Work Paper SCE17LG098

**Revision 0**

**Southern California Edison**

**Fluorescent to LED Retrofits in Reach-in Display Cases**

# At-a-Glance Summary

|  |  |
| --- | --- |
| **Measure Codes** | LT-17642, LT-20643, LT-30954, LT-49651, LT-58674, LT-65612, LT-69439, LT-75912, LT-78303, LT-79548, LT-80693, LT-84544, LT-89513, LT-93848, LT-97154 |
| **Measure Description** | 1. Vertical light emitting diode (LED) lighting system in refrigerated display cases 2. Horizontal LED lighting system in refrigerated display cases for shelf and canopy |
| **Base Case Description** | 1. 4-ft/5-ft T8 fluorescent fixture with electronic ballast and a 4-ft/5-ft/6-ft T12 HO fluorescent fixture with magnetic ballast in refrigerated display cases 2. 3-ft/4-ft T8 fluorescent fixture with electronic ballast and a 3-ft/4-ft T12/T12HO fluorescent fixture with magnetic ballast in refrigerated display cases for shelf and canopy |
| **Units** | Per Door, Per Fixture |
| **Energy Savings** | Refer to Excel Calculation Attachment |
| **Full Measure Cost ($/unit)** | Refer to Excel Calculation Attachment |
| **Incremental Measure Cost ($/unit)** | Refer to Excel Calculation Attachment |
| **Effective Useful Life** | 4 years (DEER EUL ID: GrocDisp-FixtLtg-LED) per Resolution E-4807 |
| **Measure Installation Type** | Retrofit or Early Retirement (RET/ER) |
| **Net-to-Gross Ratio** | 0.6 (DEER NTGR ID: Com-Default>2yrs)  0.85 (DEER NTGR ID: Com-Default-HTR-di) |
| **Important Comments** | This work paper has a complementary Ex Ante Database data set that will be provided in a separate submission to the California Public Utilities Commission (CPUC). |

# Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Rev** | **Date** | **Author** | **Summary of Changes** |
| 0 | 11/18/2016 | David Douglass-Jaimes, TRC | * This work paper is an update of SCE13LG089.4 * New calculation template for 2017 program year * Updated code reference to Title 24 2016 * Updated DesignLights Consortium Qualified Products List requirements * Removed ROB and changed EUL per Resolution E-4807 * All (16) California Climate Zones added to calculation template |

# Commission Staff and Cal TF Comments

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Rev** | **Party** | **Submittal Date** | **Comment Date** | **Comments** | **WP Developer Response** |
|  |  |  |  |  |  |

Cal TF website: <http://www.caltf.org/>

# Section 1. General Measure & Baseline Data

## 1.1 Measure Description & Background

**Base, Standard, and Measure Cases**

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measure | 1. Vertical light emitting diode (LED) lighting system in refrigerated display cases 2. Horizontal LED lighting system in refrigerated display cases for shelf and canopy |
| Existing Condition | N/A |
| Code/Standard | 1. 4-ft/5-ft T8 fluorescent fixture with electronic ballast and a 4-ft/5-ft/6-ft T12 HO fluorescent fixture with magnetic ballast in refrigerated display cases 2. 3-ft/4-ft T8 fluorescent fixture with electronic ballast and a 3-ft/4-ft T12/T12HO fluorescent fixture with magnetic ballast in refrigerated display cases for shelf and canopy |
| Industry Standard Practice | N/A |

