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2023 Review of Key Assumptions for Luminaire Level Lighting Controls

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1. Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) contracted with Cadmus to review its approach for estimating potential energy savings from the Luminaire Level Lighting Controls (LLLC) program. Cadmus addressed three questions in its review:

- **Question 1.** NEEA utilizes the Regional Technical Forum's (RTF) control savings fractions (CSFs) in calculating co-created savings for new construction commercial buildings. The mathematical sum of control savings fractions (CSFs) for daylight control and occupancy sensor as determined by the Regional Technical Forum (RTF) is lower than the value for the combined controls in the RTF's CSF table (RTF, 2023). Is it appropriate for NEEA to adjust the RTF's CSF for the combined controls (occupancy sensor with daylighting control) to the mathematical sum of the individual CSF values from daylight control and occupancy sensor or to a lower value given that interactive effects are likely to reduce the overall CSF? If so, what values might be more appropriate?

- **Question 2.** In a previous review, Cadmus recommended that NEEA consider baseline controls savings of occupancy sensors for new construction using a 25% CSF for non-warehouse spaces and 50% CSF for warehouse spaces. However, code requires different types of lighting controls based on different kinds of space types, with a range of CSF values between 15% and 40% in most cases, and in some spaces, no controls were required at all in 2015—the year when NEEA first began to model energy savings related to LLLC. NEEA is interested in refining CSF estimates using an average CSF that reflects regional new construction square footage, as suggested in the NMR Group's LLLC market assessment report (NMR Group, 2020). Is NEEA's approach to adjusting new construction baseline CSF to reflect the code requirements of various lighting control types in various space types appropriate?

- **Question 3.** Is it appropriate for NEEA to adjust the baseline CSF for retrofit LLLC applications? If so, what value might be more appropriate, given the following factors:
  - Market penetration of all lighting controls in commercial real estate in 2015 may have been closer to 18% (Navigant, 2017)
  - CSFs for other controls are lower than those provided for occupancy sensors
  - A portion of installed controls are likely realizing less savings than anticipated due to users overriding the controls or having older controls that no longer work as intended.

NEEA provided Cadmus with a document describing the rationale for revisiting the baseline CSFs for new construction and retrofit applications, as well as these supporting documents:

- *2014 Commercial Building Stock Assessment (CBSA 3) Report and Appendix* (Navigant, 2014)
- *2019 Commercial Building Stock Assessment (CBSA 4) Report and* Appendix (Cadmus, 2020)
- *Luminaire Level Lighting Controls Market Assessment* (NMR, 2020)
- "Non-Residential Code Compliant Lighting Standard Protocol Update" (RTF PowerPoint, 2023)

In addition to reviewing these materials, Cadmus conducted secondary research to determine which lighting controls were required by regional building codes and the saturation of lighting controls in existing buildings. During the review of these materials, Cadmus and NEEA discussed interim findings and interpretation of building codes.

2. Research Question 1

Is it appropriate to adjust the RTF CSF value for combined controls as the baseline CSF assumption for new construction?

Cadmus recommends that NEEA continue to use the RTF's CSF for combined controls (occupancy sensors with daylighting control), rather than adjust the value. This is because state codes in effect in 2015 (the assumed baseline year in NEEA's model), required multistep or continuous daylighting controls, not on/off daylighting controls. Given these code requirements, NEEA's concern is already addressed in the RTF's assumptions (see more below).

2.1. New Construction Baseline CSF

To address NEEA's concern, Cadmus reviewed building energy codes in the Northwest in more detail (see *Appendix A* for details). Building energy codes in the Northwest require occupancy sensing and daylighting in many commercial building spaces. The baseline for calculating new construction LLLC savings is defined by code.

The latest version of the RTF's *Non-Residential Lighting Support Document* (RTF 2023) includes CSF by space type and control type. The control types include a manual switch, bilevel switch, daylight control on/off, daylight control multistep and continuous, occupancy sensor, occupancy sensor with daylighting control (combined controls), networked lighting controls, and LLLC. Since the RTF's CSF table includes two types of daylight controls with different CSF values, Cadmus examined code requirements to select the appropriate CSF. Based on this review, Cadmus found code required daylight controls that were either multistep or continuous at the time when NEEA began modeling energy savings from lighting controls (see Table 1). NEEA staff agreed with this interpretation.

