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LIGHTING

LED, TUBE

SWLG009-01

CONTENTS

MEASURE NAME

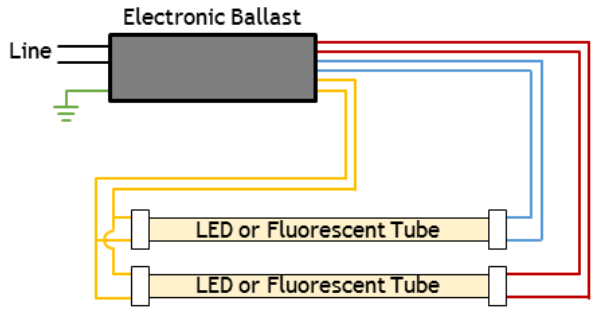
LED, Tube

STATEWIDE MEASURE ID

SWLG009-01

TECHNOLOGY SUMMARY

The Design Lights Consortium (DLC) defines the UL Type A as a four-foot or two-foot LED "tube" designed to replace a four-foot or two-foot fluorescent lamp, respectively. Products in this category utilize lamp holders to connect to the fixture being retrofitted and are designed to be "plug and play" replacements for fluorescent lamps. That is, products in this category can operate off an existing fluorescent ballast and do not require mechanical or electrical changes to the fixture. The figure below illustrates the UL Type A configuration.



UL Type A Configuration

Two U.S. Department of Energy (DOE) CALiPER studies related to LED tubes application and cost effectiveness provide context related to the quickly evolving improvement in LED lamps as well as the analysis related to applications where they are most cost effective.[1]

Additionally, two studies funded through the Emerging Technologies Program provide the basis for savings and quality of installation considered for this measure.

Linear LED Lamps – Laboratory Performance Assessment (Southern California Edison, 2015).[2] This performance assessment of linear LED lamps, conducted by Southern California Edison (SCE) through the

[1] U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2014. *CALiPER Application Summary Report 21: Linear (T8) LED Lamps.* Prepared by the Pacific Northwest National Laboratory (PNNL).

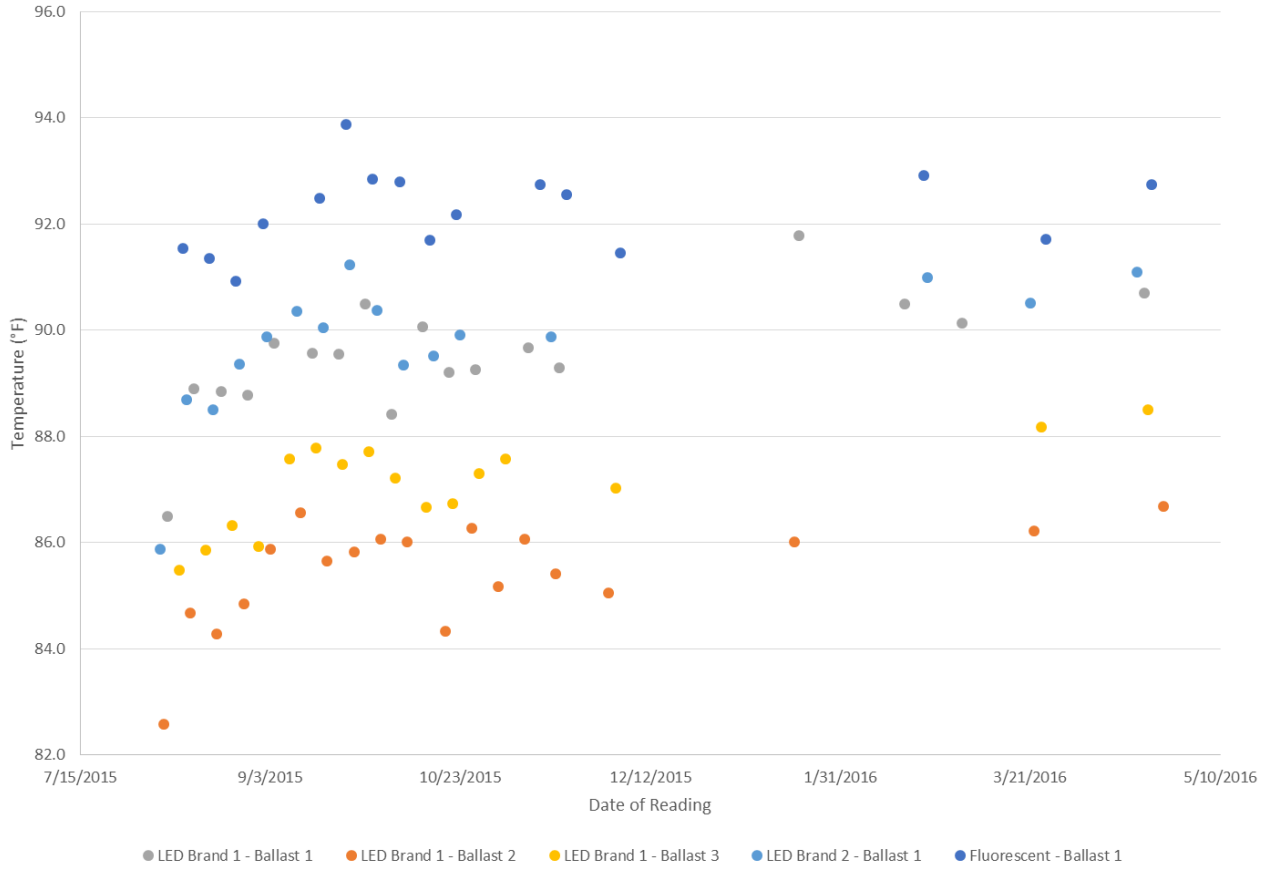
U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2014. *CALiPER Report 21.3: Cost-Effectiveness of Linear (T8) LED Lamps.* Prepared by the Pacific Northwest National Laboratory (PNNL).

[2] Southern California Edison (SCE). 2015. *Linear LED Lamps - Laboratory Performance Assessment.* ET14SCE1040.

Emerging Technologies Program, assessed long-term degradation of linear LED tube replacement lamps (ballast compatible, internal driver, external driver). This assessment included photometric and electrical measurements and testing of lamps from multiple manufacturers.