Measures and Codes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Codes** | | | | **Measure Name** |
| SCG | SDG&E | SCE | PG&E |
| N/A | N/A | LT-17642 | N/A | (1) 48in Medium Temp Reach-in Display Cases Canopy LED replacing (2) 48in T8 Linear Fluorescent |
| N/A | N/A | LT-20643 | N/A | (1) 48in Medium Temp Reach-in Display Cases Shelf LED replacing (1) 48in T12 Linear Fluorescent |
| N/A | N/A | LT-30954 | N/A | (1) 48in Medium Temp Reach-in Display Cases Shelf LED replacing (1) 48in T8 Linear Fluorescent |
| N/A | N/A | LT-49651 | N/A | (1) 36in Medium Temp Reach-in Display Cases Canopy LED replacing (2) 36in T12 Linear Fluorescent |
| N/A | N/A | LT-58674 | N/A | (1) 36in Medium Temp Reach-in Display Cases Canopy LED replacing (2) 36in T8 Linear Fluorescent |
| N/A | N/A | LT-65612 | N/A | (1) 36in Medium Temp Reach-in Display Cases Shelf LED replacing (1) 36in T12 Linear Fluorescent |
| N/A | N/A | LT-69439 | N/A | (1) 60in Retrofits in Low Temp Reach-in Display Cases LED replacing (1) 60in T12 Linear Fluorescent |
| N/A | N/A | LT-75912 | N/A | (1) 36in Medium Temp Reach-in Display Cases Shelf LED replacing (1) 36in T8 Linear Fluorescent |
| N/A | N/A | LT-78303 | N/A | (1) 60in Retrofits in Low Temp Reach-in Display Cases LED replacing (1) 60in T8 Linear Fluorescent |
| N/A | N/A | LT-79548 | N/A | (1) 72in Retrofits in Medium Temp Reach-in Display Cases LED replacing (1) 72in T12 Linear Fluorescent |
| N/A | N/A | LT-80693 | N/A | (1) 60in Retrofits in Medium Temp Reach-in Display Cases LED replacing (1) 60in T8 Linear Fluorescent |
| N/A | N/A | LT-84544 | N/A | (1) 60in Retrofits in Medium Temp Reach-in Display Cases LED replacing (1) 60in T12 Linear Fluorescent |
| N/A | N/A | LT-89513 | N/A | (1) 48in Medium Temp Reach-in Display Cases Canopy LED replacing (2) 48in T12 Linear Fluorescent |
| N/A | N/A | LT-93848 | N/A | (1) 72in Retrofits in Low Temp Reach-in Display Cases LED replacing (1) 72in T12 Linear Fluorescent |
| N/A | N/A | LT-97154 | N/A | (1) 48in Medium Temp Reach-in Display Cases Canopy LED replacing (1) 48in T12 Linear Fluorescent |

**Eligibility requirements**

To qualify for a rebate, the product must be listed on Design Lights Consortium’s Qualified Products List. Current requirements (version 4.1) for listing on the Qualified Products List are as follows:

* Minimum Luminaire Efficacy (Lm/w) - 80 Lm/W
* Minimum Lifetime - must be ≥ 50,000 hours
* Manufacturer Warranty - 5 years
* Power Factor - ≥ 0.9
* Total Harmonic Distortion - ≤ 20%
* Minimum Light Output – 50 lm/ft
* Zonal Lumen Density - ≥95%: 10°-90°
* Allowable CCT - ≤ 5,000K
* Minimum CRI - 80 CRI
* Off-State Power - 0W
* Zonal Lumen Density
  + Vertical Refrigerated Case Luminaires - ≥95%: 10°-90°
  + Horizontal Refrigerated Case Luminaires - ≥95%: 0°-90°

**Implementation and installation requirements**

Documentation of the above criteria is required for qualification of the proposed/installed lighting system. Documentation is also required to verify the base case lighting system.

## 1.2 Technical Description

**T8 Fluorescent (Baseline Technology)**

The baseline for vertical LED is a 5-foot T8 fluorescent lighting fixture for medium temperature (MT) display cases and a 5-foot T8 High Output (HO) fluorescent lighting fixture for low temperature (LT) display cases. The reason different fixtures are used is because colder temperatures make the fixtures operate less efficiently and output less light, so high output fixtures are used in the low temperature applications.

The fixture code used as the medium temperature base case for this work paper is F51LL from Appendix B: Table of Standard Fixture Wattages of the 2012 Statewide Customized Offering Procedures Manual for Business, included below as Attachment 2. This fixture consumes 36 Watts. The system used as the low temperature base case for this work paper is an F40T8/HO. This fixture consumes 56.3 Watts, based on field test data [223].

The baseline for horizontal LED is a 3-foot and 4-foot T8 fluorescent lighting fixture for MT display cases. The fixture code used as the MT base case for this work paper is F32ILL and F42ILL from Appendix B (Attachment 2). The 3-foot fixture consumes 46 Watts for 2 lamps. The 4-foot fixture consumes 59 Watts for 2 lamps.

**T12 Fluorescent (Baseline Technology)**

The baseline for vertical LED is a 5-foot and 6-foot T12 HO fluorescent lighting fixture for both MT and LT display cases. The 5-foot T12 HO uses fixture code F52SHE, consuming 176 Watts for a 2-lamp system, 88 Watts/lamp. The 6-foot T12 HO uses fixture code F62SHE, consuming 194 Watts for a 2-lamp system, 97 Watts/lamp.

