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LIGHTING

LED AMBIENT FIXTURES AND RETROFIT KITS, COMMERCIAL

SWLG012-01

CONTENTS

MEASURE NAME

LED Ambient Fixtures and Retrofit Kits, Commercial

STATEWIDE MEASURE ID

SWLG012-01

TECHNOLOGY SUMMARY

Recessed rectangular light fixtures, sometimes known as troffers, have traditionally used linear fluorescent light sources: Predominately T8 lamps with small T5 market share, and a diminishing T12 presence in non-residential building stock. Similar fixture shapes are in use for much less common surface mountings in non-residential buildings, for spaces where recessed ceiling space is unavailable, but ease of maintenance dictates a common lamp type: 4-foot lamps predominate, with 2-foot or U-bent lamps common in 2x2 fixtures.

Linear ambient fixtures have a wide array of uses in non-residential applications. These fixtures are used for direct and indirect lighting in office and retail environments, industrial and warehouse linear lighting, ingress-protected linear lighting, and other uses. Lighting for these applications has been traditionally provided by various forms of linear fluorescent fixtures that span a wide range of aesthetic quality from Class A office space to industrial workspace to retail stockroom: fluorescent strips, fluorescent wraps, fluorescent suspended fixtures, and fluorescent vapor-tight fixtures.

LED products offer advantages over linear fluorescent products for the general commercial fixture market. LED chip efficacies now routinely surpass the best fluorescent lamp-and-ballast system efficacies, and the superior directional light control of LEDs allows even greater fixture efficacy improvements. LED products reduce maintenance costs relative to linear fluorescent products that require re-lamping.

LED ambient commercial products (most commonly offered as recessed, surface-mounted, or suspended fixtures) are available both as new fixtures (e.g., luminaires) and as integrated retrofit kits. Both options include new LED chips, an LED driver or power supply, and optical control or lenses. Retrofit kits allow these components to be fit into existing linear fluorescent metal housing, whereas new LED luminaires are sold complete with a new metal housing.

Improvements in LED technology, particularly improving efficacies able to compete with and exceed the best T8 lamp-and-ballast systems producing over 95 lumens per watt (LPW), have made high-performance LED fixtures available for troffer and linear ambient applications.

Summaries of Market and Evaluation Studies

A Comprehensive Store Retrofit to LED lighting in Common Lighting Applications (Energy Solutions, 2014).[1] This study conducted a comprehensive LED retrofit in a retail store environment with multiple fixture and lamp types. The research confirmed that completing a storewide, comprehensive LED retrofit is feasible and cost-effective. Overall, the project achieved a 58% reduction in energy use for LED Accelerator (LEDA) Program eligible products, and 47% on a storewide basis. The study participant was satisfied with the energy savings, projected maintenance savings, and lighting quality provided by the LED products that were installed.

LED Office Lighting and Advanced Lighting Control System (ALCS) (EMCOR Energy Services, 2012).[2] This study demonstrated LED panel fixtures in an office lighting application with an Advanced Lighting Control System (ALCS). It demonstrated that it is easier to integrate controls with the latest LED products in the market to achieve even deeper savings. An initial energy savings of 21% resulted from replacing fluorescent lighting with LED lighting in an office. Additional energy savings of 41% resulted from adding the ALCS.

California LED Pricing Analysis (Navigant, 2018).[3] This market study to evaluate LED product pricing was completed by Navigant Consulting, Inc. in January 2018. This study objectives were to: 1) identify the range of current prices for DLC and ENERGYSTAR-qualified LED products in the California nonresidential lighting market for specific priority product categories (including the LED troffer lighting product category), 2) determine the factors that significantly influence LED price, 3) develop an incremental cost estimate relative to identified baseline technologies, and 4) determine how and at what rate LED price ranges are anticipated to change as the market matures three and five years out from 2017.

Price data from 2016 Q4 and 2017 Q2 was collected from California IOU Program data and from the Navigant LED Price Tracker, a tool that utilizes web-scraping software to collect data on product pricing and specifications online. Of the LED products, only those that met DLC technical requirements were included in the study analysis. Navigant identified key drivers of LED prices through a multivariate regression model that estimated the correlation between price and other product specifications.

The results of the study initially showed that the biggest driver influencing LED price is lumen output, followed by manufacturer, DLC qualification, and CRI. Efficacy was not one of the significant price-determining characteristics. Furthermore, even as DLC efficacy requirements have increased over time, prices have continued to decline. According to the study, price does not appear to scale with efficacy for any of the LED product categories evaluated.

The study determined that prices will continue to decrease over the next five years; however, the rate of decline is slowing across all product categories.

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[1] Kisch, T., Steuben, J., van Tijen, M., and Pang, T. (Energy Solutions). 2014. *A Comprehensive Store Retrofit to LED lighting in Common Lighting Applications.* Emerging Technologies Project Number: ET12PGE1481.

[2] EMCOR Energy Services. 2012. *LED Office Lighting and Advanced Lighting Control System (ALCS).* Emerging Technologies Project Number: ET11PGE3251.

[3] Navigant Consulting, Inc. 2018. *California LED Pricing Analysis.* Prepared for Southern California Edison, Pacific Gas and Electric Company, and Sempra Energy. January 18.

The study also noted that the cost to manufacture a product is separate from the consumer purchase price of that product. Although it may cost more to increase the efficacy of a product, that additional cost is not reflected in the purchase price the way lumen output/wattage and manufacturer affect product price.

