savings for all commercial interior controls measures with a CF of 1.0. Without better regional information, the peak demand savings for all of the commercial control technologies should be calculated using the CT PSD CFs for occupancy sensors.

The adjusted measure lifetime (AML) for Commercial Interior Lighting Controls was determined to be 12.2 years for lost opportunity and 7 years for retrofit, aligning with the measure life for fixtures (LED) based on a 2021 study conducted in CT regarding measure life (Connecticut C2014 C&I Lighting Saturation and Remaining Potential – Phase One Results and Recommendations). For the Residential Connected LED Lighting and Residential Occupancy Sensor measures, the team selected a measure lifetime of 10 years based on the CT PSD lifetime for conventional commercial lighting controls. The AMLs determined for residential bulbs would not be applicable to the residential measures because they are adjusted based on the CT lighting market, which would not apply to controls measures.

SAVINGS FACTORS

The savings factors utilized in the energy and demand savings calculations were determined based on the literature review. The team selected the commercial savings factors in Table 2 below from two references:

- DLC and Northwest Energy Efficiency Alliance (NEEA), "Energy Savings from Networked Lighting Control (NLC) Systems with and without LLLC", Energy Solutions, Sept 24 2020. **(DLC and NEEA, 2020)**

- This source analyzed data from NLC systems, with and without LLLC, in 194 buildings across a variety of building types in North America, with an average of 13 weeks of data per building. The data included in the analysis was provided by manufacturers and by utilities/end users. This source was referenced in other reviewed sources and the IL TRM; an older version of the study (published in 2017) is referenced in the Mid-Atlantic and NY TRMs.

- Williams, A., B. Atkinson, K. Garesi, E. Page, and F. Rubinstein. 2012. “Lighting Controls in Commercial Buildings.” The Journal of the Illuminating Engineering Society of North America 8 (3): 161-180. **(Williams, et al., 2012)**
  - This source was a meta-analysis of energy savings identified in the literature – 240 savings estimates from 88 papers and case studies. Only papers and case studies with primary data sources were included in the meta-analysis. Additional research was conducted through a literature review and by consulting utilities, controls manufacturers, California Energy Commission, and NEMA. This source was referenced in other reviewed sources and the MA, Mid-Atlantic, PA, and WI TRMs.

Table 2. Commercial savings factors developed from literature review

Control Technology	Savings Factor	Source
Networked Lighting Controls (NLC)	49%	DLC and NEEA, 2020
Luminaire-Level Lighting Controls (LLLC)	49%	DLC and NEEA, 2020
Dual Occupancy and Daylight Sensors	38%	Williams, et al., 2012
Combination of High-End Trim and Daylight Dimming	35%	Calculated based on High-End Trim and Daylight Dimming savings factors from Williams, et al., 2012
Combination of High-End Trim and Occupancy Sensors	33%	Calculated based on High-End Trim and Occupancy Sensor savings factors from Williams, et al., 2012
High-End Trim	27%	DLC and NEEA, 2020
Daylight Dimming	28%	Williams, et al., 2012
Occupancy Sensors	24%	Williams, et al., 2012

Few of the reviewed sources provide LLLC-specific savings. The IL TRM groups NLC and LLLC technologies into one category and uses the same savings factor to calculate the savings for both technologies. An NEEA study[1] compared savings for four LLLC systems to a NLC system. The finding of this study was that there were not significant differences between the energy savings of a group of four LLLC systems and the NLC system. A PG&E study[2] represents the savings for luminaire-level controls with integrated occupancy sensors, daylight sensors, and high-end trim. The savings for this one facility are similar to the NLC savings factor presented in the DLC and NEEA study. Based on the study findings the team applied the NLC savings factor from the 2020 DLC and NEEA study to LLLC.

Savings factors should be selected and applied based on the controls that are being installed/implemented. If NLC or LLLC systems are being installed, the corresponding savings factor should be selected. In Phase 2, the team will request post-installation data to attempt to determine how NLCs and LLLCs are being used to control facility systems and will develop additional recommendations. The team added savings factors for controls combinations that were identified through the PA interviews but were not explicitly called out in the initial table or referenced in the literature review, such as high-end trim with daylight dimming and high-end trim with occupancy sensor controls. The savings factors for these controls combinations were calculated based on the references for high-end trim, occupancy sensing, and daylight dimming, and the assumption that high-end trim would be applied first and then then occupancy

[1] NEEA, "Luminaire Level Lighting Controls Replacement vs Redesign Comparison Study." Sept 3 2020

[2] PG&E’s Emerging Technologies Program, "Ace Hardware LED High Bay Lighting and Controls Project" Sept 27 2013.

sensors or daylight dimming savings would be applied using the reduced controlled wattage resulting from high end trim controls.

The team selected the residential savings factors in Table 3 below from one reference:

- Navigant Consulting. Department of Energy Solid-State Lighting Program. Energy Savings Forecast of Solid-State Lighting in General Illumination Applications. December 2019. **(Navigant, 2019)**
    - This source determined energy savings for each control strategy using: (1) baseline lighting load profiles from the CPUC, (2) the energy reduction of each control strategy based on research and stakeholder input, and (3) the percent of time that the control is used from 2014 Commercial Building Stock Assessment. An older version of this study was referenced in the Mid-Atlantic TRM and adjusted in the IL TRM.