The baseline for horizontal LED is a 3-foot and 4-foot T12 fluorescent lighting fixture for MT display cases. The fixture code used as the MT base case for this work paper is F32SE, F42EIS, and F42SHS. The 3-foot fixture consumes 74 Watts for 2 lamps. The 4-foot fixture consumes 82 Watts for 2-lamps (F42EIS) and 72.5 Watts for 1 HO lamp (F42SHS). LED is replacing either (1) HO T12 lamp or (2) T12 lamps. The 4-foot T12 fluorescent will use 4-foot T8 as the code baseline.

**LED (Proposed Technology)**

The measure case involves LED lights installed in refrigerated display cases. The LED lighting system also provides the additional benefit of reduced heat dissipation into the cold space, thereby reducing the cooling load. As a result, the new lighting systems reduce compressor run time and energy consumption. This work paper applies to lighting for reach-in glass door display cases of low temperature (“freezer” – below 32°F) and medium temperature (“cooler – above 32°F) cabinets for single-compressor systems in food stores, small office, fast food restaurants, and small retail and multiplex compressors in grocery stores, sit down restaurants, multistory large retail, single story large retail, and refrigerated warehouses.

## 1.3 Installation Types and Delivery Mechanisms

The delivery method is:

**Financial Support – Direct Install**

**Financial Support – Downs-Stream Incentive – Deemed**

**Midstream Programs / Mid-Stream incentive**

The install type is:

**Retrofit (RET) for Financial Support – Direct Install**

The Non Residential Direct Install program quality control ensures correct documentation of existing measure, base case, and specification of the energy efficient product installed.  SCE requires a detailed Product Location Form (PLF) for each project submitted for rebate or incentive.  The PLF is a form which information for measures installed in all building types related to the Non Residential Direct Install program.  The PLF contains the following fields: Service Account Address, Measures Proposed/Installed, Product Make/Model, Install Locations (detailed to define separate spaces/floors, as well as specific locations within the space including but not limited to:  Bathrooms, Hallways, Meeting Rooms, Offices, Warehouse, etc.).

Customers are solicited to participate primarily through field visits.  Contractors conduct energy consultation and provide recommendation that can help eligible customers use less energy.  If the customer agrees, the Direct Install contractor will help them complete an authorization form and schedule an installation appointment.

SCE can also provide photos to show measure functionality and a sample close up photos to substantiate the measure base case where applicable.  These photos would be part of the required project package.  The project package is identified with the Service Account Number and attached to SCE’s SMART database (SCE Project Tracking System) at each specific project level. The above described information is entered and tracked in the program’s tracking database.  This level of data is provided in the Participation Data that is provided to the CPUC on a quarterly basis.

**Installation Type Descriptions**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Installation Type** | **Savings** | | **Life** | |
| 1st Baseline (BL) | 2nd BL | 1st BL | 2nd BL |
| Replace on Burnout (ROB) | 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 |

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** |
| Financial Support | The program motivates customers, through financial incentives such as rebates or low interest loans, to implement energy efficient measures or projects. |
| Mid-Stream Programs | *See Mid-Stream Incentive in the Incentive Method Descriptions table.* |

**Incentive Method Descriptions**

|  |  |
| --- | --- |
| **Incentive Method** | **Description** |
| Direct Install | The program implements energy efficiency measures for qualifying customers, at 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  Mid-Stream Buy Down | The program gives a financial incentive to a midstream market actor (distributor, vendor, or retailer) to encourage the promotion of efficient measures. Buy Down means that the incentive is required to be passed down to the end-use customer. |

## 1.4 Measure Parameters

### 1.4.1 DEER Data

DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Item** | **Used for Workpaper?** |
| Modified DEER methodology | No |
| 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 | N/A |
| Reason for Deviation from DEER | DEER does not contain this type of measure |
| DEER Measure IDs Used | N/A |

**Net-to-Gross Ratio**

The NTG values were obtained using the DEER READI tool. The relevant NTG values for the measures in this work paper are in the table below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **NTGR ID** | **Description** | **Sector** | **BldgType** | **Measure Delivery** | **NTGR** |
| Com-Default>2yrs | All other EEMs with no evaluated NTGR; existing EEM in programs with same delivery mechanism for more than 2 years | Com | Any | Any | 0.6 |
| Com-Default-HTR-di | All other EEM with no evaluated NTGR; direct install to hard-to-reach only. | Com | Any | DirInstall | 0.85 |

Note: Direct install measures that are not hard-to-reach will use the default NTG value.