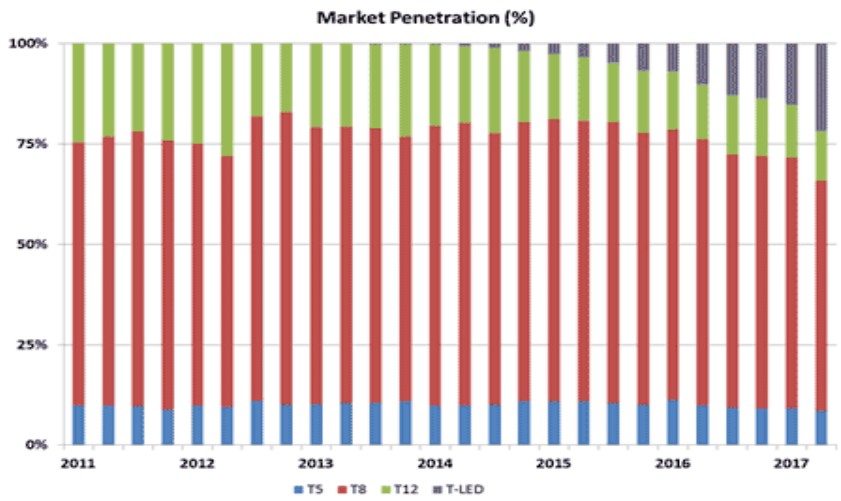
This study also revealed that a larger portion of retrofit installations include replacing lamps and ballasts only and not entirely fixtures. This is due to the extremely long life of commercial baseline linear fluorescent fixtures. This finding has implications for this measure since it assumes a fixture-to-fixture comparison between base case and measure case. The incremental measure cost of the two scenarios is very different. Since a common consumer purchasing scenario includes replacement lamps and ballasts only, this measure analysis includes that scenario in the baseline.

The California LED Pricing Analysis distinguishes the lighting luminaire market from the replacement market (page 8):

> *Navigant evaluated incremental cost both with and without baseline fixture costs, in order to represent two distinct scenarios:*
>
> 1. ***Luminaire Market:*** *For the luminaire market incremental cost, the baseline system was assumed to comprise a lamp(s), ballast, reflector/diffusor, and the housing. Pricing for each of these system components was included in the baseline system cost. The incremental cost was then calculated relative to a complete LED luminaire. This scenario represented the new construction market where owners and facility managers are comparing technology options equally. It is important to note that this represents a small proportion of total installations.*[2]
> 2. ***Replacement Market:*** *For the replacement market, the baseline system comprised of just a lamp(s) and ballast. The replacement market baseline system does not include reflector/diffusors or housing. This scenario represented the replacement on lamp or ballast burn-out where owners and facility managers are not comparing technology options equally due to the long lifetime of commercial baseline fixtures (above 100,000 hours). This represents a relatively larger proportion of total installations.*
>
> *Key findings included:*
>
> - *The incremental costs of DLC and ENERGY STAR qualified LED products to complete baseline luminaire systems (lamp(s), ballast, reflector/diffusor and fixture) for certain priority products, particularly in the outdoor groups, were negative. This indicates that LED products were sometimes less expensive than, or comparable to, baseline systems.*
> - *However, comparing fixture-to-fixture represents a small proportion of the market, accounting primarily for new construction installations. The replacement market, in which a complete DLC and ENERGY STAR qualified LED product is compared to a baseline lamp(s) and ballast, yields high incremental costs in every product category and represents a more common consumer purchasing scenario.*

NEMA Shipments Data (NEMA, 2017).[4] NEMA shipment data depicted in the figure below shows that TLED purchases have been increasing over the last several years compared to other linear lamp types. Much of that growth is driven by low cost (for similar levels of energy savings), significantly lower costs than the costs of both baseline and measure case new LED luminaires and retrofit kits.

[4] National Electrical Manufacturers Association (NEMA). 2017. "Linear Fluorescent Lamp Indexes Continue to Decline in Second Quarter 2017 while T-LED Market Penetration Increases."

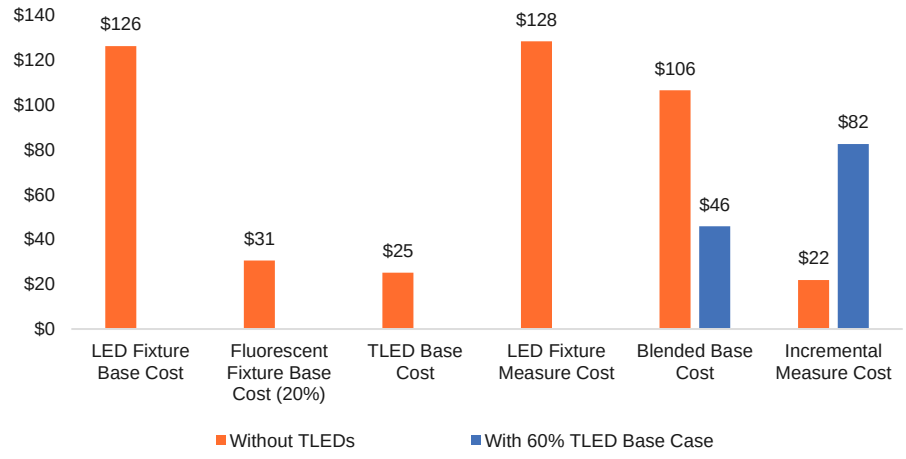


NEMA Linear Lamp Penetration, Q2 2017

Market Trends

TLEDs as a Viable Retrofit Alternative to Full Fixture Replacement. The *California LED Pricing Analysis* study distinguishes the lighting luminaire market from the replacement market and suggests that customer purchase decisions are not solely influenced by *fixture* cost differentials but include other options such as lamps that also deliver energy savings.