The sources for residential savings factors were limited. All other sources referenced in reviewed TRMs were based on commercial applications.

Table 3. Residential savings factors developed from literature review

Control Technology	Savings Factor	Source
Connected LED Lighting	29%	Navigant, 2019
Occupancy Sensors	17%	Navigant, 2019

PHASE 2 AREAS OF INTEREST

Based on the literature review and the discussions during the presentation of the Phase 1 results, the team identified the following topics to be investigated further during Phase 2 of this study.

- Should there be a savings factor differentiation between NLC and LLLC?
- How should savings factors be applied for combinations of controls beyond dual occupancy and daylight sensors?
- Potentially investigate updating the current CFs from the 2021 CT PSD for controls beyond occupancy sensors, or provide further instructions on how to apply the existing CFs to various control technologies
- Re-analyze available real-world data and determine how it should inform the study.
    - Based on the Phase 1 presentation, this type of data should be available from utilities, as the utilities review intent information when controls systems are installed.
    - The team will request post-installation data and intent information from utilities to determine how NLCs and LLLCs are being used.

To investigate these topics, the team will request any available, applicable data from the utilities and will develop questions to include in the expert interview and market actor interview guides that address the aforementioned topics.

APPENDIX A – COMMERCIAL AND RESIDENTIAL MEASURE WRITE-UPS

2.1.1 INTERIOR LIGHTING CONTROLS

Description of Measure

Installation of new occupancy sensors or daylighting sensors and controls on a new or existing interior lighting system. Interior lighting control types covered by this measure include wall, ceiling, fixture mounted or integrated controls, as well as Luminaire Level Lighting Controls (LLLCs) or Networked Lighting Controls (NLC), which may have additional high-end trim and networking capabilities.

Savings Methodology

Energy and seasonal peak demand savings are calculated for the installation of lighting controls using an energy savings factor based on the installed control type. These systems save energy and peak demand by shutting off power to lighting fixtures when the space is unoccupied or illumination is not required. They also save energy and demand by reducing power to lighting systems to correct for over-illumination due to excessive lamp output or the presence of daylight. Installation of lighting controls reduces the cooling load and provides additional savings, which are also calculated in this measure.

This measure only applies to interior lighting controls that are in addition to those required by 2018 IECC C405.2. Exterior lighting controls are not covered by this measure.

Inputs

Table 2-G: Inputs

Symbol	Description	Units
Controlled LPD	Facility controlled LPD	$Watts/ft^2$
kW_{ctrl}	Total fixture connected kW	kW
A	Facility illuminated and controlled area	ft^2
H	Facility lighting —Hours of use	Hours/year

Nomenclature

Table 2-H: Nomenclature

Item	Description	Units	Values	Comments
A	Facility illuminated area	ft^2	Input	Site-specific
CF_{os}	Occupancy sensor coincidence factor	-		*Appendix One*
COP	Coefficient of performance	-	4.5	**Note [2]**
F	Fraction of lighting energy that must be removed by the facility's cooling system	-	*Table 2-J*	**Ref [3]**
G	Estimated lighting energy heat to space based on modeling	-	0.73	**Ref [4], Note [1]**
H	Facility lighting —Hours of use	Hours/year	Input	Site-specific; Use *Appendix Five* only when site-specific assumptions do not exist.
LPD	Lighting power density	Watts/ ft^2	Input	Site-specific
S_{cool}	Annual energy savings from reduced cooling load	kWh		Calculated
S_{ctrl}	Annual energy savings from use of interior lighting controls	kWh		Calculated
S_{tot}	Annual gross electric energy savings	kWh		Calculated
SF	Lighting controls savings factor	%	*Table 2-I*	**Ref [1], Ref [2]**
SKW	Summer demand savings	kW		Calculated
WKW	Winter demand savings	kW		Calculated
Lifetime	Measure life of the fixture	Years	12.2	**Ref [5], Note [5]**
LKWH	Lifetime electric energy savings	kWh		Calculated

Description of lighting control types:

- ***Occupancy Sensor*** – Reduces lighting operating hours by switching off lighting in unoccupied spaces.
- ***Daylight Dimming Control*** – Reduces lighting output to a set level or reduces lighting operating hours in response to natural daylighting using continuous, stepped, or on/off dimming capability.
- ***High End Trim*** – Reduces lighting output of individual lights or groups of lights to a set level continuously. Must have the ability to set a maximum light level.
- ***Combination of High-End Trim & Occupancy Sensors*** – Combines the capabilities of high-end trim, reducing the lighting output to a set level continuously, and occupancy sensors, allowing lighting fixtures with reduced output to respond to occupancy.
- ***Combination of High-End Trim & Daylight Dimming Controls*** – Combines the capabilities of high-end trim, reducing the lighting output to a set level continuously, and daylight sensors, allowing lighting fixtures with reduced output to respond to daylight.
- ***Dual Occupancy & Daylight Dimming Controls*** – Combines the capabilities of occupancy and daylight sensors, allowing lighting fixtures to respond to occupancy and daylight.

