

Work Paper PGECOLTG179
LED Ambient Commercial Fixtures and
Retrofit Kits
Revision # 5

Pacific Gas & Electric Company
Customer Energy Solutions

LED Ambient Commercial
Fixtures and Retrofit Kits

Measure Codes LT148 - LT159

7/12/2017

At-a-Glance Summary

Applicable Measure Codes:	LT148– LT159						
Measure Description:	LED Luminaires/Retrofit Kits rated ≥ 125 LPW, Ambient Interior Commercial Spaces						
Energy Impact Common Units:	Kilolumen of LED initial light output						
Base Case Description:	Linear fluorescent recessed fixture or kit in 2x4, 2x2 or 1x4 size, with lamp and ballast meeting federal standard. Source: PG&E Calculations.						
Base Case Energy Consumption:	Various. Refer to .xlsx file attached Source: PG&E Calculations.						
Measure Energy Consumption:	Various. Refer to .xlsx file attached Source: PG&E Calculations.						
Energy Savings (Base Case – Measure):	Various. Refer to .xlsx file attached Source: PG&E Calculations.						
Costs Common Units:	\$ per kilolumen.						
Base Case Equipment Cost (\$/kilolumen):	Various. Refer to .xlsx file attached. Source: Distributor Quotations and Web links						
Measure Equipment Cost (\$/kilolumen):	Various. Refer to .xlsx file attached Source: Manufacturer Rep & Distributor Quotations and Web links						
Gross Measure Cost (\$/kilolumen)	Various. Refer to .xlsx file attached Source: Manufacturer Rep & Distributor Quotations and Web links						
Measure Incremental Cost (\$/kilolumen):	Various. Refer to .xlsx file attached Source: PG&E Calculations						
Effective Useful Life (years):	16 years, ILtg-Com-LED-50000hr+16yr 16 years, ILtg-Res-LED-50000hr+16yr Source: DEER2016						
Program Type:	ROB, NC.						
Net-to-Gross Ratios:	<table border="1"> <thead> <tr> <th>NTGR ID</th><th>NTGR</th></tr> </thead> <tbody> <tr> <td>Com-Default>2yrs</td><td>0.6</td></tr> <tr> <td>Res-Default>2</td><td>0.55</td></tr> </tbody> </table> <p>Source: DEER 2016</p>	NTGR ID	NTGR	Com-Default>2yrs	0.6	Res-Default>2	0.55
NTGR ID	NTGR						
Com-Default>2yrs	0.6						
Res-Default>2	0.55						
Important Comments:							

Document Revision History

Revision #	Date	Section by Section Description of Revisions	Author (Company)
Revision 0	2/25/2015	PGECOLTG179 R0 LED Ambient Commercial Fixtures and Retrofit Kits.doc Original Workpaper	Author: Greg Barker (Energy Solutions) Reviewer: Alina Zohrabian (PG&E)
Revision 1	1/1/2016	Added upstream delivery channel. Updated NTG & EUL IDs per DEER2016.	Alina Zohrabian (PG&E)
Revision 2	6/1/2016	Added DLC Premium Tier requirement for transition on July 15,2016; removed 12 measure codes that fall below DLC Premium efficacy. Updated costs based on recent cost data. No changes in savings, EUL, NTG.	Author: Greg Barker (Energy Solutions) Reviewer: Alina Zohrabian (PG&E)
Revision 3	11/28/2016	Updated Residential Interactive Effect(IE) factors per DEER 2017; The ET_NTG expired so the Direct Install NTG changes from 0.85 to 0.7	Mini Damodaran (PG&E)/ Alina Zohrabian (PG&E)
Revision 4	6/28/2017	-NTG values changed from All-Default<=2yrs =0.7 to Com-Default>2yrs = 0.6 for Commercial and Res-Default>2 =0.55 for Residential sector effective 10/1/2017	Mini Damodaran (PG&E)
Revision 5	7/12/2017	-Updated to DLC Technical Requirements v4.2 -Updated costs; Measure codes to be -Retired as of 12/31/2017 are LT042, LT043 LT046, LT047, LT050, LT051, LT054, LT055, LT058, LT059, LT062, LT063 -New measure codes LT148-LT159 added and will be effective 1/1/2018	Greg Barker (Energy Solutions)/ Mini Damodaran (PG&E)

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Section 1. General Measure & Baseline Data