As the key findings of the LED Pricing Analysis suggest (and as shown in the figure below) the inclusion of TLEDs has a significant effect on incremental costs for these measures. The measure cost analysis for this measure indicate that TLEDs are less expensive than either base case (100+ LPW) or measure case (125+ LPW) LED products.



Impact of TLEDs on IMC for LED Troffer measures

With an increasing percentage of TLEDs in the base case, a positive incremental measure cost starts to emerge, which more accurately represents the proportion of the market that is the replacement market as explained in the *California LED Pricing Analysis*.

TLED market share: Costs Continue to be a Barrier to Customer Purchase Decisions. Customers who intend to upgrade their existing non-LED technologies to LED technology are faced with the two scenarios Navigant highlights, a full LED luminaire fixture/retrofit kit replacement or upgrading to TLEDs. Cost-sensitive customers may choose the less expensive TLED option; coupled with the data that indicates steady increases in TLED market penetration, PG&E believes this should reasonably be included as part of the NR baseline scenario.

Bonneville Power Administration (BPA) conducted the *Non-Residential Lighting Market Characterization Study* for the Pacific Northwest Region that indicated that LED sales continue to increase rapidly, accounting for 15% of all nonresidential sales, with LED lamps and tubes representing the majority of the growth at 10% of total sales.[5]

CALiPER Snapshot: Troffers (U.S. DOE, 2016).[6] A few of the conclusions that CALiPER reported in its most recent snapshot report on LED Troffers:

- About 10% of the listed products had a luminous efficacy greater than 125 LPW, therefore DLC Premium-level products are less than one- tenth of the market by this dataset.
- The output of some of the DLC "listed" LED products exceeds what is typical of a fluorescent troffer, supporting the continuation of an upper lumen output limit for this measure.

CALiPER Snapshot: T-LEDs (U.S. DOE, 2016).[7] A few of the conclusions that CALiPER reported in its most recent snapshot report on TLEDs:

- Over 90% of the currently listed TLEDs exceed 100 LPW, which is roughly the efficacy of a bare linear fluorescent lamp, and near to the qualification threshold for the DesignLights Consortium™ Products List of 110 LPW. In the broad LightingFacts database, both LED troffer retrofit kits and LED troffer luminaires tend to have lower efficacies compared to bare TLEDs, but when luminaire efficiency is considered, the retrofit kits and troffers are comparable to the high end of TLED efficacy.
- When evaluating TLEDs, it is important to consider their efficacy when installed in a luminaire. As the number of lamps increases, the luminaire efficiency is slightly reduced. In order to appropriately compare the efficacy of TLEDs to that of other LED luminaires, this workpaper uses a fixture efficiency multiplier of 0.8 to represent the luminous efficiency of the luminaire, per this CALiPER report from the DOE.

[5] Bonneville Power Administration (BPA). 2017. *2016 Non-Residential Lighting Market Characterization.* July.

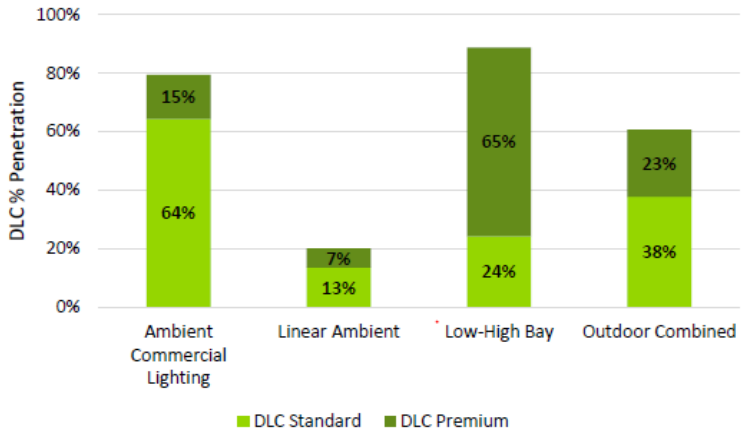
[6] U.S. Department of Energy, Energy Efficiency & Renewable Energy, Building Technologies Office. 2016. "CALiPER Snapshot Troffers." December.

[7] U.S. Department of Energy, Energy Efficiency & Renewable Energy, Building Technologies Office. 2016. "CALiPER Snapshot Linear Lamps (TLEDs)." July.

Based on the data collected by PG&E in February 2019, the 25th percentile of the TLED efficacy is determined to be 111 LPW.[8]

In addition, many TLEDs operate with existing fluorescent ballasts which increase the TLED wattage consumption. CALiPER does not address the percentage of TLEDs operating with a fluorescent ballast. Anecdotal market evidence suggests the plug-and-play, Type A, approach to TLEDs is the most popular, with no electrician requirement to plug in new lamps; this is also the most inefficient strategy because it leaves the fluorescent ballast powered. Without a thorough study available on TLED trends, this measure analysis assumes a conservative 40.4% of TLEDs operate with fluorescent ballasts, based on the percentage of the DLC QPL listed TLEDs that are Type A. Fluorescent ballasts are assumed to consume 10% of system power, based on federal fluorescent ballast luminous efficiency standards (see Code Requirements). 59.6% of TLEDs are assumed to have no ballast losses. Incorporating ballast efficiency and fixture losses yields an efficacy of 85.2 LPW for TLEDs in fixtures.[9]

California Statewide Non-Residential LED Quality and Market Characterization Study, Part 2 – LED Market Characterization and Final Non-Residential LED Quality Criteria (Navigant, 2019).[10] This study revealed that a small percentage of the linear ambient fixture sales were DLC listed. The low penetration of DLC-qualified products being purchased is an indication that no utility rebates are *not* offered for those products. The deemed offerings for DLC qualified products will likely encourage customers toward purchasing the more efficient and higher quality lighting products.