This work paper includes measures that are offered via direct install activities into hard-to-reach (HTR) customer facilities. “Final Resolution E-4700”, dated December 18, 2014, defines specific criteria to classify customer facilities as HTR and also states that two criteria are sufficient to identify HTR customers if one of the criteria met is the geographic criteria.

SCE’s Commercial Direct Install program delivers free and low cost energy efficiency hardware retrofits through installation contractors to reduce peak demand and energy savings for small and medium commercial customers. The barriers for customer participation include limited capital resources, lack of expertise and understanding of the benefits of energy efficiency, a suspicion of the “free offer” and its legitimacy, and language and cultural barriers. The program also addresses the ongoing concern with “split incentives”, where the customer is not the owner of the property, and therefore, lack incentive to improve their energy usage. SCE’s Commercial Direct Install program will track the following three (3) customer data points to identify direct install activities in HTR customer facilities. If geography and business size criteria are satisfied, SCE will identify the customer as HTR. If geography and language criteria are satisfied, SCE will identify the customer as HTR. Other measures in the Commercial Direct Install program will receive default NTG (NTGR\_ID: Com-Default>2), unless otherwise specified in DEER.

* **Business Size** – Customer must have less than ten employees
* **Language** – Customer’s primary language spoken is not English
* **Geography** – Businesses in areas other than the United States Office of Management and Budget (OMB) Combined Statistical Areas (CSA) of the San Francisco Bay Area, the Greater Los Angeles Area and the Greater Sacramento Area or the OBM metropolitan statistical areas or San Diego County

The “Required Corrections to Measure Level Input Parameters Identified by Commission Staff per D.14-10-046 Order Paragraph 16”, dated November 3, 2014, includes additional clarification for the geographic criteria:

“Notes on OMB CSA designations:

The OMB has designated a 12-county CSA titled the San Jose-San Francisco-Oakland, CA Combined Statistical Area which includes the nine counties of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma which border the San Francisco Bay plus the three counties of San Joaquin, Santa Cruz, and San Benito that are economically tied to the nine counties that that border the San Francisco Bay.”

The OMB definition of this CSA includes Los Angeles, Orange, San Bernardino, Riverside and Ventura counties.

The OMB definition of this CSA includes Sacramento, Yolo, El Dorado, Placer, Sutter, Yuba, and Nevada counties.”

**Spillage Rate**

Spillage rates are not tracked in work papers; they are tracked in an external document which will be supplied to the Commission Staff.

**Installation Rate**

The IR values were obtained using the DEER READI tool. The relevant IR values for the measures in this work paper are in the table below.

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

**Effective and Remaining Useful Life**

Per Resolution E-4807 [510], the EUL for LED Display Case lighting is the lesser of the EUL of the LEDs (16 years) or the RUL of the display case (12/3=4 years). Thus, EUL of 4 years is used for the measure as shown in the table below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| GrocDisp-FixtLtg-LED | Display Case Lighting LED Lighting | Com | Lighting | 4 | 0 |

### 1.4.2 Codes and Standards Analysis

Title 24 2016 [496] and Title 20 2015 [493] do not apply.

Title 24 2016 [496] contains code related to refrigerated display cases that affect new (NEW) display case installations.

**Refrigerated Display Cases.** Lighting in refrigerated display cases, and lights on glass doors installed on walk-in coolers and freezers shall be controlled by one of the following:

A. Automatic time switch controls to turn off lights during non-business hours. Timed overrides for any line-up or walk-in case may only be used to turn the lights on for up to one hour. Manual overrides shall time-out automatically to turn the lights off after one hour.

B. Motion sensor controls on each case that reduce display case lighting power by at least 50 percent within 30 minutes after the area near the case is vacated.

Code Summary

|  |  |  |
| --- | --- | --- |
| **Code** | **Reference** | **Effective Dates** |
| Title 24 (2016) | 2016 Building Energy Efficiency Standards  Section 120.6(b)3 | January 1, 2017 |

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

Several Non-DEER studies were reviewed:

* Demonstration Assessment of Lighting-Emitting Diode (LED) Freezer Case Lighting [227]: This is a DOE-sponsored study of a LED lighting and occupancy sensor retrofit of refrigerated display cases in an Albertsons store.
* LED Freezer Case Lighting Systems [456]: The Sacramento Municipal Utility District led an effort to develop an LED freezer case lighting system with motion sensors and dimming controls.
* LED Lighting for Low Temperature Refrigerated Display Cases [457]: Southern California Edison evaluated the savings potential of LEDs and aisle traffic sensors on low-temperature reach-in refrigerated display cases.