- ***Networked Lighting Control*** *and* ***Luminaire-Level Lighting Controls*** – A networked lighting control system consists of an intelligent network of individually addressable luminaires and control devices. LLLCs and NLC are defined according to the DLC Networked Lighting Controls definition, which requires systems to have fixture networking capabilities, individual addressability, occupancy sensing, daylight harvesting, high-end trim, flexible zoning, continuous dimming, scheduling, and cybersecurity. The network ability allows building managers to group lights with specific zonal control and scheduling strategies, energy monitoring and high-end trim resulting in a higher savings capability. While DLC listing is not a requirement for any control type characterized in this measure, programs should consider eligibility requirements that ensure quality product is installed.

Lost Opportunity Gross Energy Savings, Electric

$$S_{tot} = S_{ctrl} + S_{cool}$$

$$S_{ctrl} = \frac{A_{ctrl}\,(ft^2) \times LPD_{ctrl}\,(W/ft^2) \times H \times (SF_{EE} - SF_{Base})}{1{,}000\ W/kW}$$

$$S_{cool} = \frac{S_{ctrl} \times F}{COP}$$

Description of variable inputs:

- **A_{ctrl}** (ft^2) is the controlled lighting building area and calculated (measured) for each project, either from architectural drawings or by physical measurement.
- **Controlled LPD** (kW/ft^2) is calculated by dividing the total Fixture Wattage by the Lighted Area, ft^2,where Fixture Wattage is the sum of the power consumed by each fixture.
- **H** (hours/yr) is the total operating hours of the controlled lighting circuit before the lighting controls are installed. This value is calculated on a site-specific basis; if no site-specific assumptions exist, use *Appendix Five*.
- **SF_{EE}** (%) is the average annual reduction in electric consumption achieved by a particular control measure type in the installed condition. Savings factors for various automated lighting control types are specified in *Table 2-I*.
- **SF_{Base}** (%) is the average annual reduction in electric consumption achieved by a particular control measure type in the baseline condition. Savings factors for various automated lighting control types are specified in *Table 2-I*; if no lighting controls were installed (or required by code), the baseline savings factor is 0%.

Table 2-I: Energy Savings Factor by Lighting Control Type

Lighting Control Type	Savings Factor (SF)
Networked Lighting Controls (NLC)	49% Ref [1]
Luminaire-Level Lighting Controls (LLLC)	49% Ref [1]
Dual Occupancy and Daylight Dimming Controls	38% Ref [2]
Combination of High-End Trim and Daylight Dimming	35% Note [4]
Combination of High-End Trim and Occupancy Sensors	33% Note [4]
High-End Trim	27% Ref [1]
Daylight Dimming	28% Ref [2]
Occupancy Sensors	24% Ref [2]
No Lighting Controls	0%

- **F** (%) is the fraction of energy savings due to the reduced cooling required as the result of reducing lighting operating hours and/or fixture illumination through lighting controls. If the HVACsystem includes an economizer, then F = 0.35. Otherwise, use *Table 2-J*.

Table 2-J: Fraction of Energy Savings due to Reduced Cooling from the HVAC System, see Ref [3]

Building Area, A, ft^2	F
< 2,000	0.48
2,000 – 20,000	$0.48 \times \frac{0.195 \times (A_{ctrl} - 2{,}000)}{18{,}000}$
> 20,000	0.675

Explanation of numerical constants:

- 1,000 converts watts to kW (1/1,000 is the conversion).
- **COP** = 4.5. See **Note [2]**.

Lost Opportunity Gross Energy Savings, Fossil Fuel

Space heating energy consumption will increase due to reduced lighting operating hours.

- Annual Oil Savings = -0.000162279 MMBtu per annual kWh saved; and
- Annual Natural Gas Savings = -0.000162279 MMBTU per kWh. See **Ref [3]**.

Lost Opportunity Gross Seasonal Peak Demand Savings, Electric (winter and summer)

$$SkW = \frac{A_{ctrl}\,(ft^2) \times LPD_{ctrl}\,(W/ft^2) \times (SF_{EE} - SF_{Base}) \times CF_{OS} \times (1 + G/COP)}{1{,}000\ W/kW}$$

$$WkW = \frac{A_{ctrl}\,(ft^2) \times LPD_{ctrl}\,(W/ft^2) \times (SF_{EE} - SF_{Base}) \times CF_{OS}}{1{,}000\ W/kW}$$

Description of variable inputs:

- $\mathbf{A_{ctrl}}$ (ft^2) is the controlled lighting building area and calculated (measured) for each project, either from architectural drawings or by physical measurement.
- **Controlled LPD** (kW/ft^2) is calculated by dividing the total Fixture Wattage by the Lighted Area, ft^2,where Fixture Wattage is the sum of the power consumed by each fixture.
- $\mathbf{SF_{EE}}$ (%) is the average annual reduction in electric consumption achieved by a particular control measure type in the installed condition. Savings factors for various automated lighting control types are specified in *Table 2-I*.
- $\mathbf{SF_{Base}}$ (%) is the average annual reduction in electric consumption achieved by a particular control measure type in the baseline condition. Savings factors for various automated lighting control types are specified in *Table 2-I*; if no lighting controls were installed, the baseline savings factor is 0%.
- $\mathbf{CF_{os}}$ is the occupancy sensor coincidence factors (summer/winter) taken from *Appendix One*. See **Note [3].**

Explanation of numerical constants:

- **G** = 0.73. See **Note [1]**.
- **COP** = 4.5. See **Note [2]**.