2017 DLC Market Penetration by Criteria Product Category

[8] Pacific Gas & Electric Company (PG&E). 2019. "TLED Cost Data_FEB2019.xlsx"

[9] Pacific Gas & Electric Company (PG&E). 2019. "Ambient Ltg Calc_Mar2019.xlsx" See "TLED info" tab.

[10] Navigant Consulting, Inc. 2019. *California Statewide Non-Residential LED Quality and Market Characterization Study. Part 2 – LED Market Characterization and Final Non-Residential LED Quality Criteria.* Final Report. Prepared for Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E). April.

MEASURE CASE DESCRIPTION.

Given the number of variations on linear fluorescent lamp and ballast configurations and resultant light outputs, and that groupings by wattage do not accurately reflect illumination between LED and linear fluorescent fixtures, the efficacy and wattages of both base case and measure case fixtures are not grouped by lamp and ballast configuration. Rather, they are characterized in units of kilolumens (kLm).

The measure case is defined as an LED luminaire or LED retrofit kit in the troffer or linear ambient product categories with efficacy ranges shown in the table below. Measure offerings vary by fixture type, size, and efficacy (LPW). Troffer eligibility is limited to products with initial light output between 2,200 and 6,500 lumens, and linear ambient eligibility is limited to products with initial light output below 6,500 lumens.

Measure Offerings

Statewide Measure Offering ID	Measure Offering Description
SWLG012A	2 x 4 LED New Luminaire rated greater than or equal to 125 LPW and < 140 LPW
SWLG012B	2 x 4 LED New Luminaire rated greater than or equal to 140 LPW
SWLG012C	2 x 2 LED New Luminaire rated greater than or equal to 125 LPW and < 140 LPW
SWLG012D	2 x 2 LED New Luminaire rated greater than or equal to 140 LPW
SWLG012E	1 x 4 LED New Luminaire rated greater than or equal to 125 LPW and < 140 LPW
SWLG012F	1 x 4 LED New Luminaire rated greater than or equal to 140 LPW
SWLG012G	2 x 4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and < 140 LPW
SWLG012H	2 x 4 LED Integrated retrofit kit rated greater than or equal to 140 LPW
SWLG012I	2 x 2 LED Integrated retrofit kit rated greater than or equal to 125 LPW and < 140 LPW
SWLG012J	2 x 2 LED Integrated retrofit kit rated greater than or equal to 140 LPW
SWLG012K	1 x 4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and < 140 LPW
SWLG012L	1 x 4 LED Integrated retrofit kit rated greater than or equal to 140 LPW
SWLG012M	LED Direct/Indirect Linear Ambient 2 ft. New Luminaire rated greater than or equal to 125 LPW and < 140 LPW
SWLG012N	LED Direct/Indirect Linear Ambient 2 ft. New Luminaire rated greater than or equal to 140 LPW
SWLG012O	LED Direct/Indirect Linear Ambient 4 ft. New Luminaire rated greater than or equal to 125 LPW and < 140 LPW
SWLG012P	LED Direct/Indirect Linear Ambient 4 ft. New Luminaire rated greater than or equal to 140 LPW
SWLG012Q	LED Direct/Indirect Linear Ambient 8 ft. New Luminaire rated greater than or equal to 125 LPW and < 140 LPW
SWLG012R	LED Direct/Indirect Linear Ambient 8 ft. New Luminaire rated greater than or equal to 140 LPW
SWLG012S	LED Direct Linear Ambient 2 ft. retrofit kit rated greater than or equal to 125 LPW and < 140 LPW
SWLG012T	LED Direct Linear Ambient 2 ft. retrofit kit rated greater than or equal to 140 LPW
SWLG012U	LED Direct Linear Ambient 4 ft. retrofit kit rated greater than or equal to 125 LPW and < 140 LPW
SWLG012V	LED Direct Linear Ambient 4 ft. retrofit kit rated greater than or equal to 140 LPW
SWLG012W	LED Direct Linear Ambient 8 ft. retrofit kit rated greater than or equal to 125 LPW and < 140 LPW
SWLG012X	LED Direct Linear Ambient 8 ft. retrofit kit rated greater than or equal to 140 LPW

The fixture performance in the applicable categories of the DesignLights Consortium (DLC) qualified product list (QPL)—LED Luminaires for Ambient Lighting of Interior Commercial Spaces, and Integrated Retrofit Kits for 2x4, 2x2, and 1x4 luminaires – were analyzed to substantiate the light output equivalency assumptions. Qualified products in these categories listed in DLC were evaluated to create the 12 measure code tiers with the appropriate luminaire efficacy.

The future DLC update, currently in the form of a draft DLC V5.0 has not proposed efficacy levels for DLC Premium at this time.

BASE CASE DESCRIPTION

The base case fixture is defined as a linear fluorescent fixture with the equivalent maintained illuminance to those LEDs at the end of effective useful life. Given the great number of variations on linear fluorescent lamp and ballast configurations and resultant light outputs, and that groupings made by wattage do not accurately reflect illumination between LED and linear fluorescent fixtures, the efficacy and wattages of both base case and measure case fixtures are not grouped by lamp and ballast configuration but characterized in units of kilolumens of initial LED light output with energy impacts scaling with these kilolumen units (see Measure Case Description).

The base case wattages were determined by simple division of kilolumen (1,000 lumens) by the efficacy minimum requirement: 100 LPW for LED fixtures and retrofit kits, and 111 LPW for TLED.