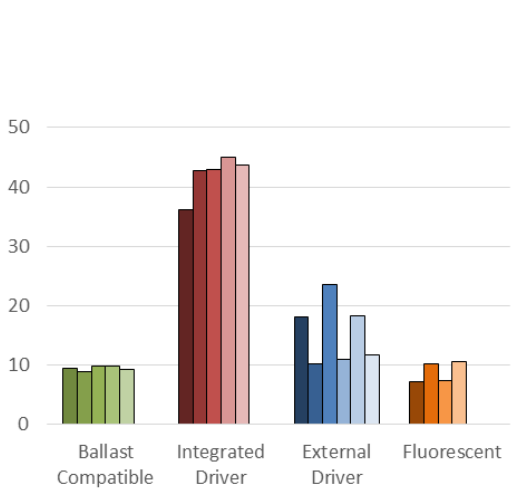
Based on the long-term testing, no major lumen degradation was observed, and no negative effects were observed for the fluorescent ballasts after approximately 3,500 hours of cycled testing. Measured temperatures of the lamps and ballast remained stable throughout the test.

Temperature measurements that were taken inside four different open fixtures in various lamp configurations showed that LEDs have considerably lower temperature than the linear fluorescent lamps. LED lamps were below 100 °F while linear fluorescent lamps were greater than 125 °F. LED T8 lamps performed better across the entire dimming range than linear fluorescent lamps in terms of efficacy and visible flicker. The figure below shows the internal fixture ambient temperature of the LED and Linear Fluorescent lamps.



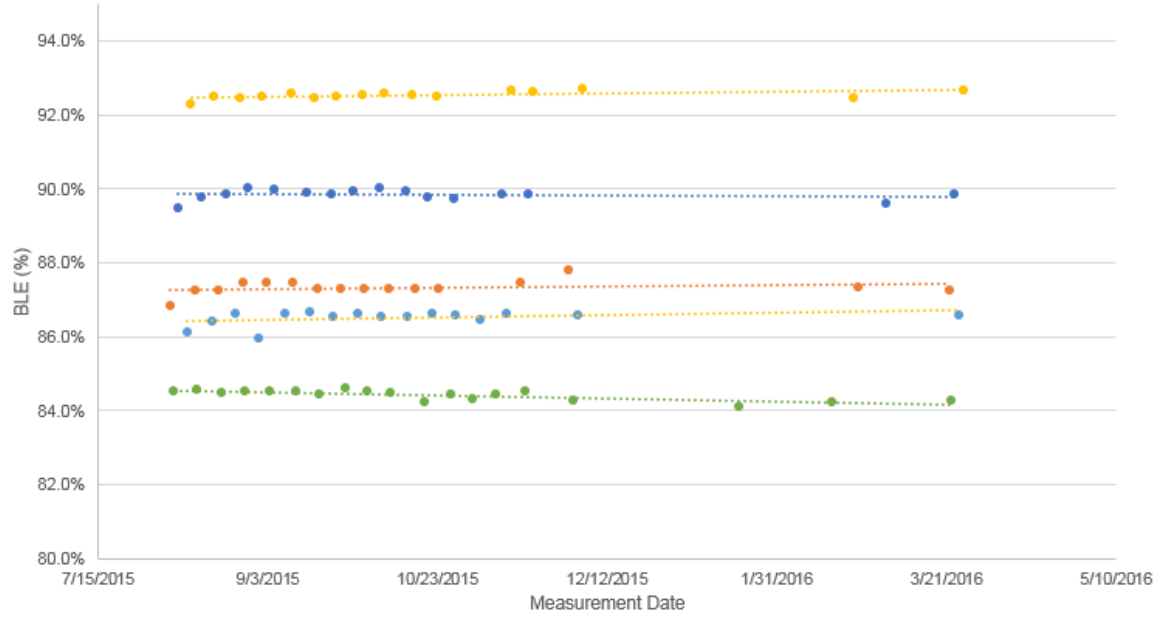
Internal Fixture Ambient Temperature (Run Time = 5.75 hours)

The figure below reveals the current total harmonic distortion (THDi) caused by each of the lamps on a two-lamp setup. Ballast-compatible lamps performed similar to linear fluorescent lamps and showed no negative signs.



Average THDi % of 2-Lamp Tests

The figure below plots the ballast luminous efficacy (BLE) of the tested LED T8 lamps. After eight months of continuous ON/OFF fixture cycling with 3,500 hours of on-time operation, the BLE measurements, which measure the ratio of electrical output to electrical input as defined by DOE test procedures, indicate that the fluorescent ballasts were not affected by the operation of replacement LED tubes. The BLE values obtained from lab testing with LED T8 lamps are consistent with typical BLE values observed on the fluorescent ballasts when operating with T8 fluorescent lamps (above 80%). This figure demonstrates that there is no indication that replacement LED tubes degrade the performance of compatible fluorescent ballasts.



Ballast Luminous Efficacy

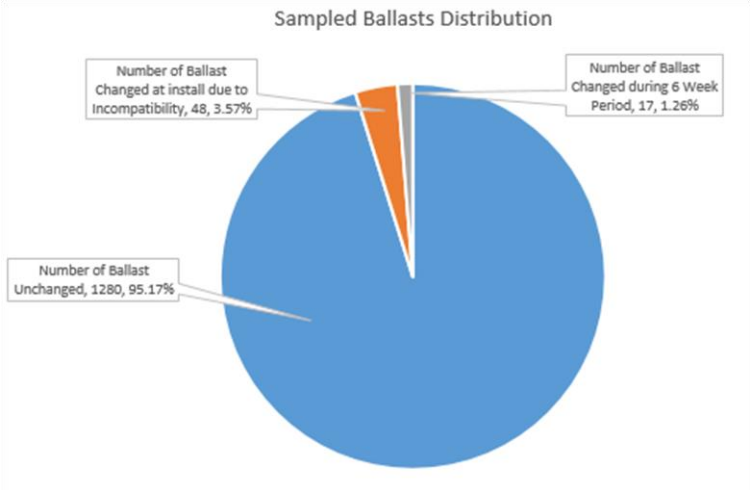
LED Tube Retrofit Scaled Field Placement (SFP) (Southern California Edison, 2016).[3] This field study was conducted by SCE through the Emerging Technologies Program to determine the remaining useful life (RUL) and average lamp wattage, and customer satisfaction from a sample of retrofit projects conducted in 2016.