# Section 2. Calculation Methodology

Assuming that the lighting power requirements of each technology are known, determining the direct power and energy savings is relatively straightforward. Secondary effects on the refrigeration system are a more difficult to quantify as they depend on many other factors. The two most important factors are: percentage of heat generated by the lighting system ending up as load on the case and efficiency of the refrigeration system.

The power required by each lighting system for the baseline 3/4/5/6-foot T8 and T12 system is based on standard wattages (see Attachment 2). For the 5-foot and 6-foot vertical LED system, the power is based on the average wattage of current LED display case fixtures (see Attachment 3). The 5-foot and 6-foot vertical LED system used as the basis for this work paper is an average between refrigerated display LED vertical lighting systems of three major lighting companies with a color temperature of about 4000K. The average center fixture consumes 20 watts and the average side fixture consumes 12 watts found in Attachment 6. The 3-foot and 4-foot horizontal LED fixture Wattage is an average of various manufacturers’ fixtures (see Attachment 5). The wattages can be found in Attachments 7 and 8.

The lighting power values for each system are shown in the following table.

Lighting Power Values

|  |  |  |
| --- | --- | --- |
| **Lighting System** | **Power** | **Comments** |
| 3’ T8 Fluorescent | 23 W | Per Lamp |
| 3’ T12 Fluorescent | 37 W | Per lamp |
| 4’ T12 Fluorescent | 41 W | Per Lamp |
| 4’ T12 HO Fluorescent | 72.5 W | Per lamp |
| 3’ Canopy LED | 15.5 W | Per lamp |
| 3’ Shelf LED | 6.8 W | Per lamp |
| 4’ Canopy LED | 18.7 W | Per lamp |
| 4’ Shelf LED | 9.6 W | Per lamp |
| 5’ T8 Fluorescent | 36 W | Per lamp |
| 5’ T8/HO Fluorescent | 56.3 W | Per lamp |
| 5’ T12 HO Fluorescent | 88 W | Per lamp |
| 6’ T12 HO Fluorescent | 97 W | Per lamp |
| 5’ LED Side | 14 W | Per Lamp |
| 5’ LED Center | 20 W | Per Lamp |
| 6’ LED Side | 17.2 W | Per Lamp |
| 6’ LED Center | 29.9 W | Per Lamp |
| 3’ T8 Fluorescent | 23 W | Per Lamp |
| 3’ T12 Fluorescent | 37 W | Per lamp |
| 4’ T12 Fluorescent | 41 W | Per Lamp |
| 4’ T12 HO Fluorescent | 72.5 W | Per lamp |
| 3’ Canopy LED | 15.5 W | Per lamp |

The calculations shown below are an example of T8/HO to vertical LED systems. The calculations for the T8 and T12 baseline were determined using the same methodology.

The calculations are based on two different types of refrigeration systems. The single-compressor system is used for the following building types:

* Restaurant – Fast-Food
* Retail – Small
* Office - Small

While the multiplex compressor system is used for the following building types:

* Grocery
* Restaurant – Sit-Down
* Retail – Multistory Large
* Retail – Single-Story Large
* Warehouse – Refrigerated

**Lighting Power and Energy Calculations**

1. The different configurations of each lighting system make direct comparison of these numbers fairly complicated. A 5-door display case will typically be equipped with 6 fluorescent bulbs. When equipped with LEDs, it will have 4 center strips and 2 end strips. To provide a comparison that would take these differences into account, the lighting power values for fluorescent lamps were converted into per door values according to the following equations:

For 5’ T8/HO Fluorescent system;



where

kWT8/HO = direct power draw of T8/HO system, kW/door

For 5’ LED system;



Per door.