The normal replacement baseline is 100% LED technology comprised of 33% TLED and 67% LED new luminaire or retrofit kit. Per Resolution E-4952[11] issued by the Energy Division of the California Public Utilities Commission (CPUC) the appropriate base case fixtures and retrofit kits are LED technology of 100 lumens per watt (LPW) efficacy, approximately equal to the 25th percentile efficacy of the LED fixture performance range. New fixtures and luminaires compose 67% of the base case. This measure analysis introduces linear LED replacement lamps (TLEDs) as the remaining 33% of the base case, with the bare-lamp TLED efficacy set at the same benchmark as luminaire and retrofit kit performance, the 25th percentile efficacy of the TLED performance range.

Evidence from Southern California Edison (SCE) and Pacific Gas and Electric Company (PG&E) program participation data, input from local distribution channels, and the Navigant *California LED Pricing Analysis Study*[12] (see Technology Summary) suggests that TLEDS are a viable and commonly-used retrofit alternative to a full fixture replacement, while the National Electrical Manufacturers Association (NEMA) national shipments data shows that TLED market penetration has been steadily increasing.[13] Supporting data on TLED market share and purchase scenarios can be found in the studies summarized in the Technology Summary.

[11] California Public Utilities Commission (CPUC). 2018. *Resolution E-4952.* October 11.

[12] Navigant Consulting, Inc. 2018. *California LED Pricing Analysis.* Prepared for Southern California Edison, Pacific Gas and Electric Company, and Sempra Energy. January 18.

[13] National Electrical Manufacturers Association (NEMA). 2017. "Linear Fluorescent Lamp Indexes Continue to Decline in Second Quarter 2017 while T-LED Market Penetration Increases."

Energy consumption is calculated based on a mix of 33% TLED and 67% LED new luminaire or full retrofit kit. The base case wattage per kilolumen is a blend of 85.2 LPW for TLEDs and 100 LPW for new luminaires and retrofit kits, or 95 LPW overall.

The 2019 draft of the DesignLights Consortium (DLC) Solid-State Lighting (SSL) Technical Requirements V5.0[14] proposes DLC Standard efficacies of 105 LPW for Troffers and 110 LPW for Linear Ambient fixtures. The base case efficacy of 100 LPW for troffers and linear ambient fixtures aligns with the DLC proposed efficacies for Version 5.

CODE REQUIREMENTS

There is no applicable state or federal codes that explicitly apply to this measure.

Note, however, that general service fluorescent lamps and ballasts are energy-using components of linear fluorescent fixtures and are regulated by federal standards, as follows:

- A 4-foot medium bi-pin lamp ≤ 4,500K is required to meet 89 LPW (2,848 lumens per 32-W lamp)[15]
- Ballasts for 4-foot medium bi-pin lamps are required by the EPCA 2011 amendment to have a luminous efficacy no less than $0.993/(1 + 0.27^{x}$ total lamp arc power - 0.25)[16]

For a *normal replacement* scenario, only the ballast performance matters, and only for TLED Type A products. For these products serving 32-Watt 4-foot products, a 90% BLE is assumed, exceeding the 89.2% federal requirement.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	None.	n/a
CA Building Energy Efficiency Standards – Title 24	None.	n/a
Federal Standards	None.	n/a

NORMALIZING UNIT

Per kilolumen (klm)

[14] Design Lights Consortium (DLC). 2019. *Solid-State Lighting (SSL) Technical Requirements Version 5.0. Draft 1: Conceptual Specification.* January 29. Page 10.

[15] Code of Federal Regulations 10 CFR 430.32(n)

[16] Code of Federal Regulations 10 CFR 430.32(n)

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.

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
Normal replacement	DnDeemed	Com
Normal replacement	DnDeemDI	Com
Normal replacement	UpDeemed	Com
Normal replacement	DnDeemed	Res
Normal replacement	DnDeemDI	Res
Normal replacement	UpDeemed	Res
Normal replacement	DnDeemed	Ind
Normal replacement	DnDeemDI	Ind
Normal replacement	UpDeemed	Ind

Eligible Products

The product must meet the minimum efficacy range specified in the Measure Case Description.

Product must meet the technical requirements listed on the current Design Lights Consortium (DLC) qualified product list (QPL) for its corresponding product category.

The product must be listed in one of the following “primary use designations” of the DLC QPL:

- 2x4 Luminaires for Ambient Lighting of Interior Commercial Spaces
- Integrated Retrofit Kits for 2x4 Luminaires for Ambient Lighting of Interior Commercial Spaces
- 2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces
- Integrated Retrofit Kits for 2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces
- 1x4 Luminaires for Ambient Lighting of Interior Commercial Spaces
- Integrated Retrofit Kits for 1x4 Luminaires for Ambient Lighting of Interior Commercial Spaces
- Direct Linear Ambient Luminaires
- Linear Ambient Luminaires with Indirect Component
- Retrofit Kits for Direct Linear Ambient Luminaires

Design Lights Consortium Requirements

Integrated Retrofit Kits & Luminaires for Ambient Lighting of Interior Commercial Spaces (2x4, 2x2, 1x4)	Indoor Ambient Lighting Products	Direct Linear Ambient Luminaires and Retrofit Kits
Spacing Criteria from 1.0 to 2.0 in both the 0°-180° and 90°-270° directions	≥ 80 Color Rendering Index (CRI)	≥40% of Lumen Output in the 0°-60° zone
≥75% of Lumen Output in the 0°-60° zone	≤ 5000 Kelvin Correlated Color Temperature (CCT)	≥35% of Lumen Output in the 90°-150° zone

Eligible Building Types and Vintages

This measure is applicable for all existing and new commercial, retail, and industrial facilities.

Eligible Climate Zones

This measure is applicable to any California climate zones.