1.1 Product Measure Description & Background

Catalog Description

Light Emitting Diode (LED) Ambient Commercial Fixtures and Retrofit Kits

Requirements:

- Must be a one for one replacement for a Linear Fluorescent Fixture with T8 or T5 lamps
- Must be a Design Lights Consortium (DLC) approved New Luminaire or an Integrated Retrofit Kit, listed on the PG&E qualified product list as Luminaires/Integrated Retrofit Kits for Ambient Lighting of Interior Commercial Spaces in one of the following sizes: 2x4, 2x2, 1x4
- Must be listed as DLC Premium by the Design Lights Consortium
- DLC-listed initial light output must be ≥ 2200 lm and ≤ 6500 lm
- Linear LED replacement lamps do not qualify
- LED Linear Retrofit kits on the PG&E QPL do not qualify.
- Only Fixtures and Retrofit kits that include new lenses between the LED package and the viewer qualify.
- Self-ballasted or screw-based lamps do not qualify.
- 5-year warranty minimum
- Must meet the minimum efficacy requirements listed in Table 1 effective 1/1/2018.

Table 1 - LED Ambient Commercial Fixtures & Retrofit Kits Minimum Measure Efficacies

Measure Code	Measure description
LT148	2x4 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces
LT149	2x4 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces
LT150	2x2 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces
LT151	2x2 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces
LT152	1x4 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces
LT153	1x4 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces
LT154	2x4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces
LT155	2x4 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces
LT156	2x2 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces
LT157	2x2 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces
LT158	1x4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces
LT159	1x4 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces

Program Restrictions and Guidelines

This workpaper details the replacement of linear fluorescent fixtures with LED Ambient Commercial Fixtures & Integrated Retrofit Kits. The workpaper offers delivery methods for non-residential customers through Upstream/Midstream, Downstream, or Direct Install Deemed programs.

The LED fixture or integrated retrofit kit must replace a linear fluorescent fixture on a 1-for-1 basis.

DLC requirements for Integrated Retrofit Kits and Luminaires for Ambient Lighting of Interior Commercial Spaces include:

- 5-year warranty
- 50,000 hour L70 Lumen Maintenance
- 36,000 hour L90 Lumen Maintenance
- ≥ 80 Color Rendering Index (CRI)
- **≥ 125 lumens / Watt**
- ≤ 5000 Kelvin Correlated Color Temperature (CCT)
- Spacing Criteria from 1.0 to 2.0 in both the 0-180° and 90-270° directions
- $\geq 75\%$ of Lumen Output in the 0-60° zone

DLC Categories Eligible under this Workpaper:	
• Must be on PG&E Qualified Products List, in one of 6 DLC categories:	○ 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

Products must meet exact technical requirements listed on DLC for these product categories stated above.

Terms and Conditions:

The customer must be a non-residential PG&E electric customer.

Market Applicability:

The customer must be a non-residential PG&E electric customer.

Type of Transaction:

The applicable types of transactions include Replace on Burnout or New Construction. The rebate incentivizes the choice of energy efficient equipment over the base case equipment, which is a Linear Fluorescent T8 fixture or retrofit kit.

1.2 Product Technical Description

Light emitting diode (LED) sources have improved over the past decade making them an efficient and reliable lighting technology. Many LED products have successfully replaced other lighting sources in some applications and made their way into the market through continuous improvement and compete with more established sources across many applications.

Recessed rectangular light fixtures, sometimes known as troffers, have traditionally used linear fluorescent light sources: T8 lamps predominate currently, 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 4 foot lamps also common.

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. Linear fluorescent lighting represents 72% of energy use in the commercial lighting sector and 80% of all commercial light fixtures, and therefore represents an enormous opportunity for potential LED savings.¹

LED Ambient Commercial products, which are most commonly used in recessed ceilings but may also be surface-mounted or suspended, are available both as complete new fixtures (a.k.a. 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.

Two Emerging Technologies reports commissioned by PG&E's ET Program have demonstrated savings potential from these measures and allowed PG&E to refine the requirements and specifications for these measures: ET12PGE1481 and ET11PGE3251. Error! Bookmark not defined..Error! Bookmark not defined.

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, have made LED panel fixtures feasible. These are fixtures with output of at least 1,500 lumens. Currently DLC requires LED panels and kits achieve output of at least 1,500 lumens. Panels eligible for these measure codes shall have initial light output rated between 2,200 lumens and 6,500 lumens.