Eligibility requirements for projects included in the LED Tube Retrofit Scaled Field Placement (SFP) that were executed by SCE account managers are noted below.[4]

- LED T8 lamp must be a Type A
- Must use existing linear fluorescent ballast
- 4-foot long
- Required check for ballast compatibility
- Dimmable ballast if existing system was dimmable
- Warranty on QPL must match the specification sheet
- Lamps were to only be installed in pre-qualified fixture types such as strip, cove, wrap, and prismatic troffers

Data such as baseline/measure information, type of fixture, pre/post light measurement, and ballast life were gathered throughout the course of the SFP study.[5] Ballast age was recorded from the date stamp on the ballast or provided verbally by the customer. Averaging all the remaining useful life (RUL) of the ballasts resulted in a RUL of 6.9 years (which is higher than the typical lamp life of 20,000 hours assumed for the Database for Energy Efficient Resources, DEER).

A follow-up review occurred six weeks after installation to monitor ballast replacements. Although 95% were unchanged, fewer than 2% were replaced within the six-week period and fewer than 1% were replaced within the one-year or 4,380 hours follow up. Note that 4% were initially replaced due to compatibility issues as shown in figure below. Program requirements for this measure address this potential compatibility problem by requiring that the LED T8 lamp documentation to provide a list of compatible ballast model numbers. Note that the compatible ballast testing will also address the potential issue of mis-matching differing ballast factors and lamps. (See Program Requirements.)



[3] The reference for "ET15SCE8040" has not been located.

[4] Southern California Edison (SCE). (n.d.). "LED Tube Requirements.docx."

[5] Southern California Edison (SCE). 2016. "SCE17LG117.0 TLEDCalcs.xlsx"

MEASURE CASE DESCRIPTION

This measure case is defined as the replacement of a 4-foot linear fluorescent T8 lamp with a LED T8 Lamp UL Type A for specified building/space types, as follows:

- 4-foot LED T8 Lamp UL Type A Replacing Linear Fluorescent T8 Lamp (Non-Res)
- 4-foot LED T8 Lamp UL Type A Replacing Linear Fluorescent T8 Lamp (Common Area)
- 4-foot LED T8 Lamp UL Type A Replacing Linear Fluorescent T8 Lamp (Dwelling Area)
- 4-foot LED T8 Lamp UL Type A Replacing Linear Fluorescent T8 Lamp (Parking Garages)

BASE CASE DESCRIPTION

The base case is defined as a 4-foot linear fluorescent T8 lamp. The base case was determined using the 2017 program application data and is considered an existing condition. The analysis of this measure utilizes the existing condition baseline (a 4-foot T8 Linear Fluorescent lamp) to calculate the energy savings.[6]

CODE REQUIREMENTS

State and federal standards that relate to this measure are noted below. Note, however, that this measure is a lamp-only replacement and thus does not trigger code. *The information provided below is for informational purposes only.*

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20 (2019)	Section 1605 (j) and (k)	January 1, 2019
CA Building Energy Efficiency Standards – Title 24 (2019)	Section 141.0(b)2I	January 1, 2020
Federal Standards	10 CFR 430.32(m) and (n)	July 14, 2012

Title 24 (2019)[7] Section 141.0(b)2I:

> ***Altered Indoor Lighting Systems****. Alterations to indoor lighting systems that include 10% or more of the luminaires serving an enclosed space shall meet the requirements of i, ii, or iii below:*
>
> *i. The alteration shall comply with the indoor lighting power requirements specified in Section 140.6 and the lighting control requirements specified in Table 141.0-F;*
>
> *ii. The alteration shall not exceed 80% of the indoor lighting power requirements specified in Section 140.6, and shall comply with the lighting control requirements specified in Table 141.0-F; or*
>
> *iii. The alteration shall be a one-for-one luminaire alteration within a building or tenant space of 5,000 square feet or less, the total wattage of the altered luminaires shall be at least 40% lower compared to their total*

[6] Southern California Edison (SCE). 2019. "SWLG009-01 TLED Delta Watts Calculation.xlsx." See "SCE Prog Data" tab.

[7] California Energy Commission (CEC). 2018. *2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24).* CEC-400-2018-020-CMF.

pre-alteration wattage, and the alteration shall comply with the lighting control requirements specified in Table 141.0-F.

Alterations to indoor lighting systems shall not prevent the operation of existing, unaltered controls, and shall not alter controls to remove functions specified in Section 130.1.

Alterations to lighting wiring are considered alterations to the lighting system. Alterations to indoor lighting systems are not required to separate existing general, floor, wall, display, or ornamental lighting on shared circuits or controls. New or completely replaced lighting circuits shall comply with the control separation requirements of Section 130.1(a)4 and 130.1(c)1D.

***EXCEPTION 1 to Section 141.0(b)2I.** Alteration of portable luminaires, luminaires affixed to moveable partitions, or lighting excluded as specified in Section 140.6(a)3.*

***EXCEPTION 2 to Section 141.0(b)2I**. Any enclosed space with only one luminaire.*

***EXCEPTION 3 to Section 141.0(b)2I**. Any alteration that would directly cause the disturbance of asbestos, unless the alteration is made in conjunction with asbestos abatement.*

***EXCEPTION 4 to Section 141.0(b)2I**. Acceptance testing requirements of Section 130.4 are not required for alterations where lighting controls are added to control 20 or fewer luminaires.*

***EXCEPTION 5 to Section 141.0(b)2I**. Any alteration limited to adding lighting controls or replacing lamps, ballasts, or drivers.*

***EXCEPTION 6 to Section 141.0(b)2I**. One-for-one luminaire alteration of up to 50 luminaires either per complete floor of the building or per complete tenant space, per annum.*

Title 20 (2019)[8] includes regulations to fluorescent lamp ballasts, replacement fluorescent lamp ballasts (§ 1605 (j)), and lamps ((§ 1605 (k)).

2012 Federal Standards for General Service Fluorescent Lamps[9] issued by the U.S. Department of Energy (DOE) includes energy conservation standards that apply to various linear fluorescent lamp types.

NORMALIZING UNIT

The normalizing unit is per lamp.

PROGRAM REQUIREMENTS

Measure Implementation Eligibility

All combinations of measure application type, delivery type, and sector that are established for this measure are specified below. Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial incentives or other services) is targeted. This table also designates the broad market sector(s) that are applicable for this measure.

[8] California Energy Commission (CEC). 2019. *California Code of Regulations Title 20.*CEC-140-2019-002.

[9] Code of Federal Regulations at 10 CFR 430.32(n) and (m).

Note that some of the implementation combinations below may not be allowed for some measure offerings by all program administrators.