Changes from Last Version

- Added new measure.

References

[1] DLC and Northwest Energy Efficiency Alliance (NEEA), "Energy Savings from Networked Lighting Control (NLC) Systems with and without LLLC", Energy Solutions, Sept 24 2020.

[2] Williams, A., B. Atkinson, K. Garesi, E. Page, and F. Rubinstein. 2012. "Lighting Controls in Commercial Buildings." The Journal of the Illuminating Engineering Society of North America 8 (3): 161-180.

[3] The derivation of the values for F is from "Calculating Lighting and HVAC Interactions," ASHRAE Journal 11-93 as used by KCPL.

[4] DNV GL (2017). *Impact Evaluation of PY2015 Massachusetts Commercial and Industrial UpstreamLighting Initiative*. DNVGL_2017_Upstream_Lighting_Impact_Evaluation.

[5] DNV (2021). *Connecticut C2014 C&I Lighting Saturation and Remaining Potential – Phase One Results and Recommendations*.

Notes

[1] If sensors are installed, the heat emitted from lighting affected by this measure will decrease due to lower lighting power and use. This will result in increased space heating energy consumption.

[2] Estimated based on 2015 Connecticut Code. An analysis was conducted by Wood, Byk, and Associates,829 Meadowview Road, Kennett Square, PA 19348, an engineering firm which was utilized to provide technical support for C&LM programs. The analysis was based on a DOE-2 default analysis and information was provided to Eversource engineering staff on Aug. 17, 2007.

[3] It is assumed that the occupancy sensor coincidence factors (summer/winter) taken from Appendix One would apply to all control types.

[4] Savings factors for the combination of high-end trim with daylight dimming and high-end trim with occupancy sensors were calculated based on savings factors from the individual controls from Ref [2].

[5] The measure life for interior lighting controls is assumed to be the adjusted measure lifetime (AML) for LED fixtures from the Connecticut C2014 study, based on the assumption that the controls are integrated with the fixture.

3.1.1 INTERIOR LIGHTING CONTROLS

Description of Measure

Installation of new occupancy sensors or daylighting sensors and controls on a new or existing interior lighting system. Interior lighting control types covered by this measure include wall, ceiling, fixture mounted or integrated controls, as well as Luminaire Level Lighting Controls (LLLCs) or Networked Lighting Controls (NLC), which may have additional high-end trim and networking capabilities.

Savings Methodology

Energy and seasonal peak demand savings are calculated for the installation of lighting controls using an energy savings factor based on the installed control type. These systems save energy and peak demand by shutting off power to lighting fixtures when the space is unoccupied or illumination is not required. They also save energy and demand by reducing power to lighting systems to correct for over-illumination due to excessive lamp output or the presence of daylight. Installation of lighting controls reduces the cooling load and provides additional savings, which are also calculated in this measure.

Inputs

Table 3-A: Inputs

Symbol	Description	Units
W_{ctrl}	Controlled fixture connected wattage	W
H	Facility lighting —Hours of use	Hours/year

Nomenclature

Table 3-B: Inputs

Item	Description	Units	Values	Comments
CF_{os}	Occupancy sensor coincidence factor	-		*Appendix One*
COP	Coefficient of performance	-	3.5	**Note [2]**
F	Fraction of lighting energy that must be removed by the facility's cooling system	-	*Table 2-J*	**Ref [3]**
G	Estimated lighting energy heat to space based on modeling	-	0.73	**Ref [4], Note [3]**
H	Facility lighting —Hours of use	Hours/year	Input	Site-specific; Use *Appendix Five* only when site-specific assumptions do not exist.
W_{ctrl}	Facility controlled lighting wattage load	W	Input	Site-specific
S_{cool}	Annual energy savings from reduced cooling load	kWh		Calculated
S_{ctrl}	Annual energy savings from use of interior lighting controls	kWh		Calculated
S_{tot}	Annual gross electric energy savings	kWh		Calculated
SF	Lighting controls savings factor	%	*Table 2-I*	**Ref [1], Ref [2]**
SKW	Summer demand savings	kW		Calculated
WKW	Winter demand savings	kW		Calculated
Lifetime	Measure life of the fixture	Years	7	**Ref [5], Note [5]**
LKWH	Lifetime electric energy savings	kWh		Calculated

Description of lighting control types:

- ***Occupancy Sensor*** – Reduces lighting operating hours by switching off lighting in unoccupied spaces.
- ***Daylight Dimming Control*** – Reduces lighting output to a set level or reduces lighting operating hours in response to natural daylighting using continuous, stepped, or on/off dimming capability.
- ***High End Trim*** – Reduces lighting output of individual lights or groups of lights to a set level continuously. Must have the ability to set a maximum light level.
- ***Combination of High-End Trim & Occupancy Sensors*** – Combines the capabilities of high-end trim, reducing the lighting output to a set level continuously, and occupancy sensors, allowing lighting fixtures with reduced output to respond to occupancy.
- ***Combination of High-End Trim & Daylight Dimming Controls*** – Combines the capabilities of high-end trim, reducing the lighting output to a set level continuously, and daylight sensors, allowing lighting fixtures with reduced output to respond to daylight.
- ***Dual Occupancy & Daylight Dimming Controls*** – Combines the capabilities of occupancy and daylight sensors, allowing lighting fixtures to respond to occupancy and daylight.