LED fixtures under this workpaper are assigned a measure code according to efficacy, fixture type, and fixture size. The energy impact common unit is the kilolumen of initial rated light output for the LED fixture, according to the DLC listing.

This workpaper describes the energy savings associated with the replacement of linear fluorescent fixtures.

1.3 Installation Type Descriptions

The DEER Measure Cost Data Users Guide found on www.deeresources.com under DEER2011 Database Format hyperlink, DEER2011 for 13-14, spreadsheet *SPTdata_format-V0.97.xls*, defines the terms as follows:

Table 2 - Installation Type Descriptions ²

Identifies the measure application type in the Measure Implementation table in DEER2011.

Installation Type	Savings		Life	
	1 st Baseline (BL)	2 nd BL	1 st BL	2 nd BL
Replace on Burnout (ROB)	Above Code or Standard	N/A	EUL	N/A
New Construction (NEW/NC)	Above Code or Standard	N/A	EUL	N/A
Retrofit or Early Replacement (RET/ER)	Above Customer Existing	Above Code or Standard	RUL	EUL-RUL
Retrofit Add-on (REA)	Above Customer Existing	N/A	EUL	N/A

All the measures within this workbook are calculated for both ROB and NC.

A delivery mechanism is a delivery method paired with an incentive method. Delivery mechanisms are used by programs to obtain program participation and energy savings.

Delivery Method Descriptions

Delivery Method	Description
New Construction	The program offers financial incentives and/or design assistance to customers involved with new building construction. This is intended is to motivate customers to exceed Title 24 building energy efficiency requirements (residential or nonresidential).
Partnership	The program implements projects through a partnership between the utility and an institutional, government, or community-based organization.
Up/mid-Stream Programs	See Up/mid-Stream Incentive in the Incentive Method table.

Incentive Method Descriptions

Incentive Method	Description
Direct Install	The program implements energy efficiency measures for qualifying customers, at low or no cost to the customer.
Down-Stream Incentive	The customer installs qualifying energy efficient equipment and submits an incentive application to the utility program. Upon application approval, the utility program pays an incentive to the customer. Such an incentive may be deemed or customized.
Mid-Stream Incentive	The program gives a financial incentive to a midstream market actor, such as a distributor, retailer or contractor, to encourage the promotion of efficient measures. The incentive may or may not be passed on to the end-use customer.
Up-Stream Incentive	The program gives a financial incentive to an upstream market actor, such as a manufacturer or distributor, to encourage the manufacture, provision, or distribution of an efficient measure. The incentive may or may not be passed on to the end-use customer.

1.4 Product Base Case and Measure Case Data

Eligible measure case fixtures for these measure codes are LED panels with initial light output between 2,200 and 6,500 lumens. Appropriate base case fixtures are linear fluorescent fixtures that will have equivalent maintained illuminance to those LEDs at the end of effective useful life. The Effective Useful Life is 50,000 hours based on the DLC-minimum rated hours, except where this value exceeds the DEER run hours for a given building type over the 16 year DEER measure maximum life, in which case the effective useful life is 16 years. Given the great number of variations on linear fluorescent lamp and ballast configurations and resultant light outputs, and that groupings made by wattage as in previous custom 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. Cost, wattage and savings are all in units of kilolumen.

Table 3 - LED Ambient Commercial Fixtures & Retrofit Kits Base and Measure Wattages

Measure Code	Measure Description	Base Case system wattage per kilolumen (COM)	LED Watts per kilolumen	Delta Watts per kilolumen (COM)
LT148, LT150, LT152, LT154, LT156, LT158	LED Luminaires/Retrofit Kits rated ≥ 125 and < 140 LPW, Ambient Interior Commercial Spaces	15.2	8.0	7.2
LT149, LT151, LT153, LT155, LT157, LT159	LED Luminaires/Retrofit Kits rated ≥ 140 LPW, Ambient Interior Commercial Spaces	15.2	7.1	8.1

1.4.1 DEER Base Case and Measure Case Information

The Database for Energy Efficient Resources (DEER) 2016 does not address LED savings for panel fixtures and kits.

Net-to-Gross Assumption:

The NTGR value is from DEER 2016³. Table 4 summarizes all applicable Net-to-Gross ratios for programs that may be used by this measure.