Implementation Eligibility

Measure Application Type	Delivery Type	Sector
Accelerated replacement	DnDeemDI	Com
Accelerated replacement	DnDeemed	Com
Accelerated replacement	UpDeemed	Com
Accelerated replacement	DnDeemDI	Ag
Accelerated replacement	DnDeemed	Ag
Accelerated replacement	UpDeemed	Ag
Accelerated replacement	DnDeemDI	Ind
Accelerated replacement	DnDeemed	Ind
Accelerated replacement	UpDeemed	Ind
Accelerated replacement	DnDeemDI	Res
Accelerated replacement	DnDeemed	Res
Accelerated replacement	UpDeemed	Res

Preponderance of Evidence Requirements (POE)

Even though POE is not explicitly required for approval by the California Public Utilities Commission (CPUC),[10] all program administrators and third-party program implementers are required to collect data as stated in the Date Collection Requirements section that will satisfy POE requirements. This technology is dependent upon the existing condition baseline, and the data collection requirements are intended to provide sufficient evidence of the disposal method and replacement of the existing products, including verification of the ballast and the compatibility.

Eligible Products

Qualified products must meet the following requirements as well as the performance criteria specified below.

- LED tube must be 4-foot and designated as UL Type A or UL Type A+B, but must be configured as a UL Type A.
- The lamp must be listed under the Primary Use Category “Replacement Lamps (“plug and play”) (UL Type A)” or “Dual Mode Internal Driver (UL Type A and Type B)” on the current Design Lights Consortium qualified product list (https://www.designlights.org/search/).
- Must meet a minimum efficacy requirement of 145 lumens per watt (LPW)
- The LED T8 Lamp specification sheet must also list all of the compatible ballast model numbers to ensure proper operation of the measure.
- Due to testing considerations, only a product that can operate off of an electronic instant start ballast is eligible.

[10] Southern California Edison (SCE). (n.d.) “Historical Account of LED Technology for Linear Fluorescent Lamp and Fixture Replacement.”

Program Requirements for LED T8 Lamps

Performance Metric	DLC Requirement	DLC Tolerance	Minimum Program Requirements
Lamp Efficacy	≥ 120 LPW	-3%	≥ 145 LPW
CRI	≥ 80	-2 points	≥ 80
CCT	2,200 K – 6,500 K	n/a	2,200 K – 6,500 K
Power Factor	≥ 0.9	-3%	≥ 0.9
Total Harmonic Distortion	≤ 20%	+5%	≤ 20%
Lumen Maintenance	L70 ≥ 50,000	n/a	L70 ≥ 50,000
Minimum Warranty	5 years	n/a	5 years

Eligible Building Types and Vintages

This measure is eligible in all commercial and multifamily (common and dwelling areas) and double-wide mobile homes. Parking garages are also eligible.

Eligible Climate Zones

This measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

This measure does not apply to residential single-family residences.

De-lamping is not eligible.

Re-ballast is not eligible.

Replacement lamps designed to operate off of existing magnetic ballasts or off of other types of electronic ballasts are not eligible.

DATA COLLECTION REQUIREMENTS

Mandatory data collection requirements are:

Pre-existing data that must be collected includes:

1. Total number of fixtures on site
2. Number of fixtures sampled (must sample at least 10% of the fixtures present)
3. Number of lamps per fixture
4. Number of ballasts per fixture
5. Ballast model number
6. Ballast manufacturer
7. Fluorescent lamp wattage
8. Disposal method of tube
9. Manufacturer cut sheet showing ballast compatibility

USE CATEGORY

Lighting

ELECTRIC SAVINGS (kWh)

The calculation of annual electric unit energy savings (UES) of the LED T8 lamp is a function of the difference between the baseline and measure case lamp wattage, hours of operation, and interactive effects.

$$UES = \frac{\Delta W \times HOURS \times IE}{1{,}000\ Wh\ /\ kWh}$$

UES =	*unit energy savings (kWh per lamp)*
ΔWatts/unit =	*(Base Case Average Watts per lamp) – (Measure Case Average Watts per lamp)*
HOURS =	*Annual hours of use, by building type/space*
IE =	*Interactive Effects, by building type/space*

The inputs to the UES calculation are explained below.

Baseline Average Watts per Lamp. The base case average lamp wattage was derived from a weighted average of the base case type lamps (25 W, 28 W, 30 W and 32 W). 2017 program participation data on 167,075 lamps were analyzed; the base case lamp wattage distribution is shown below. Base case wattages were normalized to account for a normal ballast factor of 0.88. For simplicity of the analysis, only 28W and 32W lamps were included in the weighted average as they comprised more than 99% of the baseline.

Base Case Wattage Saturation Distribution

Base Case Wattage (W)	% Saturation (% used in analysis)	Normalized Base Case Wattage (W)	Source
25	0.36% (0%)	22.0	Southern California Edison (SCE). 2019. "SWLG009-02 TLED Delta Watts Calculation.xlsx."
28	41.69% (42%)	24.6	
30	0.18% (0%)	26.4	
32	57.77% (58%)	28.2	
Total Weighted Average		26.68	

Base Case In-Situ Fixture Lumens

A major goal of any lighting measure is to provide similar or improved lighting performance compared to the incumbent technology. One way to compare performance is to compare the total amount of lumens provided to the space for each technology. However, linear fluorescent lamps emit light in all directions, while TLED lamps emit light directionally. So, while linear fluorescent lamps may emit more total lamp lumens than TLEDs, much of their light is directed away from working surfaces. Furthermore, bare lamp performance is not a preferred metric, as it does not account for the performance of the lamp while enclosed in lighting fixtures ("in-situ" performance).

The US DOE has published several application summaries and detailed reports that can be used to compare the photometric performance of incumbent T8 lamps in fixtures with LED T8 lamps. In these reports, they provide a metric called luminaire efficiency. Luminaire efficiency is the ratio of the total bare lamp lumens and the total lumens the fixture provides to the space, expressed as a percent.[11] The metric can be used to compare the in-situ performance of linear fluorescent lamps to new high efficiency TLEDs. An average of in-situ luminaire efficiencies was calculated for linear fluorescent lamps for nine troffers [12] and two parking/linear pendant fixtures[13] from DOE CALiPER reports. Troffer performance was selected to represent the performance of non-parking garage measures, as it is the most common linear fluorescent fixture type.[14] Using the saturation weighting from the "Base Case Wattage Saturation Distribution" table above, the weighted average fixture lumens for both types of fixtures was calculated. Most CALiPER reports tested 2-lamp fixtures; thus, this analysis assumes 2-lamp fixtures.