PROGRAM EXCLUSIONS

Products that are classified as "de-listed" on the DLC QPL are not eligible.

Fixtures in a DLC QPL "primary use designations" category that begins with "specialty" are not eligible.

Other fixture configurations, including LED troffer linear retrofit kits or external driver lamp-style retrofit kits (UL Listing Type C) do not qualify.

Exterior or high/low-bay installations of these products do not qualify.

Products in the "Eligible Products" categories above, but less than 2,200 lumens or greater than 6,500 lumens do not qualify.

Screw-based lamps and linear replacement lamps do not qualify.

DATA COLLECTION REQUIREMENTS

Historically, the cost analysis of LED deemed lighting measures assumed that measure costs have scaled with efficacy, therefore the finding that efficacy may not be a key price driver implies that further analysis should be conducted to consider how to incorporate other price drivers in measure design to encourage the adoption of higher degrees of efficiency.

Additional data collection requirements are to be determined.

USE CATEGORY

Lighting

ELECTRIC SAVINGS (kWh)

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

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

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

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

The inputs to the UES calculation[17] are explained below.

Delta Watts. (ΔW). The lighting wattage difference (Watts per kilolumen) was calculated as the difference between the baseline and measure case average watts per kilolumen, defined below.

Baseline and Measure Case Wattages for LED Ambient Commercial Fixtures & Retrofit Kits

Measure Case Description	Baseline Wattage (W/kLm)	Measure Case LED Wattage (W/kLm)	Delta (W/kLm)
LED Luminaire/Retrofit Kit rated ≥125 and <140 LPW	10.6	8.0	2.6
LED Luminaire/Retrofit Kit rated ≥140 LPW	10.6	7.1	3.4
LED Linear Ambient Luminaire/Retrofit Kit rated ≥125 and <140 LPW	10.6	8.0	2.6
LED Linear Ambient Luminaire/Retrofit Kit rated ≥140 LPW	10.6	7.1	3.4

The *normal replacement* scenario baseline is 100% LED: 33% TLED and 67% LED new luminaire or retrofit kit. Therefore, the lighting wattage difference is calculated as follows:

$$Delta\ Watts = (Baseline\ Average\ Watts\ per\ lamp) - (Measure\ Case\ Average\ Watts\ per\ lamp)$$

$$= \left(\frac{1000\ lm}{(33\% \times 85.2\ LPW + 67\% \times 100\ LPW)}\right) - \left(\frac{1000\ lm}{125\ or\ 140\ LPW}\right)$$

$$= 10.5\ LPW - 8.0\ LPW = 2.6\ LPW$$

$$= 10.5\ LPW - 7.1\ LPW = 3.4\ LPW$$

[17] Pacific Gas & Electric Company (PG&E). 2019. "SWLG012-01 LED Ambient Savings Calc_2020 - Final.xlsx."

Baseline Average Watts per Lamp. The base case linear fluorescent fixtures were modeled across the DLC light output range according to the most common fixture type with a configuration that meets appropriate federal lamp standards, federal ballast standards, and California Title 24 interior commercial lumen power density (LPD) requirements. Rather than assume a single base case lamp-and-ballast-and-fixture combination as a base case, the efficacy of a standards-compliant base case fixture in terms of lumens per Watt was used to calculate savings.

The code-compliant base case fixture model is specified in the 2011 Codes and Standards Enhancement (CASE) Report for Indoor Lighting Controls.[18] This report developed the most thorough commercial interior lighting model available in California standards proceedings. The model offers a combination of interior spaces: large open-plan areas as found in many offices, as well as small spaces typical of private offices or meeting rooms.[19] The panel fixtures modeled are 2x4 3-lamp T8 parabolic fixtures, matching a typical parabolic luminaire with 74.7% fixture efficacy[20].

The model was updated with the LPD specifications of the 2013 California Building Energy Efficiency Standards (Title 24), which reduced LPDs for Office Buildings via the Complete Building Method from 0.9 W/ft^2 to 0.8 W/ft^2. The 0.8 W/ft^2 value is lower than other applicable building types in Table 140.6-B of the 2013 Title 24 specifies the following: 1.0 W/ft^2 for General Commercial/Industrial Work Buildings, 1.2 W/ ft^2 for Restaurant Buildings, and 1.0 W/ft^2 for School Buildings.[21]

Additionally, the model was changed to reflect federal fluorescent lamp minimum standards with a 2,950-lumen lamp, but the ballast was unchanged as it reflected a premium electronic ballast listed by the Consortium for Energy Efficiency (CEE) HPT8 standard and the National Electrical Manufacturers Association (NEMA) Premium listing. The CASE Report model assumption for light loss of 9.7% was used.[22] The model suggests that illumination from recessed fluorescent fixtures compliant with current code can be obtained at maintained fixture efficacy of 58.8 LPW.[23] This figure is higher, accounting for 9.7% lumen depreciation, than the 5 fluorescent benchmark troffer fixtures tested in CALiPER Rounds 9 and 13 (all of which were 2x2 fixtures).[24]

Measure Case Average Watts. Initial LED lumen efficacy assumptions were set by the measure code minimum requirements, starting with 125 LPW for the lowest-efficacy measure code corresponding with the DLC Premium tier minimum efficacy. Calculating the wattage corresponding to this efficacy for a unit

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[18] California Utilities Statewide Codes and Standards Team. 2011. *Draft Measure Information Template – Indoor Lighting Control 2013 California Building Energy Efficiency Standards.*

[19] California Utilities Statewide Codes and Standards Team. 2011. *Draft Measure Information Template – Indoor Lighting Control 2013 California Building Energy Efficiency Standards.*

[20] Eaton. 2015. "Metalux 2P2GAX 328T8 332."