Based on the "PGECOLTG1079_DispositionStaffResolution_23August2015-clean", 0.85 ET_NTG was used in direct install delivery channel. The upstream and downstream channels used the 0.7 NTG as noted in the disposition. The ET_NTG for Direct Install was effective to the portfolio from 10/1/2015 through 12/31/2016. The NTG for All-Default ≤ 2 yrs will be used through 9/30/2017, and was changed as per the table below.

Table 4 - Net-to-Gross Ratios

Delivery Type	NTGR_ID	Description	NTG
PreRebDown/PreRebUp/DirInstall	Com-Default > 2 yrs	All other EEMs with no evaluated NTGR; existing EEM in programs with same delivery mechanism for more than 2 years	0.6
PreRebDown/DirInstall	Res-Default > 2	All other EEM with no evaluated NTGR; existing EEM with same delivery mechanism for more than 2 years	0.55

Installation Rate

The IR value was obtained using the DEER READI tool. The relevant IR value for the measures in this work paper is in the table below.

Table 5 - Installation Rate

GSIA ID	Description	Sector	BldgType	ProgDelivID	GSIAValue
Def-GSIA	Default GSIA values	Any	Any	Any	1

Effective Useful Life / Remaining Useful Life

The rated life for these products is assumed to be 50,000 hours, the minimum DLC specification. Rated life for DLC-listed products varies between 50,000 hours and 500,000 hours. Since the EUL is dependent on the DEER hours of operation, the EUL expressed in years varies by building type. DEER sets an EUL maximum of 16 years for Interior Linear Fluorescent Fixtures, which this workpaper proposes applying to these LED fixtures and retrofit kits (16 year EUL maximum, equivalent of equivalent of ILtg-Com-LED-50000hr+16yr and ILtg-Res-LED-50000hr+16yr, DEER2016).

The EUL is based on 50,000 hours rated fixture life divided by average annual hours of operation for each building type, with a maximum of 16 years:

$$\text{EUL} = (\text{DLC-Minimum Fixture Life (hours)}) / (\text{Average Operating Hours per Year})$$

1.4.2 Codes & Standards Requirements Base Case and Measure Information

Title 20: These measures do not fall under Title 20 [2015] of the California Energy Regulations.

Title 24: These measures do not fall under Title 24 [2013] of the California Energy Regulations. The Lighting Power Densities of both measure and base case are capped by Title 24, but both measure and base cases are configured so as to be compliant with Title 24, with the measure capturing savings above Title 24 minimums.

Federal Standards: These measure case fixtures do not fall under Federal DOE or EPA Energy Regulations. Both General Service Fluorescent lamps and ballasts are energy-using components of linear fluorescent fixtures and are regulated by Federal Standards.

1. 4-foot medium bi-pin lamps $\leq 4500\text{K}$ are required to meet 89 LPW (2,848 lm per 32 Watt lamp)⁴
2. Ballasts for 4-foot medium bi-pin lamps are required by EPCA's 2011 amendment to have a luminous efficacy no less than $0.993/(1 + 0.27 \times \text{total lamp arc power} - 0.25)$ ⁵

1.4.3 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information

1.4.3.1 CALiPER Snapshot Report December 7, 2016:⁶

A few of the conclusions that CALiPER reported in its most recent snapshot report on LED Panels:

- About 10% of the listed products had a luminous efficacy greater than 125 lm/W, so DLC Premium products are less than a tenth of the market.
- The output of some of the listed LED products exceeds what is typical of a fluorescent troffer, supporting the continuation of an upper lumen output limit for this office/classroom/retail typical measure.

1.4.3.2 PG&E Emerging Technologies Studies:

PG&E commissioned two Emerging Technologies studies in recent years to identify and develop information on interior commercial applications.

Project ET12PGE1481 conducted a comprehensive LED retrofit in a retail store environment with multiple fixture and lamp types. It confirmed that completing a store-wide, comprehensive LED retrofit is not only

feasible, but cost-effective as well. Overall, the project achieved a 58% reduction in energy use for LED Accelerator (LEDA) Program eligible products, and 47% on a store-wide basis. The study participant was very satisfied with the energy savings, projected maintenance savings, and lighting quality provided by the LED products that were installed. Error! Bookmark not defined.

This project evaluated six different lighting applications in eight store study areas, evaluating energy consumption and lighting performance in each area. Interior applications included A-lamp shape, Directional, MR16, Decorative, Downlight, Troffer, and High-bay. The projects found cost-effective retrofit options store-wide, including a return-on-investment of 17.3% for measures eligible for the LEDA advanced incentive program.