[11] U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2014. *CALiPER Report 21.2: Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers.* Prepared by the Pacific Northwest National Laboratory (PNNL).

U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2014. *CALiPER Report 21.2: Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers.* Prepared by the Pacific Northwest National Laboratory (PNNL).

U.S. Department of Energy. 2009. "DOE SSL CALiPER Report: Product Test Reference: CALiPER 09-67 2'x4' Troffer Fluorescent Benchmark."

U.S. Department of Energy. 2009. "DOE SSL CALiPER Report: Product Test Reference: CALiPER 09-73 24"x24" Troffer Benchmark Fluorescent."

[12] U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2014. *CALiPER Report 21.2: Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers.* Prepared by the Pacific Northwest National Laboratory (PNNL).

U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2014. *CALiPER Report 21.2: Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers.* Prepared by the Pacific Northwest National Laboratory (PNNL).

U.S. Department of Energy. 2009. "DOE SSL CALiPER Report: Product Test Reference: CALiPER 09-67 2'x4' Troffer Fluorescent Benchmark."

U.S. Department of Energy. 2009. "DOE SSL CALiPER Report: Product Test Reference: CALiPER 09-73 24"x24" Troffer Benchmark Fluorescent."

[13] U.S. Department of Energy. 2010. "DOE SSL CALiPER Report: Product Test Reference: CALiPER BK 09-108 Parking Structure Fluorescent."

U.S. Department of Energy (DOE). 2012. "DOE CALiPER Detailed Test Report: CALiPER Reference: 11-79 Linear Pendant."

[14] U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2013. *CALiPER Exploratory Study: Recessed Troffer Lighting.* Prepared by the Pacific Northwest National Laboratory (PNNL). Revised June 2013.

Linear Fluorescent In-Situ Fixture Performance

Fixture Type	Nominal LF (W)	Lamp Saturation (%)	Lamp Efficacy (LPW)[15]	Bare Lamp Lumens (2-lamp) [16]	Average Fixture Efficiency	Total Fixture Lumens	Weighted Average Fixture Lumens
Troffer	28	42%	90	4,386	73%	3,199	3,515
	32	58%	89	5,134		3,744	
Parking Fixture	28	42%	90	4,386	64%	2,816	3,095
	32	48%	89	5,134		3,296	

Measure Case In-Situ Fixture Lumens

Due to the differing lamp characteristics, T8 and TLED fixture efficiencies differ. TLED in-situ fixture efficiencies were compiled from CALiPER data [17] for 22 troffer fixtures.

In-situ parking or linear fixture performance data could not be found for TLEDs from CALiPER. However, the T8 CALiPER reports for the two linear parking fixtures show that over 50% of total lamp lumens are provided in the downward direction (0°-180° zone).[18] Due to lack of parking fixture data, the same difference in fixture efficacy that was found for the T8s and TLEDs in troffer fixtures is used to determine the fixture efficiency of TLEDs in parking garage fixtures. Thus, a 9% increase in fixture efficiency is applied to the T8 parking garage fixture efficiency as measures by Caliper studies as noted in above section.

Through an iterative process, using a minimum efficacy of 145 LPW, TLED wattages yielding similar fixture lumens to the base case were selected. Since the performance of TLEDs in troffers and parking garage fixtures differ, different measure case wattages per application were selected. Also lamp wattages were also selected to meet the minimum 3000 lumen requirement for 2-lamp fixtures set forth by DLC in their technical requirements for TLEDs in version 4.3.

[15] U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2014. *CALiPER Report 21.2: Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers.* Prepared by the Pacific Northwest National Laboratory (PNNL).

[16] U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2013. *CALiPER Exploratory Study: Recessed Troffer Lighting.* Prepared by the Pacific Northwest National Laboratory (PNNL). Revised June 2013.

[17] U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2014. *CALiPER Report 21.2: Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers.* Prepared by the Pacific Northwest National Laboratory (PNNL).

U.S. Department of Energy (DOE), Building Technologies Office of Energy Efficiency & Renewable Energy. 2009. *CALiPER Benchmark Report: Performance of T12 and T8 Fluorescent Lamps and Troffers and LED Linear Replacement Lamps.* Prepared by the Pacific Northwest National Laboratory (PNNL).

[18] U.S. Department of Energy. 2010. *DOE SSL CALiPER Report: Product Test Reference: CALiPER BK 09-108 Parking Structure Fluorescent.*

LED In-Situ Fixture Performance

Fixture Type	Nominal LED (W)	Lamp Saturation Weight (%)	Lamp Efficacy (LPW)	Bare Lamp Lumens (2-lamps)	Fixture Efficiency	Total Fixture Lumens	Weighted Average Fixture Lumens	Percent Difference from T8 (%)
Troffer	14	42%	145	4,060	82%	3,331	3,469	-1.3%
	15	58%	145	4,350		3,569		
Parking Fixture	14.25	42%	145	4,133	73%	3,030	3,061	-1.1%
	14.50	48%	145	4,205		3,084		

Measure Case Average Watts. The measure case wattages of lamps selected from the table above for each fixture type were normalized based on the saturation weighting from the SCE Program data.

Measure Case Lamp Wattages

Fixture Type	Nominal LED (W)	Lamp Saturation Weight (%)	Weighted Average Fixture Wattage (W)	Source
Troffer	14	42%	14.58	Southern California Edison (SCE). 2019. "SWLG009-01 TLED Delta Watts Calculation.xlsx."
	15	58%		
Parking Fixture	14.25	42%	14.40	
	14.50	48%		

Demand Difference. The demand difference is the difference between the electric demand of the base case lamp and the electric demand of the measure case lamp.

Interactive Effects Multiplier. Heating, ventilating and air conditioning (HVAC) interactive effects refers to the change in HVAC energy usage due to the installation of energy-savings measures that directly change electric energy use within the conditioned space of a building. Interactive effective multipliers are developed and maintained by the California Public Utilities Commission (CPUC) Energy Division and its team of consultants via building simulation techniques that incorporate results from building site surveys, field measurements, laboratory tests, and facility billing data analysis. Interactive effects multipliers for lighting measures vary by building type, vintage, climate zone, lighting type, and occupancy sensor scenario. The relevant designations to identify the appropriate interactive effects multipliers for LED T8 replacement lamps are provided below.