1. Lighting power savings for the retrofit technologies is the difference between their direct power draw and that of the T8/HO.



where

ΔkWlighting = lighting power savings, kW/door

1. Lighting energy savings is the product of power savings and run time. Many supermarkets and other stores turn their case lighting systems off at night when the stores are closed or when shopper traffic is light. This will impact both the lighting and refrigeration energy use. It is assumed that lights are turned on for 12.9 hours each day (or 4,710 hours per year) [386].This value comes from DEER.



where

ΔkWhlighting = annual lighting energy savings, kWh/door/year

**Cooling Load Calculation**

1. Heat generated by the lighting system results in additional cooling load on the refrigeration system. Because of the different equipment present in the lighting systems, each has its own equation for determining the cooling load.
   1. For T8/HO fluorescent, some heat is dissipated by the ballast, which is located outside the refrigerated space. The ballast efficiency factor (BEF) accounts for the ratio of output to input power of the ballast. A typical value for BEF is 0.89. Fluorescent lamps become less efficient at lower temperatures. However, this factor varies for different types of lamps and between manufacturers. There is uncertainty regarding the operating temperature inside the lens/jacket surrounding the lamp, but it is believed to be close to the 70°F temperature used to test lamps. Therefore, ktemp is assumed to be 1. It is assumed that 70% of the power fed into the lamp is converted to heat [485].

where

QT8/HO = cooling load due to lighting system, Btu/hr/door

BEF = ballast efficiency factor, 0.89 (typical)

ktemp = temperature correction factor, 1.0 (assumed)

klamp heat = lamp heat factor, 0.79 (typical)

* 1. For LED, some heat is dissipated by the power supply, which is located outside the refrigerated space. It is assumed that 80% of the total lighting power is converted to heat inside the case [28].



where

QLED = cooling load due to lighting system, Btu/hr/door

klamp heat = lamp heat factor, 0.80 (typical)

1. The change in lighting cooling load from T8 to each retrofit technology is quantified as the difference in measured cooling load between the two scenarios.

∆Q = QT8/HO – QLED

where

ΔQ = change in lighting cooling load, Btu/hr/door

1. Table below contains a summary of all power, energy and cooling load values calculated thus far in the analysis. Summary for other measures can be found in Attachments 6, 7, and 8.

Summary of direct power, energy and cooling load calculations for 5-foot T8 base case

|  |  |  |
| --- | --- | --- |
| **Key Parameters** | **5-foot T8 Fluorescent** | **5-foot T8/HO Fluorescent** |
| Direct power (kW/lamp) | 0.036 | 0.0563 |
| Direct power (kW/door) | 0.0432 | 0.0676 |
| Direct annual energy (kWh/door/year)\* | 210 | 328 |
| Cooling load due to lighting system (Btu/hr/door) | 48 | 74 |

**Compressor Efficiency**

Once the lighting cooling load was determined, the following steps were followed to determine the compressor power requirements and energy savings. Because this work paper addresses lighting for several different types of equipment with various refrigeration system configurations, compressor analysis is *limited to the differential cooling load imposed by the lighting system, not the total cooling load* *of a particular display case or walk-in box*. Compressor analyses for two different types of refrigeration systems are included. The first analysis focuses on smaller single-compressor systems typically seen in small convenience and grocery stores. The second analysis deals with larger supermarket systems comprised of several multiplex compressors serving multiple refrigeration cases in the store. The differential compressor power requirements are based on calculated cooling load and energy-efficiency ratios (EER) obtained from manufacturers’ data, for the compressor sizes expected in each type of system.

1. Determine the saturated condensing temperature (SCT)

For medium temperature (MT): 

For low temperature (LT): 

where

DBadj = dry-bulb temperature (°F) of ambient or adjacent space where the compressor/condensing units reside. Defaults are based on climate zone design values in the table below.

Climate Zone Design Dry Bulb Temperature and Representative City

|  |  |  |  |
| --- | --- | --- | --- |
| **Climate Zone** | **Description** | **Representative City** | **Summer Design Dry-Bulb (ASHRAE Climatic Region X Data, 0.5% Column via proxy Title 24) [°F]** |
| 6 | South Coast | Torrance | 86 |
| 8 | South Coast | Fullerton | 94 |
| 9 | South Inland | Burbank-Glendale | 96 |
| 10 | South Inland | Riverside | 100 |
| 13 | Central Valley | Fresno | 101 |
| 14 | Desert | Palmdale | 103 |
| 15 | Desert | Palm Springs-Intl | 113 |
| 16 | Mountain | Blue Canyon | 85 |

Source: ASHRAE 1982. Climatic Data for Region X. [221]

**For small single compressor systems:**

1. Determine the EER for both MT and LT applications
   1. Compressor performance curves were obtained from a review of manufacturer data for small reciprocating compressors as a function of SCT, cooling load, and cooling capacity of compressor.
   2. Part-load ratio (PLR):