[21] California Energy Commission (CEC). 2012. *2013 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. CEC-400-2012-004-CMF-REV2. Table 140.6-B

[22] California Utilities Statewide Codes and Standards Team. 2011. *Draft Measure Information Template – Indoor Lighting Control 2013 California Building Energy Efficiency Standards.*

[23] California Utilities Statewide Codes and Standards Team. 2011. *Draft Measure Information Template – Indoor Lighting Control 2013 California Building Energy Efficiency Standards.*

[24] U.S. Department of Energy. 2011. *DOE Solid-State Lighting CALiPER Program Summary of Results: Round 13 of Product Testing.* Prepared by Pacific Northwest National Laboratory. Page 21.

of one kilolumen was accomplished by dividing 1,000 lumens by 125 LPW, resulting in 8.0 W/kLm for the measure case.

The LED fixture performance calculation relies on the fact that test lamp performance for LED fixtures is measured via absolute photometry, compared to the relative photometry, which is the standard for linear fluorescent fixtures. The practical implication of this is that the LED product efficacies found in the DLC Premium listing (125 LPW and higher) already reflect the light losses inside the fixture, giving a 125 LPW LED fixture a significant advantage in supplying illumination over a fluorescent fixture with a 125 LPW lamp-and-ballast system.

Maintained lumen output equivalency was based on the full list of DLC products and on LED lumen maintenance data from the Lighting Facts database. All 156 Lighting Facts fixtures with lumen maintenance information were considered as a full dataset, as well as the subset of 20 fixtures that were both DLC-listed and available with lumen maintenance values for the 25,000-hour mark, the mid-point of the 50,000 DLC specification minimum.

Lumen Maintenance. Analysis of the full set and subset, in accordance with the LED lumen output extrapolation formula published in Federal rulemaking, suggests LED fixture lumen maintenance of 89.6% for the blended Commercial building type with 2,420 operating hours per year:

$$\textit{Com EUL hours per DEER} = \textit{DEER Annual Measure HOUstd}^{x} \textit{ x EUL fixture maximum}$$

$$= 2{,}420 \text{ hours/year x}^{x} 12\text{-year maximum EUL}$$

$$= 29{,}040 \text{ hours}$$

This is less than 50,000, so 29,040 hours EUL is used for Com building type

LED lumen maintenance varies by building type due to varying hours of operation by building type. Motel annual run hours of 1,000 result in 12,000 run hours over 12-year EUL and thus 95.5% lumen maintenance. The annual operating hours for some of the DEER building types, such as Large Retail, Hospital, Warehouse, and Grocery, over 12 years will exceed 50,000 hours. Thus, the 50,000 DLC-minimum rated fixture life is assumed, along with an 89.6% lumen maintenance. The calculation, based on the Federal extrapolation formula, is taken across all 20 DLC-listed fixtures with 25,000-hour Lighting Facts data available, as follows:

$$\textit{Lumen Maintenance at Com EUL} = \textit{ hours} \times \ln \textit{Lumen Maintenance \% @ 25,000 hours} \div \textit{25,000 hours}$$

$$= e^{38{,}720 \times \ln 93.12 \div 25{,}000}$$

$$= 89.6\% \text{ lumen maintenance}$$

Annual Hours of Operation. Annual hours of operation, which varies by building type, was drawn directly from the DEER 2020 update.[25]

[25] California Public Utilities Commission (CPUC), Energy Division, Ex Ante Review Team. 2018. "DEER2020-Lighting-HVAC-IE-values.xlsx" September 7.

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 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 interactive effects multipliers for commercial buildings were adopted from the DEER 2020 update.[26]

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, CZ14, CZ15, CZ16
PG&E	CZ01, CZ02, CZ03, CZ04, CZ05, CZ11, CZ12, CZ13
SDG&E	CZ07

PEAK ELECTRIC DEMAND REDUCTION (KW)

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

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

$\Delta Watts/unit =$ *(Base Case Average Watts per lamp) – (Measure Case Average Watts per lamp)*

$CDF =$ *Coincident demand factor*

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

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

See the Electric Savings for an explanation of the base case and measure case average watts per lamp used to derive the ΔW and the 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

[26] California Public Utilities Commission (CPUC), Energy Division, Ex Ante Review Team. 2018. "DEER2020-Lighting-HVAC-IE-values.xlsx" September 7.

factor is applied to the demand savings to align the savings with this peak period. The CDF varies by building type and climate zone.

The sources for all input for this calculation are specified below.

Demand Reduction Inputs

Parameter	Value	Source
Base case average lamp wattage (W)	Varies by building type	Calculated.
Measure case average lamp wattage (W)	8.0 7.1	See Electric Savings.
Lighting coincident demand factor (CDF) – commercial	Varies by building type, vintage, lighting type and occupancy sensor scenario	California Public Utilities Commission (CPUC), Energy Division, Ex Ante Review Team. 2018. "DEER2020-Lighting-HVAC-IE-values.xlsx" September 7.
Interactive effects - commercial	Varies by climate zone, building type, vintage, lighting type and occupancy sensor scenario	California Public Utilities Commission (CPUC), Energy Division, Ex Ante Review Team. 2018. "DEER2020-Lighting-HVAC-IE-values.xlsx" September 7.

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, CZ14, CZ15, CZ16
PG&E	CZ01, CZ02, CZ03, CZ04, CZ05, CZ11, CZ12, CZ13
SDG&E	CZ07

GAS SAVINGS (THERMS)

Gas estimates are entirely based on the estimated increased gas use through calculated interactive effects.