Project ET11PGE3251 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 which can help achieve even deeper savings. An initial energy savings of 21% resulted from replacing fluorescent lighting with LED lighting in an office. A further energy savings of 41% resulted from adding the ALCS. Error! Bookmark not defined.

This study focused on a Class A commercial office space, and used a phased approach to study different levels of control (task-tuning, occupancy-sensing, daylight-sensing, individual dimming) in conjunction with LED fixtures. The LED luminaires were found to be highly configurable for these multiple control strategies, making them attractive to customers at the leading edge of technology adoption in both the workplace data and lighting product segments. Customers who have interest in maximizing both individualized distributed environmental control and sustainable energy saving practices will be particularly attracted to these options. The payback on the combined luminaire and controls retrofit was very high (generally > 50 years), but customers looking for workplace data benefits or already planning fixture replacement will see a lower incremental cost. The study recommended LED sources for this application based on several benefits: “lighting distribution, color rendering, and color temperature which are comparable to or better than fluorescent sources.”

Linear fluorescent lighting represents 72% of energy use in the commercial lighting sector and 80% of all commercial light fixtures, and therefore represents an enormous opportunity for potential LED savings. Due to the high efficacy of linear fluorescent lamps, there have only recently been suitable LED replacements for traditionally linear fluorescent applications, such as general purpose commercial lighting.

1.4.4 Assumptions and Calculations from other sources – Base and Measure Cases

The fixture performance in the applicable categories of the DLC list—LED Luminaires for Ambient Lighting of Interior Commercial Spaces, and Integrated Retrofit Kits for 2X4, 2X2, and 1X4 luminaires were analyzed to justify the light output equivalency assumptions. There were 47,538 fixtures in these categories downloaded from DLC on 6/26/2017. These were used to create the 12 measure code tiers with the appropriate luminaire efficacy.

Delta Wattage Assumption (ΔW)

The base case linear fluorescent fixtures were modeled across the DLC light output range according to the most common fixture type in a configuration meeting appropriate Federal lamp standards, Federal ballast standards, and California Title 24 (T24) 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 (LPW) is used to calculate savings.

The code-compliant base case fixture model used is from the 2011 Codes and Standards Enhancement (CASE) Report for Indoor Lighting Controls.⁷ This report developed the most thorough commercial interior lighting model available in California standards proceedings. The model used by CASE author 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. The panel fixtures modeled are 2x4 3-lamp T8 parabolic fixtures, matching a typical parabolic luminaire with 74.7% fixture efficacy.⁸

The model was updated to 2013-T24 LPD specifications, which reduce LPDs for Office Buildings via the Complete Building Method from 0.9 W/sf to 0.8 W/sf.⁹ The 0.8 W/s.f. value used is lower than other applicable building types in Table 140.6-B of 2013-T24: 1.0 W/s.f. for General Commercial/Industrial Work Buildings, 1.2 W/s.f. for Restaurant Buildings, and 1.0 W/s.f. for School Buildings. The model was changed to reflect Federal fluorescent lamp minimum standards with a 2950-lumen lamp, but the ballast was unchanged as it reflected a premium electronic ballast listed by the Consortium for Energy Efficiency's HPT8 standard and the National Electrical Manufacturers Association's NEMA Premium listing. The CASE Report model's assumption for Light Loss of 9.7% was used. The model suggests that illumination from recessed fluorescent fixtures compliant with current code can be obtained at maintained fixture efficacy of 58.8 LPW. 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).¹⁰

The DOE Solid-State Lighting CALiPER Reports have examined 12 LED panel fixtures combined in application summary reports 1, 5, 7, 9 and 13, but none of these tests are dated more recently than September of 2011, making them of limited relevance for a workpaper in 2015 given LED improvements. Given their age, CALiPER reports were not used for determining equivalency.

Initial LED lumen efficacy assumptions are set by the measure code minimum requirements, starting with 125 LPW for the lowest-efficacy measure code corresponding with DLC's Premium tier minimum efficacy. Calculating the wattage corresponding to this efficacy for a unit of one kilolumen can be accomplished by dividing 1000 lumens by 125 lumens per watt, resulting in 8.0 Watts per kilolumen 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 an 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. The full dataset is provided in the calculations file for this workpaper. Analysis of both the full set and subset, in accordance with the LED lumen output extrapolation formula published in Federal rulemaking,¹¹ suggests LED fixture lumen maintenance at EUL of 89.6% for the blended Commercial building type with 2420 DEER Measure hours per year for 16 years, based on the following calculation:

$$\begin{aligned}\text{Com EUL hours per DEER} &= \text{DEER Annual Measure HOU}_{\text{std}} \times \text{EUL fixture maximum} \\ &= 2420 \text{ hours/year} \times 16 \text{ year maximum EUL} \\ &= 38720 \text{ hours}\end{aligned}$$