Interactive Effects Multiplier Designations for LED T8 Replacement Lamps UL Type A

Sector	Lighting Type	Building Vintage and HVAC	Source
Commercial	Indoor Linear fluorescent lamps (Hardwired)	Existing, Commercial Weighted	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."
Residential	Indoor Non-CFL lamps and fixtures (Screw-in)	Existing, Residential Weighted	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Res-InLtg.csv."

The sources of the input parameters for the electric energy savings calculation are provided below.

LED T8 Replacement Lamps UL Type A Electric Energy Savings Parameters

Parameter	Value	Source
Base case weighted average lamp wattage (W)	26.68	Southern California Edison (SCE). 2019. "SWLG009-01 TLED Delta Watts Calculation.xlsx."
Non-Res, Dwelling and Common Area: Measure case weighted average lamp wattage (W)	14.58	
Parking Garage: Measure case weighted average lamp wattage (W)	14.40	
Annual hours of operation – commercial	Varies by building type, lighting type and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."
Interactive effects multiplier - commercial	Varies by climate zone, building type, vintage, lighting type and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."
Annual hours of operation – residential	Varies by dwelling or common area space for multi-family/double-wide mobile homes	California Public Utilities Commission (CPUC), Energy Division, Ex Ante Team. 2015. "2015 Workpaper Guidance- Lighting Retrofits." Memorandum submitted to the California Energy Efficiency Program Administrators. January 27.
Interactive effects multiplier - residential	Varies by climate zone, building type, and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Res-InLtg.csv."
Annual hours of operation – parking garages	2,613.75	California Public Utilities Commission (CPUC), Energy Division. 2016. "Disposition for Workpaper SCE13LG123 revision 0." September 30.
Interactive effects multiplier – parking garages (interactive effects multiplier for unconditioned spaces)	1.0	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."

Parking garage annual hours of operation: Parking garage hours of operation represent the equivalent full-load hours (EFLH) and was calculated as the average of the allowed low power usage at 35% power[19] and lower-power usage at 20% power.[20] The calculated mid-point or average of 20% and 35% is 27.5%, which is within the range allowed for the dimmed-power state by Title24. Calculations for a lamp replacement in a parking garage conforms to the Disposition for Workpapers Covering Exterior LED Lighting Fixtures,

[19] California Public Utilities Commission (CPUC), Energy Division. 2016. "Disposition for Workpaper SCE13LG123 revision 0." September 30.

[20] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.* CEC-400-2015-037-CMF. Section 130.2(c)3

issued March 1, 2017.[21] (The same hours of use were also calculated for the "PGECOLTG151 R8 Outdoor InterimSolution" workpaper,[22] which was subsequently approved by the CPUC Energy Division.)

The resultant LED T8 lamp energy savings vary by market sector and building type, due to operating hours and interactive effects that vary by building type and sector.

The table below maps each California climate zone to an IOU service area to identify the appropriate saving value for each California climate zone.

Climate Zone-IOU Service Area Mapping

Program Administrator	Climate Zone
SCE	CZ06, CZ08, CZ09, CZ10, CZ13, CZ14, CZ15, CZ16
PG&E	CZ01, CZ02, CZ03, CZ04, CZ05, CZ11, CZ12
SDG&E	CZ07

Sample Calculation. A sample energy savings calculation is provided below for a 4-foot LED T8 Lamp UL Type A replacing Linear Fluorescent T8 Lamp in an Assembly building type, Climate Zone 6, and accelerated replacement installation type.

$$UES = \frac{(26.68 - 14.58) \times 1100 \times 1.08}{1{,}000\left(\frac{Watthours}{kWh}\right)}$$

$$UES = 14.38\ kWh/year$$

PEAK ELECTRIC DEMAND REDUCTION (KW)

The calculation of demand reduction impacts (kW) for the LED T8 lamp is a function of the difference between the baseline and measure case lamp wattage (ΔW), a coincident demand factor (CDF) and interactive effects.

$$Peak\ Demand\ Reduction = \frac{\Delta W \times CDF \times IE_{elec}}{1{,}000\ W/kW}$$

ΔWatts/unit = *(Base Case Average Watts per lamp) – (Measure Case Average Watts per lamp)*

CDF = *Coincident demand factor*

IE_{elec} = *Interactive Effects, by building type/space*

[21] California Public Utilities Commission (CPUC), Energy Division. 2017. "Disposition For Workpapers Covering Exterior LED Lighting Fixtures." March 1.

[22] Pacific Gas and Electric Company (PG&E). 2018. *Work Paper PGECOLTG151 LED Outdoor Area and Street Lighting Revision 8*. April 11.

See the Electric Savings section for a discussion of the base case and measure case average watts per lamp used to derive the ΔW and the HVAC interactive effects multiplier.

Coincident Demand Factor (CDF). The coincident demand factor (CDF) represents the percentage of the time that all the lights in the building are on at the same time, during the CPUC-defined peak hours. This factor is applied to the demand savings to align the savings with this peak period. This factor varies by building type and climate zone.

The sources for the input parameters for this calculation are specified below.

LED T8 Replacement Lamps UL Type A Demand Reduction Parameters

Parameter	Value	Source
Base case average lamp wattage (W)	26.68	Southern California Edison (SCE). 2019. "SWLG009-01 TLED Delta Watts Calculation.xlsx."
Non-Res, Dwelling and Common Area: Measure case weighted average lamp wattage (W)	14.58	
Parking Garage: Measure case weighted average lamp wattage (W)	14.40	
Lighting coincident demand factor (CDF) – commercial	Varies by building type, vintage, lighting type and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."
Interactive effects - commercial	Varies by climate zone, building type, vintage, lighting type and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."
Lighting coincident demand factor (CDF) – residential	Varies by building type and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Res-InLtg.csv."
Interactive effects - residential	Varies by climate zone, building type, and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Res-InLtg.csv."
Lighting coincident demand factor (CDF) – parking garages	Varies by building type, vintage, lighting type and vintage	Parking garage CDF is assumed to be the same as the Non-Res building CDF.
Interactive effects multiplier – parking garages (interactive effects multiplier for unconditioned spaces)	1.0	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."

The resultant LED T8 lamp demand reduction varies by market sector and building type, due to differences in interactive effects.

The table below maps each California climate zone to an IOU service area to identify the appropriate saving value for each California climate zone.