- ***Networked Lighting Control*** *and* ***Luminaire Level Lighting Controls*** – A networked lighting control system consists of an intelligent network of individually addressable luminaires and control devices. LLLCs and NLC are defined according to the DLC Networked Lighting Controls definition, which requires systems to have fixture networking capabilities, individual addressability, occupancy sensing, daylight harvesting, high-end trim, flexible zoning, continuous dimming, scheduling, and cybersecurity. The network ability allows building managers to group lights with specific zonal control and scheduling strategies, energy monitoring and high-end trim resulting in a higher savings capability. While DLC listing is not a requirement for any control type characterized in this measure, programs should consider eligibility requirements that ensure quality product is installed.

Retrofit Gross Energy Savings, Electric

$$S_{tot} = S_{ctrl} + S_{cool}$$

$$S_{ctrl} = \frac{W_{ctrl} \times H \times (SF_{EE} - SF_{Base})}{1{,}000\ W/kW}$$

$$S_{cool} = \frac{S_{ctrl} \times F}{COP}$$

Description of variable inputs:

- **W_{ctrl}** (W) is the facility lighting load that is controlled by the lighting control system. This value is site-specific.
- **H** (hours/yr) is the total operating hours of the controlled lighting circuit before the lighting controls were installed. This value is calculated on a site-specific basis; if no site-specific assumptions exist, use *Appendix Five*.
- **SF_{EE}** (%) is the average annual reduction in electric consumption achieved by a particular control measure type in the installed condition. Savings factors for various automated lighting control types are specified in *Table 2-I*.
- **SF_{Base}** (%) is the average annual reduction in electric consumption achieved by a particular control measure type in the baseline condition. Savings factors for various automated lighting control types are specified in *Table 2-I*; if no lighting controls were installed, the baseline savings factor is 0%.

Table 2-I: Savings Factor by Lighting Control Type

Lighting Control Type	Savings Factor (SF)
Networked Lighting Controls (NLC)	49% Ref [1]
Luminaire-Level Lighting Controls (LLLC)	49% Ref [1]
Dual Occupancy and Daylight Dimming Controls	38% Ref [2]
Combination of High-End Trim and Daylight Dimming	35% Note [4]
Combination of High-End Trim and Occupancy Sensors	33% Note [4]
High-End Trim	27% Ref [1]
Daylight Dimming	28% Ref [2]
Occupancy Sensors	24% Ref [2]
No Lighting Controls	0%

- **F** (%) is the fraction of energy savings due to the reduced cooling required as the result of reducing lighting operating hours and/or fixture illumination through lighting controls. If the HVACsystem includes an economizer, then F = 0.35. Otherwise, use *Table 2-J*.

Table 2-J: Fraction of Energy Savings due to Reduced Cooling from the HVAC System, see Ref [3]

Building Area, A, ft^2	F
< 2,000	0.48
2,000 – 20,000	$0.48 \times \frac{0.195 \times (A_{ctrl} - 2{,}000)}{18{,}000}$
> 20,000	0.675

Explanation of numerical constants:

- 1,000 converts watts to kW (1/1,000 is the conversion).
- **COP** = 3.5. See **Note [2]**.

Retrofit Gross Energy Savings, Fossil Fuel

Space heating energy consumption will increase due to reduced lighting operating hours.

- Annual Oil Savings = -0.000162279 MMBtu per annual kWh saved; and
- Annual Natural Gas Savings = -0.000162279 MMBTU per annual kWh saved. See **Ref [3]**.

Retrofit Gross Seasonal Peak Demand Savings, Electric (winter and summer)

$$SkW = \frac{W_{ctrl} \times (SF_{EE} - SF_{Base}) \times CF_{OS} \times (1 + G/COP)}{1{,}000\ W/kW}$$

$$WkW = \frac{W_{ctrl} \times (SF_{EE} - SF_{Base}) \times CF_{OS}}{1{,}000\ W/kW}$$

Description of variable inputs:

- **CF_{os}** is the occupancy sensor coincidence factors (summer/winter) taken from *Appendix One*. See **Note [3].**
- **W_{ctrl}** (W) is the facility lighting load that is controlled by the lighting control system. This value is site-specific.
- **SF_{EE}** (%) is the average annual reduction in electric consumption achieved by a particular control measure type in the installed condition. Savings factors for various automated lighting control types are specified in *Table 2-I*.
- **SF_{Base}** (%) is the average annual reduction in electric consumption achieved by a particular control measure type in the baseline condition. Savings factors for various automated lighting control types are specified in *Table 2-I*; if no lighting controls were installed, the baseline savings factor is 0%.

Explanation of numerical constants:

- **G** = 0.73. See **Ref [5], Note [1]**.
- **COP** = 3.5. See **Note [2]**.

Changes from Last Version

- Added new measure.

References

[1] DLC and Northwest Energy Efficiency Alliance (NEEA), "Energy Savings from Networked Lighting Control (NLC) Systems with and without LLLC", Energy Solutions, Sept 24 2020.