This is less than 50,000, so 38720 hour EUL is used for Com building type

LED lumen maintenance varies by building type due to differing DEER run hours. Motel annual run hours of 1000 result in 16,000 run hours over 16 year EUL and thus 95.5% lumen maintenance. DEER annual run hours in half of the DEER building types, including the Large Retail, Restaurant and Grocery, over 16 years will exceed 50,000 hours, so the 50,000 DLC-minimum rated life fixture is used, along with an 89.6% lumen maintenance figure. 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:

Lumen Maintenance at Com EUL =

$$e^{ComEUL\ hours \times \ln Lumen\ Maintenance\ \% @\ 25,000\ hours \div 25,000\ hours}$$

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

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

Section 2. Calculation Methods

This workpaper does not group base and measure case fixtures by wattages. The base case and measure wattages are determined by the methods described in section 1.4.4.

Table 6 - LED Ambient Commercial Fixtures & Retrofit Kits Base and Measure Wattages

Measure Case Description	Base Case Wattage	Measure Case Wattage	Delta Wattage
LED Luminaires/Retrofit Kits rated ≥ 125 and < 140 LPW, Ambient Interior Commercial Spaces	14.8 – 16.3	8.0	6.8 – 8.3
LED Luminaires/Retrofit Kits rated ≥ 140 LPW, Ambient Interior Commercial Spaces	14.8 – 16.3	7.1	7.7 – 9.2
Base case wattage varies by building type			

2.1 Electric Energy Savings Estimation Methodologies

The lighting wattage difference (Watts per unit) is the difference between the electric demand of the base case unit and the electric demand of the measure case unit. The operating hours and interactive effects for Commercial were taken from DEER 2016 data. The operating hours and interactive effects for Residential were taken from DEER 2017.

Δ Watts/kilolumen: The demand difference (watts per kilolumen) is simply the difference between the electric demand of a kilolumen unit of the base case fixture and the electric demand of a kilolumen unit of the measure case fixture.

$$\Delta \text{Watts/kilolumen} = \text{Base Case Watts/kilolumen} - \text{Measure Case Watts/kilolumen}$$

Example:

$$\Delta \text{Watts/kilolumen} = 14.8 \text{ W} - 8.0 \text{ W} = 6.8$$

Annual Electric Savings:

$$\text{Annual Energy Savings [kWh/kilolumen]} = (\Delta \text{Watts/kilolumen}) \times (\text{Annual Hours of Operation}) \times (\text{Energy Interactive Effects}) / (1,000 \text{ Watts} / \text{kW})$$

2.2. Demand Reduction Estimation Methodologies

This measure includes HVAC interactive effects savings. The operating hours and interactive effects for Commercial were taken from DEER 2016 data. The operating hours and interactive effects for Residential were taken from DEER 2017.

Δ Watts/kilolumen: 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.

$$\Delta \text{Watts/kilolumen} = \text{Base Watts/kilolumen} - \text{Energy Efficient Watts/kilolumen}$$

Where:

Base Case Watts/Kilolumen represents code/industry standard base unit demand.

Demand Reduction:

$$\text{Demand Reduction [kW/kilolumen]} = (\Delta \text{Watts/kilolumen}) \times (\text{Lighting Coincident Demand}) \times (\text{Demand Interactive Effects}) / (1,000 \text{ Watts/kW})$$

2.3. Gas Energy Savings Estimation Methodologies

Gas estimates are entirely based on the estimated increased gas use through calculated interactive effects. This measure includes HVAC interactive effects impacts. The operating hours and interactive effects for Commercial were taken from DEER 2016 data. The operating hours and interactive effects for Residential were taken from DEER 2017.