The demand difference (watts per kilolumen) is simply the difference between the electric demand of a kilolumen unit of the base fixture and the electric demand of a kilolumen unit of the energy efficient fixture.

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

UES = *Gas unit energy savings (therms)*

ΔWatts/kLm = *(Baseline Average Watts per lamp) – (Measure Case Average Watts per lamp),*

HOURS = *Annual hours of operation, by building type/space*

IE = *Interactive Effects, by building type/space*

See Electric Savings for an explanation of inputs for this calculation.

LIFE CYCLE

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.

The EUL is calculated as the fixture rated hours divided by the DEER building hours per year or DEER non-res lighting EUL cap of 12-years, whichever is less.

$$EUL\ (Grocery\ Bldg\ Type) = \frac{(Fixture\ Rated\ Hours)}{(DEER\ Hours\ of\ Operation)}$$

$$= \frac{50{,}000\ Hr}{4{,}710\ Hr/Yr}$$

$$= 10.6\ years$$

Effective Useful Life Inputs

Parameter	Value	Source
Fixture Lifetime Operating Hours	50,000	Minimum lifetime of DLC-listed products
Average Hours of Operation	Varies by building type	California Public Utilities Commission (CPUC), Energy Division, Ex Ante Review Team. 2018. "DEER2020-Lighting-HVAC-IE-values.xlsx" September 7.

Fixture Lifetime Operating Hours. The rated life for these lighting products is assumed to equal the minimum lifetime hours of DLC-listed products (though DLC products average more than 56,000 hours). The minimum of the rated life for DLC-listed products 50,000 hours is adopted for this measure.

The EUL and RUL adopted for this measure are specified below. RUL is only applicable for add-on equipment and accelerated replacement installations and is not applicable for this measure.

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs)	12.0 (Max)	DEER2020
RUL (yrs)	n/a	n/a

BASE CASE MATERIAL COST ($/UNIT)

The base case material costs were derived from online pricing obtained via web-scraping conducted in February 2019.[27] Because TLEDs vary widely in wattage, price, and light output, the prices were normalized by light output at the midpoint of the lumen bin.[28]

MEASURE CASE MATERIAL COST ($/UNIT)

The measure equipment costs were developed from California distributor catalogs and websites in October and November of 2018 and confirmed with manufacturer representatives if possible.[29]

BASE CASE LABOR COST ($/UNIT)

It is assumed the labor cost of replacing the measure case fixture will be the same as the base case fixture. See Measure Case Labor Cost.

MEASURE CASE LABOR COST ($/UNIT)

The labor installation cost is equal to the product of installation time and labor rate that were derived from RSMeans data.[30]

Labor Cost Inputs

Parameter	Value	Source
Labor Time (hours/fixture)	1.509	Pacific Gas & Electric Company (PG&E). 2019. "SWLG012-01 LED Ambient Savings Calc_2020 - Final.xlsx." See "Cost" tab.
Labor Time (hours/kilolumen)	0.3320	
Labor Rate ($/hr)	$70.11	

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. This NTG is stipulated in Resolution E-4952 and only applies to normal replacement and new construction installations.

[27] Pacific Gas & Electric Company (PG&E). 2019. "TLED Cost Data_FEB2019.xlsx"

[28] Pacific Gas & Electric Company (PG&E). 2019. "SWLG012-01 LED Ambient Savings Calc_2020 - Final.xlsx." See "Cost" tab.

[29] Pacific Gas & Electric Company (PG&E). 2019. "SWLG012-01 LED Ambient Savings Calc_2020 - Final.xlsx." See "Cost" tab.

[30] Pacific Gas & Electric Company (PG&E). 2019. "SWLG012-01 LED Ambient Savings Calc_2020 - Final.xlsx." See "Cost" tab.

Net-to-Gross Ratios

Parameter	Value	Source
NTG	0.91	California Public Utilities Commission (CPUC). 2018. *Resolution E-4952*. October 11. Page A-34 – A-35.

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 GSIA rate is the current "default" rate specified for measures for which an alternative GSIA has not been estimated and approved.

Gross Savings Installation Adjustments

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

NON-ENERGY BENEFITS

Non-energy benefits for this measure have not been quantified.

DEER DIFFERENCES ANALYSIS

This section provides a summary of DEER-based inputs and methods, and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	Yes
Scaled DEER measure	No
DEER Base Case	No
DEER Measure Case	No
DEER Building Types	Yes
DEER Operating Hours	Yes
DEER eQUEST Prototypes	No
DEER Version	2019
Reason for Deviation from DEER	DEER does not address LED savings for panel fixtures and retrofit kits
DEER Measure IDs Used	Propose new
NTG	Source: DEER 2019. The NTG of 0.91 is associated with NTG ID: *NonRes-In-Ltg-LEDFixt* and *Res-InCmn-Ltg-LEDFixt*
GSIA	Source: DEER. The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: DEER. The value of 12 years is associated with EUL ID: *ILtg-Com-LED-50000hr*

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Complete Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision
01	03/31/2018	Tim Melloch, Cal TF Staff	Draft of consolidated text for this statewide measure is based upon: PGECOLTG179, Revision 5 (July 12, 2017) Consensus reached among Cal TF members.
	04/15/2019	Randy Kwok PG&E	Updated based upon: PGECOLTG179, Revision 6 (March 1, 2019)
		Jennifer Holmes Cal TF Staff	
	01/27/2020	Bryan Boyce, Energy Solutions	Updated EAD tables with new multifamily common area building type code (MFmCmn), updated NTG ID, QC of all documents.
	10/01/2021	Soe Hla PG&E	Corrected ElecImpactProfile IDs in EAD.