Table 1. Daylighting Controls by State Energy Code in Effect in 2015

State and Code	Effective Date	Section	Daylighting Requirement
Idaho 2012 International Energy Conservation Code (IECC)	Jan 1, 2015	C405.2.2.3.2	Continuous or multistep
Montana 2012 IECC	Nov 1, 2014	C405.2.2.3.2	Continuous or multistep
2014 Oregon Energy Efficiency Specialty Code	Jul 1, 2014	505.2.2.3	Multistep
2012 Washington State Energy Code	Jul 1, 2013	405.2.2.3.2	Continuous or multistep

2.2. RTF CSF Comparison

NEEA was concerned that the CSFs for occupancy sensors with daylighting controls were higher than the mathematical sum of CSFs for daylight controls on/off and occupancy sensors. Cadmus reviewed the RTF's *Non-Residential Lighting Support Document* (RTF 2023) to learn more about what assumptions went into the combined CSF calculation. First, notes in the file indicated that the RTF used multiple sources to develop the CSF by space type. Second, in instances where the RTF combined CSFs for daylighting and occupancy sensors, the calculation avoided double-counting savings by reducing savings from daylighting controls when the occupancy sensor would have resulted in the lights staying off. For example, to calculate open office CSF, the RTF used the following formula, which accounts for the reduced daylighting savings when the lighting is shut off due to occupancy controls:

$$CSF_{Occupancy} + \left(1 - CSF_{Occupancy}\right) * CSF_{Daylighting}$$

Table 2 shows the RTF's CSF values for three control types in the middle columns: daylight multistep and continuous (as required in 2015), occupancy sensor, and occupancy sensor with daylighting control. The column furthest to the right shows the mathematical sum of the separate daylight multistep and continuous CSF, plus the occupancy sensor CSF. Note that the combined RTF CSF is below the mathematical sum (and aligns with avoiding double-counting savings). This confirms that NEEA's concern is already addressed and that savings are not likely to be underreported due to using the combined CSF value.

Table 2. Comparison of RTF CSF Values

Space Type	RTF CSF Value			Mathematical Sum of Daylight Continuous and Occupancy
	Daylight Multistep and Continuous	Occupancy Sensor	Combined Controls (Occupancy Sensor with Daylighting Control)	
Non-Warehouse/Open Office	30%	15%	**40%**	45%
Warehouse Aisle	30%	50%	**55%**	80%

3. Research Question 2

Is it appropriate to adjust CSF values for warehouse and non-warehouse spaces to reflect a weighted average CSF?

Cadmus recommends adjusting the new construction baseline CSF to 28% for non-warehouse spaces, while continuing to use 50% for warehouses. Because the regional weights by code-required control types were developed across all building types, it is appropriate for generic non-warehouse applications. However, it is unclear whether the regional floor space allocation by control type is representative of annual new construction in warehouses, as warehouses have greater amounts of storage and process areas which likely do not use daylighting controls. If NEEA wishes to develop a weighted CSF for warehouses, it should analyze floor area by required lighting control for warehouses separately.

3.1. Code Weighted CSF

In a previous review, Cadmus recommended using a simple 25% CSF for non-warehouse spaces and 50% CSF for warehouse spaces. NEEA wanted to refine this estimate given building codes require different types of controls in different space types and commissioned a study to estimate the percentage of new construction floor space by required lighting control type across the Northwest (NMR Group, 2020). Using these values and the RTF's CSF values[1], NEEA calculated average regional CSF values: 23.05% for office spaces and 37.3% for warehouse spaces. Table 3 shows the regional average for warehouse and non-warehouse applications (open office), as calculated by Cadmus using the updated CSF values.

Table 3. New Construction Northwest Weighted CSF Values

Code Requirement	Daylight Control Multi-Step Continuous	Occupancy Sensor	Occupancy Sensor with Daylighting	Exempt/ Manual	Floor Space Weighted CSF
Percentage of Northwest New Construction Floor Area (average across all building types)	25.8%	14.6%	45.7%	13.9%	
Open Office CSF	30%	15%	40%	0%	**28%**
Warehouse Aisle CSF	30%	50%	55%	0%	**40%**

The results were slightly different than NEEA's calculated regional average CSFs, as Cadmus used daylight continuous with a higher CSF of 30% instead of daylight control on/off with a CSF of 10%. For the non-warehouse (open office) space type, the results were close to the 25% CSF Cadmus originally recommended, and Cadmus recommends adopting the more refined average CSF of 28%. For the warehouse space type, the regional average CSF is lower. However, Cadmus has concerns with the analysis validity for the warehouse space type and does not currently recommend adjusting the CSF to 40%.