ΔWatts/kilolumen: 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.

$$\Delta\text{Watts/kilolumen} = \text{Base Watts/kilolumen} - \text{Energy Efficient Watts/kilolumen}$$

Annual Gas Savings:

Annual Gas Savings [Δ Therms/kilolumen] = (Δ Watts/kilolumen) x (Annual Hours of Operation) x (Gas Interactive Effects (Therms/kwh)) / 1,000 Watts/kW

Section 3. Load Shapes

Load Shapes are an important part of the life-cycle cost analysis of any energy efficiency program portfolio. The net benefits associated with a measure are based on the amount of energy saved and the avoided cost per unit of energy saved. For electricity, the avoided cost varies hourly over an entire year. Thus, the net benefits calculation for a measure requires both the total annual energy savings (kWh) of the measure and the distribution of that savings over the year. The distribution of savings over the year is represented by the measure's load shape. The measure's load shape indicates what fraction of annual energy savings occurs in each time period of the year. An hourly load shape indicates what fraction of annual savings occurs for each hour of the year. A Time-of-Use (TOU) load shape indicates what fraction occurs within five or six broad time-of-use periods, typically defined by a specific utility rate tariff. Formally, a load shape is a set of fractions summing to unity, one fraction for each hour or for each TOU period. Multiplying the measure load shape with the hourly avoided cost stream determines the average avoided cost per kWh for use in the life cycle cost analysis that determines a measure's Total Resource Cost (TRC) benefit.

3.1 Base Case Load Shapes

The closest load shape chosen for this measure is the "DEER:Indoor_Non-CFL_Ltg" load shape.

3.2 Measure Load Shapes

The measure load shape for this measure is determined based on the applicable non-residential market sector and the lighting end-use.

The closest load shape chosen for this measure is the DEER:Indoor_Non-CFL_Ltg load shape. See the KEMA report [31] for a more thorough discussion regarding the load shapes for this measure.

Section 4. Base Case & Measure Costs

DEER 2016 does not have measure cost data for LED fixtures.

4.1 Base Case Costs

It is assumed the labor cost of replacing the measure case fixture would be the same as the base case fixture. The base case and measure case costs include just equipment costs. The base case costs are taken from distributor catalogs and websites and confirmed with manufacturer representatives where possible.

Table 7 - LED Ambient Commercial Fixtures & Retrofit Kits Base Case Cost Table

Measure Description	Base Case Equipment Cost(\$/kilolumen)
All LED Luminaires/Retrofit Kits Measures for Ambient Interior Commercial Spaces	\$15.55

4.2 Measure Costs

The measure equipment costs were developed from California distributor catalogs and websites and confirmed with manufacturer representatives where possible.

Table 8 - LED Ambient Commercial Fixtures & Retrofit Kits Measure Cost Table

Measure Code	Measure Description	Measure Equipment Cost(\$/kilolumen)
LT148	2x4 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$25.83
LT149	2x4 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$35.99
LT150	2x2 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$21.89
LT151	2x2 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$48.29
LT152	1x4 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$34.18
LT153	1x4 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$56.08
LT154	2x4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$23.00
LT155	2x4 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$32.38
LT156	2x2 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$23.41
LT157	2x2 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$48.29
LT158	1x4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$27.58
LT159	1x4 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$32.04

4.3 Incremental & Full Measure Costs

Measure Application Type	Gross Measure Cost (RUL Period/First Baseline)	Gross Measure Cost (EUL-RUL Period/ Second Baseline)	Incremental Measure Cost
ER	Measure Equipment Cost + Measure Labor Cost	(-1)x(Base Equipment Cost + Base Labor Cost)	Measure Equipment Cost – Base Case Equipment Cost
ROB	Measure Equipment Cost – Base Case Equipment Cost	N/A	Measure Equipment Cost – Base Case Equipment Cost
NC	Measure Equipment Cost – Base Case Equipment Cost	N/A	Measure Equipment Cost – Base Case Equipment Cost

4.3.1 Full Measure Cost

The Full Measure Cost is applicable to Direct Install programs. There is an effort on updating systems to collect actual costs from implementers, till then the following costs will be used for direct install.

FMC = Measure Equipment Cost + Measure Labor Cost

Table 9 - LED Ambient Commercial Fixtures & Retrofit Kits Full Measure Cost

Measure Code	Measure Description	Measure Equipment Cost	Measure Labor Cost ¹²	Full Measure Cost
LT148	2x4 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$25.83	\$23.27	\$49.10
LT149	2x4 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$35.99	\$23.27	\$59.26
LT150	2x2 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$21.89	\$23.27	\$45.16
LT151	2x2 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$48.29	\$23.27	\$71.56
LT152	1x4 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$34.18	\$23.27	\$57.45
LT153	1x4 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$56.08	\$23.27	\$79.35
LT154	2x4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$23.00	\$23.27	\$46.27
LT155	2x4 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$32.38	\$23.27	\$55.65
LT156	2x2 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$23.41	\$23.27	\$46.68
LT157	2x2 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$48.29	\$23.27	\$71.56
LT158	1x4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$27.58	\$23.27	\$50.85
LT159	1x4 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$32.04	\$23.27	\$55.31

4.3.2 Incremental Measure Costs

The labor costs for measure and base cases are equivalent.