It is the ratio of total cooling load to compressor capacity. It indicates the percentage of compressor capacity needed to remove the total cooling load. It is calculated by following equation:



where,

PLR = Part Load Ratio

Qcoolinge = cooling load

Qcapacity = total compressor capacity

NOTE: Compressor capacity is determined by multiplying cooling load by compressor over-sizing factor of 15%:

Qcapacity = Qcooling \* 1.15

Therefore, PLR = 1/1.15 = 0.87

* 1. For medium temperature compressors, the following equation is used to determine the EERMT (Btu/hr/watts) [E]

EERMT = a + (b \* SCT) + (c \* PLR) + (d \* SCT2) + (e \* PLR2) + (f \* SCT \* PLR) + (g \* SCT3) + (h \* PLR3) + (i \* SCT \* PLR2) +   
(j \* SCT2 \* PLR)

where,

a = 3.75346018700468

b = -0.049642253137389

c = 29.4589834935596

d = 0.000342066982768282

e = -11.7705583766926

f = -0.212941092717051

g = -1.46606221890819E-06

h = 6.80170133906075

i = -0.020187240339536

j = 0.000657941213335828

PLR = 0.87

* 1. For low temperature compressors, the following equation is used to determine the EERLT (Btu/hr/watts) [404]

EERLT = a + (b \* SCT) + (c \* PLR) + (d \* SCT2) + (e \* PLR2) + (f \* SCT \* PLR) + (g \* SCT3) + (h \* PLR3) + (i \* SCT \* PLR2) +   
(j \* SCT2 \* PLR)

where,

a = 9.86650982829017

b = -0.230356886617629

c = 22.905553824974

d = 0.00218892905109218

e = -2.48866737934442

f = -0.248051519588758

g = -7.57495453950879E-06

h = 2.03606248623924

i = -0.0214774331896676

j = 0.000938305518020252

PLR = 0.87

* 1. Typically, reduction in cooling load results in a decreased EER for a retrofit measure due to a change in the PLR. However, this analysis deals with the change in cooling load for many different sizes of equipment in multiple applications with varying baseline cooling loads. Therefore, it would be difficult to assume a new PLR that would be applicable to all types of equipment addressed here. To simplify the analysis, EER is assumed to remain constant for both the baseline and retrofit situations.

**Power & Energy Use**

1. Power savings
   1. Differential power used by the compressor to remove the cooling load imposed by the lighting system is determined based on calculated cooling load and EER, as outlined below.



where

ΔkWcomp = change in compressor power, kW/door

ΔQdoor = change in cooling load per door for MT or LT, Btu/hr/door

EER = EER for LT or MT, Btu/hr/watts

* 1. Total power savings (ΔkW) is the sum of lighting and compressor savings.



1. Equivalent full load hours (EFLH) of operation

EFLH is determined by multiplying annual available operation hours (8,760) by overall duty cycle factor. Duty cycle is a function of compressor capacity, defrost and weather, as shown below.

The following equation shows the relationship between capacity, defrost and weather factor. Capacity factor is a function of compressor capacity and cooling load, determined by subtracting the PLR from 1. Using a compressor capacity factor of 15% results in a PLR of 87%. The defrost factor depends on the number and duration of defrost cycles and is determined by dividing the defrost duration (in hours) by 24 hours. Weather factor is a function of CTZ. Using DOE-2 simulation results for a typical supermarket, weather factors were determined for each CTZ [E]

Duty cycle = Capacity factor x Defrost factor x Weather factor

where,

Capacity factor = function of PLR, (1-PLR)

Defrost factor = 10% (2.4 hrs / 24 hrs) for LT, (1 – 0.10)

= 5% (1.2 hrs / 24 hrs) for MT, (1 – 0.05)

Weather factor = function of CTZ (see discussion below)

To estimate weather factor for each CTZ, the annual energy usage of a refrigeration system for a typical supermarket in each CTZ, based on a DOE-2 computer simulation, was used**.** [E] Using CTZ 15 as a benchmark with 85% weather factor, weather factors for the other 15 CTZs were estimated. The following equation shows this methodology. The following table illustrates the annual energy usage of refrigeration for each CTZ and corresponding weather factors.



where,

WFCTZ = weather factor for each CTZ

Annual kWh CTZ = annual energy usage of refrigeration system for each CTZ, kWh/yr

Annual kWh CTZ15 = annual energy usage of refrigeration system for CTZ 15, kWh/yr