Cadmus' main concern with developing a regional baseline CSF for warehouse spaces is that the floor area weights (shown in Table 3) by control type do not change by space type in the NMR Group, 2020

[1] The RTF shared intentions to update the CSF values for lighting controls in September, 2023, after this work was contracted. Since the values were not ratified and published at the time of this review, all examples feature the published CSF values before the update – the current ones of that time. NEEA and Cadmus determined that the research question was still relevant for the program, however, even with the slightly adjusted values previewed by the RTF.

study. While a regional floor area allocation is acceptable for general, non-warehouse installations, a warehouse does not typically have as many windows or skylights as an open office, thus reducing the opportunities for daylighting. According to Table 3, over 70% of the floor area has daylighting controls (45.7% + 25.8%), which appears high when applied to warehouse spaces. Figure 1 shows how space types differ between warehouse and non-warehouse buildings from NEEA's fourth Commercial Building Stock Assessment (CBSA 4, 2019; Cadmus, 2020). Warehouses are primarily storage and process spaces, while the other building types are composed of common areas, public access, office, and classrooms, spaces where Cadmus expects more windows and skylights to be located. The Washington energy code (405.2.2.2) requires occupancy sensors in warehouse spaces, which puts the CSF at 50% for this sector. The Oregon energy code requires occupancy sensors in buildings larger than 2,000 square feet, with exceptions allowed for spaces such as classrooms and small offices. Therefore, Cadmus recommends that NEEA continue to use 50% CSF for warehouse spaces until a more specific allocation of floor space by code is available for this building type.

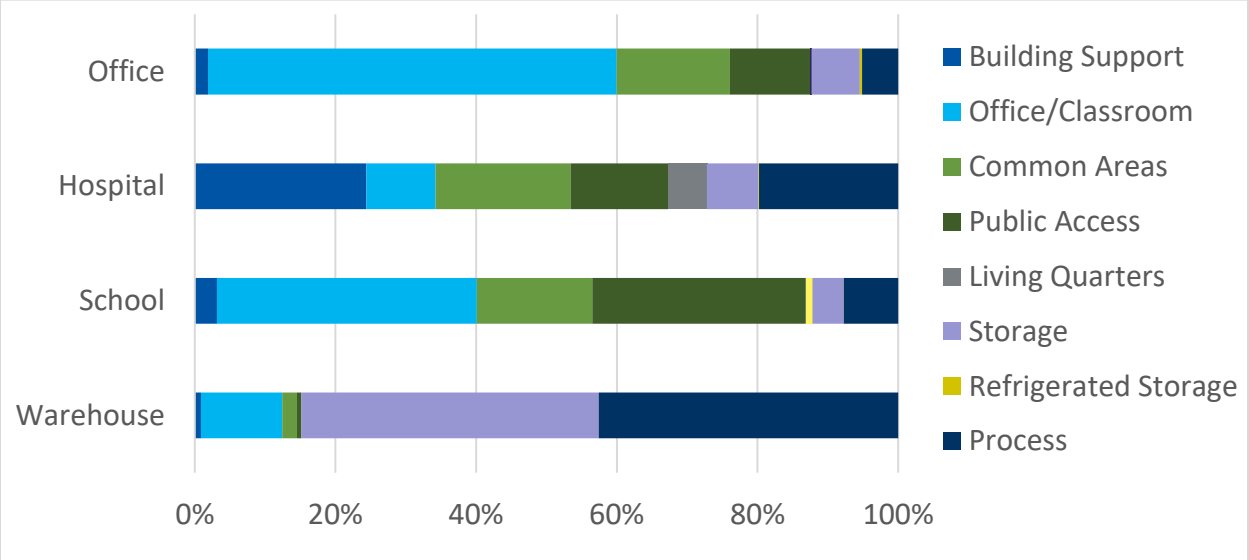

Figure 1. CBSA 4 Space Types in Selected Building Types

4. Research Question 3

Is it appropriate to adjust baseline CSF values for retrofits given that controls market penetration in the baseline year is likely lower than estimated, CSF values for other controls are lower than those for occupancy sensors, and a portion of controls are likely realizing less savings than anticipated?

Cadmus recommends that NEEA adjust the baseline CSF values for retrofits to 1.7% for non-warehouse and 8.5% for warehouse applications, based on revisions to market penetration of controls at the inception of the program and the weighting of CSFs for retrofits (based on using CBSA 3 data). This is a departure from the previous review Cadmus provided for lighting control market penetration, due to reviewing a broader array of studies (see Table 5).

4.1. Market Penetration of Controls

NEEA asked Cadmus to revisit the baseline CSF of LLLC installations in existing buildings (prior to the 2015 launch of the LLLC program) and determine if it is appropriate to adjust the value given concerns with the market penetration of lighting controls in 2015 and the desire for a more refined value that accounts for different types of installed controls. Given the challenges in tracking individual installations of LLLC, NEEA plans to apply a market-average baseline CSF for LLLC installation in existing buildings.