Incremental cost (INCR) = Measure Cost – Base Case Cost

Table 10 - LED Ambient Commercial Fixtures & Retrofit Kits Incremental Cost

Measure Code	Measure Description	Incremental Measure Cost
LT148	2x4 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$10.28
LT149	2x4 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$20.43
LT150	2x2 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$6.34
LT151	2x2 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$32.73
LT152	1x4 LED new Luminaire rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$18.63
LT153	1x4 LED new Luminaire rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$40.53
LT154	2x4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$7.45
LT155	2x4 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$16.83
LT156	2x2 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$7.85
LT157	2x2 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$32.73
LT158	1x4 LED Integrated retrofit kit rated greater than or equal to 125 LPW and less than 140 LPW, Ambient Interior Commercial Spaces	\$12.02
LT159	1x4 LED Integrated retrofit kit rated greater than or equal to 140 LPW, Ambient Interior Commercial Spaces	\$16.48

References:

¹ US Department of Energy, “2010 U.S. Lighting Market Characterization,” prepared by Navigant Consulting. January 2012. Accessed at <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf>. 72% energy use is shown in Table 4.8; 80% lamp penetration shown in Table 4.2.

² The DEER Measure Cost Data Users Guide found on www.deeresources.com under *DEER2011 Database Format* hyperlink, DEER2011 for 13-14, spreadsheet *SPTdata_format-V0.97.xls*.

³ DEER2016, see calculations workbook

⁴ Code of Federal Regulations 10 CFR 430.32(n) ; accessed at http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/70

⁵ Fed Register 2011-28451.pdf ; accessed at <http://www.gpo.gov/fdsys/pkg/FR-2011-11-14/pdf/2011-28451.pdf>

⁶ CALiPER Snap Report. DOE. December 7, 2016.

https://energy.gov/sites/prod/files/2016/12/f34/snapshot2016_troffers.pdf

⁷ CASE_Nonres_Indoor_Lighting_Controls.pdf; accessed at http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/2011-04-04_workshop/review/Nonres_Indoor_Lighting_Controls.pdf

⁸ Cooper_2P2GAX332_3L_T8_18C_spec-sheet.pdf; accessed at http://www.cooperindustries.com/content/dam/public/lighting/products/documents/metalux/spec_sheets/090386_2P2GAX332_3L_T8_18C.pdf

⁹ CEC-Title24-2013.pdf, p. 205 (header indicating p. 190); accessed at <http://www.energy.ca.gov/2012publications/CEC-400-2012-004/CEC-400-2012-004-CMF-REV2.pdf>

Table 140.6-B reads as follows:

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TABLE 140.6-B COMPLETE BUILDING METHOD LIGHTING POWER DENSITY VALUES

TYPE OF BUILDING	ALLOWED LIGHTING POWER DENSITY (WATTS PER SQUARE FOOT)
Auditorium Building	1.5
Classroom Building	1.1
Commercial and Industrial Storage Building	0.6
Convention Center Building	1.2
Financial Institution Building	1.1
General Commercial Building/Industrial Work Building	1.0
Grocery Store Building	1.5
Library Building	1.3
Medical Building/Clinic Building	1.1
Office Building	0.8
Parking Garage Building	0.2
Religious Facility Building	1.6
Restaurant Building	1.2
School Building	1.0
Theater Building	1.3
All others buildings	0.6

¹⁰ CALiPER Summary Report Round 13, chart p. 21. DOE. October 2011.

¹¹ Fed Register 2014-12127.pdf p. 17; accessed at <http://www.gpo.gov/fdsys/pkg/FR-2014-06-03/pdf/2014-12127.pdf>

¹² Measure Labor Cost is product of Installation time and Labor Rate. Labor rate of \$70.11 per hour taken from RS Means for PG&E Territory cities. Installation time of 1.509 hours per fixture (0.39 hours per kilolumen) taken from RS Means, Interior LED Fixtures Line # 265113551000; accessed at <http://www.rsmeans.com/>