[2] Williams, A., B. Atkinson, K. Garesi, E. Page, and F. Rubinstein. 2012. "Lighting Controls in Commercial Buildings." The Journal of the Illuminating Engineering Society of North America 8 (3): 161-180.

[3] The derivation of the values for F is from "Calculating Lighting and HVAC Interactions," ASHRAE Journal 11-93 as used by KCPL.

[4] DNV GL (2017). *Impact Evaluation of PY2015 Massachusetts Commercial and Industrial UpstreamLighting Initiative*. DNVGL_2017_Upstream_Lighting_Impact_Evaluation.

[5] DNV (2021). *Connecticut C2014 C&I Lighting Saturation and Remaining Potential – Phase One Results and Recommendations*.

Notes

[1] If sensors are installed, the heat emitted from lighting affected by this measure will decrease due to lower lighting power and use. This will result in increased space heating energy consumption.

[2] Estimated based on 2015 Connecticut Code. An analysis was conducted by Wood, Byk, and Associates,829 Meadowview Road, Kennett Square, PA 19348, an engineering firm which was utilized to provide technical support for C&LM programs. The analysis was based on a DOE-2 default analysis and information was provided to Eversource engineering staff on Aug. 17, 2007.

[3] It is assumed that the occupancy sensor coincidence factors (summer/winter) taken from Appendix One would apply to all control types.

[4] Savings factors for the combination of high-end trim with daylight dimming and high-end trim with occupancy sensors were calculated based on savings factors from the individual controls from Ref [2].

[5] The measure life for interior lighting controls is assumed to be the adjusted measure lifetime (AML) for LED fixtures from the Connecticut C2014 study, based on the assumption that the controls are integrated with the fixture.

4.1.1 CONNECTED LED LIGHTING

Description of Measure

This measure details the savings associated with connected LED lighting that allows for remote user control through Wifi and/or a smart device. Using the remote controls, users can remotely turn the light on and off, adjust its brightness, and set a schedule for the light. Connected lighting controls savings are based on a reduction of operating hours and dimming. The savings for this measure are the estimated incremental control savings compared to a non-connected efficient lamp.

Savings Methodology

The following assumptions are made to calculate savings for connected LED lighting. “Direct install” bulbs and luminaires are installed by vendors that have verified installation. “Retail” refers to bulbs and luminaires sold through retailers that do not have verified installation. Actual rated bulb wattage and location of the bulbs is used to calculate savings for direct install. For retail, the actual rated bulb wattage and a default (estimated) hours-of-use are used to calculate savings. There is a lighting interactive effect that applies to fossil fuel homes. Refer to *Table 4-F: Nomenclature*.

Inputs

Table 4-E: Inputs

Symbol	Description	Units
$Watt_{controlled}$	Rated wattage of installed or purchased connected high-efficiency (LED) bulb.	Watts
Location	Location of direct install bulb. See *Table 4-H* for available options.	

Nomenclature

Table 4-F: Nomenclature

Symbol	Description	Units	Values	Comments
AKWH	Annual electric energy savings	kWh/yr		Calculated
CF_S	Average summer seasonal peak coincidence factor for residential (lighting)	unit-less	13.0%	*Appendix One*, **Ref [3]**
CF_W	Average winter seasonal peak coincidence factor for residential (lighting)	unit-less	20.0%	*Appendix One*, **Ref [3]**
H_d	Daily hours of use, by room type for direct install. For Lost Opportunity or Retail, use "unknown" as the room type	Hours per day	*Table 4-G* for all known locations	**Ref [2]**
Lifetime	Measure life of the bulb	Years	10	*Appendix Four*, **Note [2]**
LKWH	Lifetime electric energy savings	kWh		Calculated
SF	Percentage of annual lighting energy saved by connected lighting controls	%	29%	**Ref [4]**
SKW	Summer demand savings	kW		Calculated
$Watt_{controlled}$	Rated wattage of installed or purchased connected high-efficiency (LED) bulb	Watts (W)	Input	
WKW	Winter demand savings	kW		Calculated
ABTU	Lighting interactive effect	Btu/kWh	-1,902	**Note [1]**

Retail and direct install savings calculation:

$$AkWh = 1.04 \times SF \times \frac{Watt_{controlled} \times h_d \times 365}{1000\ W/kW}$$

Note: *1.04 is the average energy factor due to lighting interactive effect* ***Ref [1]****. Please refer to Table 4-G for the correct hours of use per day by location (h_d).*

Table 4-G: Hours of Use per Day by Location (h_d)

Location	All Customers
	H_d
Bedroom	2.1
Bathroom	1.7
Kitchen	4.1
Living room	3.3, **Ref [2]**
Dining room	2.8
Exterior	5.6
Other	1.7
Unknown	2.7, **Ref [2]**

Gross Energy Savings, Example

Example: *A 10-Watt connected LED bulb installed in the living room of a home by direct install. What is the annual savings?*

Using the equations from above:

$$\Delta kWh = 1.04 \times SF \times \frac{Watt_{controlled} \times h_d \times 365}{1{,}000\ W/kW}$$

$$\Delta kWh = 1.04 \times 29\% \times 10\ Watts \times 1\ kW / 1{,}000\ W \times 3.3\ hrs/day \times 365\ days/year$$

$$\Delta kWh = 3.6\ kWh/year$$

Gross Seasonal Peak Demand Savings, Electric (winter and summer)

$$SkW = 1.05 \times SF \times \frac{Watt_{controlled} \times CF_S}{1{,}000\ W/kW}$$

$$WkW = SF \times \frac{Watt_{controlled} \times CF_W}{1{,}000\ W/kW}$$

- 1.05 is an average capacity factor due to lighting interactive effect **Ref [7]**.
- Values for CF_s and CF_w can be found in *Appendix One* as the Residential Lighting Coincidence Factors.