In a previous review, Cadmus recommended using a 20% baseline market penetration of lighting controls, with a simplified assumption of all controls delivering a CSF equivalent to occupancy sensors. However, Cadmus based this value on a national study that was not specific to the Northwest (Navigant, 2017). Table 4 summarizes the results found in the various studies that Cadmus reviewed; the incidence of manual on/off controls usually decreases over time, except for the source Cadmus originally used in the second row. A more appropriate value would be from the CBSA 3, with an overall control penetration of 25% of indoor lighting power. Of the 25% of this power, 8% is controlled by occupancy sensors and the remaining are other types of controls, such as time clocks. Given the available data in the CBSA 3, Cadmus recommends that NEEA use the CBSA 3 controls penetration to develop a weighted CSF that accounts for different installed control types. This calculation is discussed next.

Table 4. Comparison of Control Penetration Rates in Commercial Buildings

Study	Region	Datapoint Year	Indoor Lighting Power by Control Type		
			No controls (on/off switch)	Occupancy Sensor Controls	Other Controls
Navigant 2012	U.S.	2010	70%	5%	25%
Navigant 2017	U.S.	2015	82%	10%	8%
Navigant 2019	U.S.	2017	66%	6%	28%
CBSA 3	**Northwest**	**2014**	**75%[a]**	**8%**	**17%**
CBSA 4	Northwest	2017-2019	68%	13%	19%

[a] Includes manual and no controls/continuous

4.2. Retrofit Baseline CSF

To calculate a baseline CSF that accounts for different types of controls in existing office buildings, Cadmus multiplied the percentage of lighting power by control type from the CBSA 3 with the corresponding CSF (shown in Table 5). This resulted in an office (non-warehouse) baseline CSF of 1.7%. Since the other control types do not have a corresponding RTF CSF, it addresses NEEA's concerns that

Cadmus' previous recommendation was overly conservative due to some portion of installed controls being overridden by users or no longer working as intended. This also addresses NEEA question on whether CSF values for other controls are lower than those provided for occupancy sensors.

Table 5. Calculation of Weighted CSF - Office

	Manual On/Off	Occupancy Sensor	All Other Controls	Average
CSF	0%	15%	0%	1.7%
Percentage of Lighting Power	69%	11%	20%	

Cadmus calculated a baseline CSF for warehouses in the same manner, using the warehouse-specific CSF and percentage of lighting power (see Table 6). This resulted in a warehouse baseline CSF of 8.5%.

Table 6. Calculation of Weighted CSF - Warehouse

	Manual On/Off	Occupancy Sensor	All Other Controls	Average
CSF	0%	50%	0%	8.5%
Percentage of Lighting Power	83%	17%	0%	

5. References

Cadmus. 2020. *Commercial Building Stock Assessment (CBSA) 4 (2019) Final Report.* Prepared for NEEA. https://neea.org/resources/cbsa-4-2019-final-report
(Cadmus 2020)

Navigant Consulting, Inc. 2017. *2015 U.S. Lighting Market Characterization.* Prepared for the U.S. Department of Energy. https://www.energy.gov/sites/default/files/2017/12/f46/lmc2015_nov17.pdf
(Navigant 2017)

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(NMR 2020)

Regional Technical Forum. 2023. PowerPoint: "Non-Residential Code Compliant Lighting Standard Protocol Update."
(RTF PowerPoint 2023)

Regional Technical Forum. 2023. Supporting Document: *Non-Residential Lighting CSF and HOU v 3.0.* https://rtf.nwcouncil.org/standard-protocol/non-residential-lighting-code-compliant/
(RTF 2023)

Appendix A. Daylighting Requirements in 2015 State Building Codes

Table A-1 shows the daylighting requirements in effect in 2015, along with the effective date, code section, and relevant text excerpts.

Table A-1. 2015 Commercial Daylighting Requirements

State	Code	Effective Date	Section	Relevant text from code
Idaho	2012 IECC	Jan 1, 2015	405.2.2.3.2	"...Daylighting controls device shall be capable of automatically reducing the lighting power in response to available daylight by either one of the following methods: 1) Continuous dimming… 2) Stepped dimming using multi-level switching…"
Montana	2012 IECC	Nov 1, 2014	405.2.2.3.2	"...Daylighting controls device shall be capable of automatically reducing the lighting power in response to available daylight by either one of the following methods: 1) Continuous dimming… 2) Stepped dimming using multi-level switching…"
Oregon	2014 OEESC	Jul 1, 2014	505.2.2.3	"…Automatic daylight sensing controls shall reduce the light output of the controlled luminaires within the daylighted area by at least 50 percent, and provide an automatic OFF control, while maintaining a uniform level of illumination."
Washington	2012 WSEC	Jul 1, 2013	405.2.2.3.2	"...Daylighting controls device shall be capable of automatically reducing the lighting power in response to available daylight by either one of the following methods: 1) Continuous dimming… 2) Stepped dimming using multi-level switching…"