Climate Zone-IOU Service Area Mapping

Program Administrator	Climate Zone
SCE	CZ06, CZ08, CZ09, CZ10, CZ13, CZ14, CZ15, CZ16
PG&E	CZ01, CZ02, CZ03, CZ04, CZ05, CZ11, CZ12
SDG&E	CZ07

Sample Calculation. A sample demand reduction calculation is provided below for a 4-foot LED T8 Lamp UL Type A replacing Linear Fluorescent T8 Lamp in an Assembly building type, Climate Zone 6, and accelerated replacement installation type.

$$Demand\ Reduction = \frac{(26.68 - 14.58) \times .226 \times 1.23}{1{,}000\left(\frac{Watt}{kW}\right)}$$

$$Demand\ Reduction = 0.00336\frac{kW}{Unit}$$

GAS SAVINGS (THERMS).

The estimated gas savings of an LED T8 lamp are based solely on the estimated change of gas consumption as reflected by a gas HVAC interactive effects multiplier.

$$UES = \frac{\Delta W \times HOURS \times IE_{gas}}{1{,}000\ Wh/\ kWh}$$

UES = *Unit energy savings (therms per lamp)*
ΔWatts/unit = *(Base Case Average Watts per lamp) – (Measure Case Average Watts per lamp)*
HOURS = *Annual hours of use, by building type/space*
IE_{gas} = *HVAC gas interactive effects, by building type/space*

See the Electric Savings section for a discussion of each parameter in the UES calculation. The sources of the input parameters for this calculation are provided below.

LED T8 Replacement Lamps UL Type A Gas Energy Savings Parameters

Parameter	Value	Source
Base case average lamp wattage (W)	26.68	Southern California Edison (SCE). 2019. "SWLG009-01 TLED Delta Watts Calculation.xlsx."
Non-Res, Dwelling and Common Area: Measure case weighted average lamp wattage (W)	14.58	
Parking Garage: Measure case weighted average lamp wattage (W)	14.40	
Annual hours of operation – commercial	Varies by building type, lighting type and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."
Gas interactive effects multiplier-commercial	Varies by climate zone, building type, vintage, lighting type, and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv."
Annual hours of operation – residential	Varies by dwelling or common area space for multi-family/double-wide mobile homes	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Res-InLtg.csv."
Gas interactive effects multiplier - residential	Varies by climate zone, sector, and vintage	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Res-InLtg.csv."

Annual hours of operation – parking garages	2,613.75	California Public Utilities Commission (CPUC), Energy Division. 2016. "Disposition for Workpaper SCE13LG123 revision 0." September 30.
Gas interactive effects multiplier – parking garages	0.0	California Public Utilities Commission (CPUC), Energy Division. 2017. "Disposition For Workpapers Covering Exterior LED Lighting Fixtures." March 1.

Parking garage annual hours of operation: Parking garage hours of operation represent the equivalent full-load hours (EFLH) and was calculated as the average of the allowed low power usage at 35% power[23] and lower-power usage at 20% power.[24] The calculated mid-point or average of 20% and 35% is 27.5%, which is within the range allowed for the dimmed-power state by Title24. Calculations for a lamp replacement in a parking garage conforms to the Disposition for Workpapers Covering Exterior LED Lighting Fixtures, issued March 1, 2017.[25] (The same hours of use were also calculated for the "PGECOLTG151 R8 Outdoor InterimSolution" workpaper,[26] which was subsequently approved by the CPUC Energy Division.)

The resultant LED T8 lamp gas energy savings varies by market sector and building type, due to differences in operating hours and interactive effects. Note that the gas interactive effective multipliers are negative and reflect the slight increase in gas space heat usage as a result of the installation of this measure.

The table below maps each California climate zone to an IOU service area to identify the appropriate saving value for each California climate zone.

Climate Zone-IOU Service Area Mapping

Program Administrator	Climate Zone
SCE	CZ06, CZ08, CZ09, CZ10, CZ13, CZ14, CZ15, CZ16
PG&E	CZ01, CZ02, CZ03, CZ04, CZ05, CZ11, CZ12
SDG&E	CZ07

Sample Calculation. The following is sample gas energy savings calculation (therms) for a 4-foot LED T8 Lamp UL Type A replacing Linear Fluorescent T8 Lamp in an Assembly building type, Climate Zone 6, and accelerated replacement installation type.

$$Annual\ Gas\ Savings = \frac{(26.68 - 14.58)}{1000} \times (1100) \times (-0.00687) = \ -0.0915\ therms/year$$

[23] California Public Utilities Commission (CPUC), Energy Division. 2016. "Disposition for Workpaper SCE13LG123 revision 0." September 30.

[24] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.* CEC-400-2015-037-CMF. Section 130.2(c)3

[25] California Public Utilities Commission (CPUC), Energy Division. 2017. "Disposition For Workpapers Covering Exterior LED Lighting Fixtures." March 1.

[26] Pacific Gas and Electric Company (PG&E). 2018. *Work Paper PGECOLTG151 LED Outdoor Area and Street Lighting Revision 8*. April 11.

LIFE CYCLE

This measure replaces the linear fluorescent lamp with an LED lamp while using the existing linear fluorescent ballast. Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention not caused the replacement or alteration.

As per Resolution E-4807, the California Public Utilities Commission (CPUC) revised add-on equipment measures so that the EUL of the measure itself is equal to the lower of the RUL of the modified system or equipment or the EUL of the add-on component."[27] Even though this measure is an accelerated replacement measure, the performance of the lamp is dependent upon the "host" ballast and therefore the calculation of the EUL is based upon the EUL of the ballast. Specifically, the EUL of the T8 LED is equal to the RUL of the host equipment – the ballast of the fixture.

The RUL of the ballast is derived in two steps: 1) determine the EUL of the ballast, and 2) determine the RUL of the ballast. The EUL of the ballast is equal to the total expected lifetime operating hours divided by the average annual operating hours (effective full-load hours, EFLH) for each building type, as shown below. Insofar as average hours of operation vary by building type, the EUL of the ballast varies by building type.

$$EUL_{ballast} = \frac{(Expected\ Lifetime\ Operating\ Hours)}{(Building\ Type\ Average\ Operating\ Hours\ Per\ Year, EFLH)}$$

$$RUL_{ballast} = \frac{1}{3} \times EUL_{ballast}$$

The RUL conforms with Version 5 of the Energy Efficiency Policy Manual, which recommends "one-third of the effective useful life in DEER as the remaining useful life until further study results are available to establish more accurate values."[28] This approach provides a reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced.[29]

Note that the EUL is capped at a maximum value of 15 years (and therefore the RUL is capped at a maximum value of 5 years.

The inputs and resultant EUL and RUL of LED T8 Replacement Lamps UL Type A are presented below.