Gross Peak Demand Savings, Example

Example: *A 10-Watt connected LED bulb in the living room of a home. What is the savings?*

$$SkW = 1.05 \times SF \times \frac{Watt_{controlled} \times CF_S}{1000\ W/kW}$$

$$SkW = 1.05 \times 29\% \times \frac{10\ Watt \times 13\%}{1000\ W/kW}$$

$$SkW = 0.0004\ kW$$

$$WkW = SF \times \frac{Watt_{controlled} \times CF_W}{1000\ W/kW}$$

$$WkW = 29\% \times \frac{10\ Watt \times 20\%}{1000\ W/kW}$$

$$WkW = 0.0006\ kW$$

Changes from Last Version

- Added measure

References

[1] *Connecticut Residential Lighting Interactive Effect*, NMR Group Inc., Dec. 2014, Table 1, p. 2.

[2] NMR Group Inc., Connecticut LED Lighting Study Report (R154), Jan. 28, 2016, p. 45.

[3] NMR Group Inc., *Northeast Residential Lighting Hour-of Use Study*, May 5, 2014, Table ES-7, p. VIII.

[4] Navigant Consulting. Department of Energy Solid-State Lighting Program. Energy Savings Forecast of Solid-State Lighting in General Illumination Applications. December 2019.

[5] ENERGY STAR Program Requirements. Product Specification for Lamps (Light Bulbs). Eligibility Criteria 2.1.

Notes

[1] The Lighting interactive effect penalty is based on the results from Connecticut Residential Lighting Interactive Effects Memo, Completed by NMR Group, Inc., Dec. 20, 2014. Penalty to be applied to non-electric benefits when planning.

[2] The measure lifetime is based on the lifetime of lost opportunity conventional commercial controls from *Appendix Four*.

4.1.2 OCCUPANCY SENSORS

Description of Measure

This measure details the savings associated with installing occupancy sensor(s) (hard-wired, fixture-, wall-, or ceiling-mounted) that switch lights off after a brief delay when they do not detect occupancy. Occupancy sensors reduce energy consumption by reducing the operating hours for lighting equipment in low occupancy areas, such as hallways, storage rooms, and restrooms. The savings for this measure are the estimated control savings compared to lighting fixtures being controlled by manual wall switches (no occupancy sensors).

Savings Methodology

The following assumptions are made to calculate savings for occupancy sensor-controlled lighting. "Direct install" bulbs and luminaires are installed by vendors that have verified installation. "Retail" refers to bulbs and luminaires sold through retailers that do not have verified installation. Actual rated bulb wattage and location of the bulbs is used to calculate savings for direct install. For retail, the actual rated bulb wattage and a default (estimated) hours-of-use are used to calculate savings. There is a lighting interactive effect that applies to fossil fuel homes. Refer to *Table 4-I: Nomenclature*.

Inputs

Table 4-H: Inputs

Symbol	Description	Units
$Watt_{controlled}$	Rated wattage of installed or purchased connected high-efficiency (LED) bulb.	Watts
Location	Location of direct install bulb. See *Table 4-H* for available options.	

Nomenclature

Table 4-I: Nomenclature

Symbol	Description	Units	Values	Comments
AKWH	Annual electric energy savings	kWh/yr		Calculated
CF_S	Average summer seasonal peak coincidence factor for residential (lighting)	unit-less	13.0%	*Appendix One*, **Ref [3]**
CF_W	Average winter seasonal peak coincidence factor for residential (lighting)	unit-less	20.0%	*Appendix One*, **Ref [3]**
h_d	Daily hours of use, by room type for direct install. For Lost Opportunity or Retail, use "unknown" as the room type	Hours per day	*Table 4-K* for all known locations	**Ref [2]**
Lifetime	Measure life of occupancy sensor	Years	10	*Appendix Four*, **Note [3]**
LKWH	Lifetime electric energy savings	kWh		Calculated
SF	Percentage of annual lighting energy saved by connected lighting controls	%	17%	**Ref [4]**
SKW	Summer demand savings	kW		Calculated
$Watt_{controlled}$	Rated wattage of installed or purchased connected high-efficiency (LED) bulb	Watts (W)	Input	
$Watt_{default}$	If $Watt_{controlled}$ is unknown, use this wattage.	Watts (W)	*Table 4-J* for default wattage calculation	**Note [2], Ref [5]**
WKW	Winter demand savings	kW		Calculated
ABTU	Lighting interactive effect	Btu/kWh	-1,902	**Note [1]**

Retail and direct install savings calculation:

$$\text{AkWh} = 1.04 \times \text{SF} \times \frac{\text{Watt}_{\text{controlled}} \times h_d \times 365}{1000}$$

Note: *1.04 is the average energy factor due to lighting interactive effect* ***Ref [1]****. Please refer to Table 4-K for the correct hours of use per day by location (h_d).*

For unknown wattage:

Table 4-J: Default Wattage Assumption

Number of lamps in space with control	Average lamp wattage	Connected space wattage
6.8	34	230

Table 4-K: Hours of Use per Day by Location (h_d)

Location	All Customers
	H_d
Bedroom	2.1
Bathroom	1.7
Kitchen	4.1
Living room	3.3, **Ref [2]**
Dining room	2.8
Exterior	5.6
Other	1.7
Unknown	2.7, **Ref [2]**

Retrofit Gross Energy Savings, Example

Example: *A 10-Watt connected LED bulb installed in the living room of a home by direct install. What is the annual savings?*

Using the equations from above:

$$AkWh = 1.04 \times SF \times \frac{Watt_{controlled} \times h_d \times 365}{1000}$$

$$AkWh = 1.04 \times 17\% \times 10\ Watts \times 1\ kW / 1{,}000\ W \times 3.3\ hrs/day \times 365\ days/year$$

$$AkWh = 2.1\ kWh/year$$

Retrofit Gross Seasonal Peak Demand Savings, Electric (winter and summer)

$$SkW = 1.05 \times SF \times \frac{Watt_{controlled} \times CF_S}{1000\ W/kW}$$

$$WkW = SF \times \frac{Watt_{controlled} \times CF_W}{1000\ W/kW}$$

- 1.05 is an average capacity factor due to lighting interactive effect **Ref [1]**.

- Values for CF_s and CF_W can be found in *Appendix One* as the Residential Lighting Coincidence Factors.

Retrofit Gross Peak Demand Savings, Example

Example: *A 10-Watt connected LED bulb in the living room of a home. What is the savings?*

$$SkW = 1.05 \times SF \times \frac{Watt_{controlled} \times CF_S}{1000\ W/kW}$$

$$SkW = 1.05 \times 17\% \times \frac{10\ Watt \times 13\%}{1000\ W/kW}$$

$$SkW = 0.0002\ kW$$

$$WkW = SF \times \frac{Watt_{controlled} \times CF_W}{1000\ W/kW}$$

$$WkW = 17\% \times \frac{10\ Watt \times 20\%}{1000\ W/kW}$$

$$WkW = 0.0003\ kW$$

Lost Opportunity Gross Energy Savings (for rebate and upstream), Electric

For bulb/luminaire:

$$AkWh = 1.04 \times SF \times \frac{Watt_{controlled} \times h_d \times 365}{1{,}000\ W/kW}$$

$$AkWh = 1.04 \times 17\% \times 34\ Watts \times 1\ kW / 1{,}000\ W \times 2.7\ hrs/day \times 365\ days/year$$

$$AkWh = 5.9\ kWh/year$$

Lost Opportunity Gross Energy Savings, Example

Example: What are the electric energy savings when any LED bulb is purchased through a retailer?

$$AkWh = 5.9\ kWh/year$$

Lost Opportunity Gross Peak Demand Savings, Example

For bulb/luminaire:

$$SkW = 1.05 \times SF \times \frac{Watt_{controlled} \times CF_S}{1000\ W/kW}$$

$$SkW = 1.05 \times 17\% \times \frac{34\ Watt \times 13\%}{1000\ W/kW}$$

$$SkW = 0.0007\ kW$$

$$WkW = SF \times \frac{Watt_{controlled} \times CF_W}{1000\ W/kW}$$

$$WkW = 17\% \times \frac{34\ Watt \times 20\%}{1000\ W/kW}$$

$$WkW = 0.0011\ kW$$

Changes from Last Version

- Added measure

References

[1] *Connecticut Residential Lighting Interactive Effect*, NMR Group Inc., Dec. 2014, Table 1, p. 2.

[2] NMR Group Inc., Connecticut LED Lighting Study Report (R154), Jan. 28, 2016, p. 45.

[3] NMR Group Inc., *Northeast Residential Lighting Hour-of Use Study*, May 5, 2014, Table ES-7, p. VIII.

[4] Navigant Consulting. Department of Energy Solid-State Lighting Program. Energy Savings Forecast of Solid-State Lighting in General Illumination Applications. December 2019.

[5] Connecticut LED Lighting Study Report (R154). NMR Group, Inc. January 28, 2016.

Notes

[1] The Lighting interactive effect penalty is based on the results from Connecticut Residential Lighting Interactive Effects Memo, Completed by NMR Group, Inc., Dec. 20, 2014. Penalty to be applied to non-electric benefits when planning.

[2] Average of number of sockets in dining room, living space, bedroom, bathroom, and kitchen spaces and average connected wattage of lamps in dining room, living space, bedroom, bathroom, and kitchen spaces.

[3] The measure lifetime is based on the lifetime of a lost opportunity commercial occupancy sensor from *Appendix Four*. The occupancy sensor is assumed to be a stand-alone control that will outlast the bulb that it is controlling and is not subject to the same measure lifetime constraints as the bulb.