[27] California Public Utilities Commission (CPUC). 2016. *Resolution E-4807*. December 16. Page 13.

[28] California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 32.

[29] KEMA, Inc. 2008. "Summary of EUL-RUL Analysis for the April 2008 Update to DEER." Memorandum submitted to Itron, Inc.

Effective Useful Life and Remaining Useful Life Inputs

Parameter	Linear Fluorescent w/ Electronic Ballast (primarily com)	All Building Types (primarily res)	Source
Expected Ballast Lifetime Operating Hours	70,000	70,000	The source for this data/information is unknown.
Hours of Use	Varies by building type	Varies by building type	California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Com-InLtg.csv." California Public Utilities Commission (CPUC). 2018. "SupportTable_2020-Res-InLtg.csv."
EUL (yrs) – host ballast	Varies by building type (max. 15 years)	Varies by building type (max. 15 years)	The source for this data/information is unknown.
RUL (yrs) – host ballast	Varies by building type (max of 5 years)	Varies by building type (max of 5 years)	-

BASE CASE MATERIAL COST ($/UNIT)

The base case material cost was derived from online price data collected via web scraping from 1000 bulbs, Bulbs.com, Lighting Supply, and Home Depot websites. The material cost was calculated as the weighted average material cost per TLED wattage.[30] The weighting factor was derived from the estimates of market saturation from the Southern California Edison (SCE) program data, using average costs for the estimated measure case wattages described in the Electric Savings section. The base case material costs were weighted using 42% 28W T8 lamps and 58% 32W T8 lamps.[31]

MEASURE CASE MATERIAL COST ($/UNIT)

The measure case material cost was derived from online price data collected via web scraping from 1000 bulbs, BeesLighting, Amazon, Bulbs.com, Top Bulbs, Pro Lighting, and Grainger websites. The material cost was calculated as the weighted average material cost per TLED wattage.[32] The weighting factor was derived from the estimates of market saturation from the Southern California Edison (SCE) program data, using average costs for the estimated measure case wattages described in the Electric Savings section. The measure material costs were calculated using 42% 14W TLEDs and 58% 15W TLEDs.

BASE CASE LABOR COST ($/UNIT)

The base case installation labor cost is assumed to equal the measure case installation labor cost. See Measure Case Labor Cost.

[30] Southern California Edison (SCE). 2019. "SWLG009-01 Cost Calculations.xlsx."

[31] Southern California Edison (SCE). 2019. "SWLG009-01 Cost Calculations.xlsx."

[32] Southern California Edison (SCE). 2019. "SWLG009-01 Cost Calculations.xlsx."

MEASURE CASE LABOR COST ($/UNIT)

Labor costs is based upon a 4-foot T8 LED tube from the RSMeans 2019 online cost database (item 266123558100).[33] The incremental labor cost for Type A ("plug and play") TLED lamps for all other delivery types is assumed to equal to $0.

NET-TO-GROSS (NTG)

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. The default NTG values are based upon the average of all NTG ratios for all evaluated 2006 – 2008 residential and commercial programs, as documented in the 2011 DEER Update Study conducted by Itron, Inc. These sector average NTGs are applicable to all energy efficiency measures that have been offered through residential and commercial sector programs for more than two years and for which impact evaluation results are not available.

Net-to-Gross Ratios

Parameter	Value	Source
NTG – commercial	0.60	Itron, Inc. 2011. *DEER Database 2011 Update Documentation.* Prepared for the California Public Utilities Commission. Page 15-4 Table 15-3.
NTG – industrial	0.60	
NTG – agriculture	0.60	
NTG – residential	0.55	

GROSS SAVINGS INSTALLATION ADJUSTMENT (GSIA)

The gross savings installation adjustment (GSIA) rate represents the ratio of the number of verified installations of the measure to the number of claimed installations reported by the utility. This factor varies by end use, sector, technology, application, and delivery method. This "default" GSIA rate for measures for which an alternative GSIA has not been estimated and approved.

Gross Savings Installation Adjustment Rate

Parameter	Value	Source
GSIA - default	1.0	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 31.

NON-ENERGY IMPACTS

The non-energy impacts of this measure have not been quantified.

[33] Southern California Edison (SCE). 2019. "SWLG009-01 Cost Calculations.xlsx."

DEER DIFFERENCES ANALYSIS

This section provides a summary of inputs and methods based upon the Database for Energy Efficient Resources (DEER), and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	No
Scaled DEER measure	Yes
DEER Base Case	No
DEER Measure Case	No
DEER Building Types	Yes
DEER Operating Hours	Yes
DEER eQUEST Prototypes	No
DEER Version	Non-DEER
Reason for Deviation from DEER	DEER does not contain this type of measure
DEER Measure IDs Used	n/a
NTG	Source: DEER. The NTG of 0.60 is associate with NTG IDs: *Com-Default>2yrs, Ind-Default>2yrs, Ag-Default>2yrs*. The NTG of 0.55 is associated with NTG ID *Res-Default>2yrs*
GSIA	Source: DEER. The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: DEER2014. EUL ID: *ILtg-Lfluor-Elec* is associated with (70,000/HOU)/3 or the max of RUL value. Source: DEER2016. EUL ID: *LtgFixture-Default* is associated with (70,000/HOU)/3 or the max of RUL value. Ballast lifetime hours of use of 70,000 is the specified basis value in SupportTable_EUL_basis.csv

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Complete Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision
01	12/31/2017	Tim Melloch Jennifer Holmes Cal TF Staff	Draft of consolidated text for this statewide measure is based upon: SCE17LG117, Version 0 (February 16, 2017) WPSDGENRLG0084, Version 0 (August 14, 2017) – short form Consensus reached among Cal TF members.
	11/06/2018	Jennifer Holmes Cal TF Staff	Updates based upon: SCE17LG117, Revision 1 (July 11, 2018)
	4/3/2019	Lake Casco, TRC	Updated eligibility requirements based on new efficiency, Dual mode lamps, and DLC V5. Updated measure case wattage based on CALiPER fixture efficiency testing and new efficiency requirements. Updated material costing based on online retailers. Labor cost updated using 2019 RSMeans Online. Updated code language. Energy savings and demand reduction updated using DEER2020 HVAC IE and CDF.
	4/29/2019	Jennifer Holmes Cal TF Staff	Revisions for submittal of version 01.
	7/1/2019	Ajay Wadhera SCE	Revision of workpaper document and relative calculations for parking garages. Revised some languages in word document to better reflect the requirements for programs.