WFCTZ-15 = weather factor for CTZ 15, 85%

**Weather Factor Values for SCE Climate Zones**

|  |  |  |
| --- | --- | --- |
| **CTZ** | **Refrigeration Annual Energy Usage (kWh/yr)\*** | **Weather Factor (%)** |
| 6 | 502,982 | 78.9% |
| 8 | 506,024 | 79.4% |
| 9 | 500,936 | 78.6% |
| 10 | 495,565 | 77.7% |
| 13 | 496,488 | 77.9% |
| 14 | 491,056 | 77.0% |
| 15 | 541,873 | 85.0% |
| 16 | 452,877 | 71.0% |

\*From DOE-2 simulations for a typical supermarket [N]

Accordingly, EFLH = 8,760 x Duty cycle (hrs/yr)

1. Energy savings (∆kWh):
   1. Annual energy savings of the compressor (ΔkWhcomp) is determined based on calculated differential compressor power and EFLH, as outlined below.



* 1. Total energy savings (ΔkWh) is the sum of compressor and lighting energy.



**For large multiplex compressor systems:**

1. Determine the EER for both MT and LT applications
   1. Compressor performance curves were obtained from a review of manufacturer data for large reciprocating compressors as a function of SCT and SET. In multiplex systems, suction pressure controls ensure SET remains constant, so no PLR analysis is necessary.
   2. For medium temperature compressors, the following equation is used to determine the EERMT (Btu/hr/watts) at SET of 28°F. [E]
   3. EERMT = a \* SCT3 + b \* SCT2 + c \* SCT + d

where,

a = 0.00002515

b = 0.0100767

c = -1.45844836

d = 82.96962576

* 1. For low temperature compressors, the following equation is used to determine the EERLT (Btu/hr/watts) [E]
  2. EERLT = a \* SCT3 + b \* SCT2 + c \* SCT + d

where,

a = 0.00000491

b = -0.00107023

c = -0.03013591

d = 15.74788397

* 1. This analysis assumes no change in EER due to a reduction in cooling load for a retrofit measure.

1. These demand and energy savings values are reported per door. No further normalization is required.

Table shown below summarizes the demand and energy savings of 5’ T8 fixtures for MT and LT applications for all SCE climate zones in the grocery market sector. The calculations and the savings for the rest of the applicable market sectors and measures can be found in Attachments 6, 7, and 8.

Demand and Energy Savings for 5-foot T8 to LED Retrofit

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Climate Zone** | **Representative City and Temperature (Summer Design Dry-Bulb, ASHRAE Climatic Region X Data, 0.5% Column)** | **Measure Unit** | **Grocery** | | | **Grocery** | | |
| **MT, T8 to 5' LED retrofit** | | | **LT, T8/HO to 5' LED retrofit** | | |
| **Demand Savings (ΔkW/unit)** | **Energy Savings (ΔkWh/unit)** | | **Demand Savings (ΔkW/unit)** | **Energy Savings (ΔkWh/unit)** | |
| 6 | Torrance - 86⁰F | Door | 0.02090 | | 108.34 | 0.04725 | | 244.97 |
| 8 | Fullerton - 94⁰F | Door | 0.02155 | | 111.20 | 0.04902 | | 252.99 |
| 9 | Burbank-Glendale - 96⁰F | Door | 0.02209 | | 114.63 | 0.05036 | | 261.26 |
| 10 | Riverside - 100⁰F | Door | 0.02251 | | 113.93 | 0.05151 | | 260.67 |
| 13 | Fresno - 101⁰F | Door | 0.02236 | | 115.11 | 0.05121 | | 263.64 |
| 14 | Palmdale - 103⁰F | Door | 0.02291 | | 113.13 | 0.05259 | | 259.66 |
| 15 | Palm Springs-Intl - 113⁰F | Door | 0.02260 | | 122.94 | 0.05247 | | 285.41 |
| 16 | Blue Canyon - 85⁰F | Door | 0.02105 | | 102.90 | 0.04757 | | 232.51 |

# Section 3. Load Shapes

The ideal load shape for net benefits estimates would represent the difference between the base case and measure case. The closest load shapes that are applicable to the measures in this work paper are listed in the table below.

Building Types and Load Shapes

|  |  |  |
| --- | --- | --- |
| **Building Type** | **Load Shape** | **E3 Alternate Building Type** |
| Grocery | DEER:Indoor\_Non-CFL\_Ltg | NON\_RES |
| Office - Small | DEER:Indoor\_Non-CFL\_Ltg | NON\_RES |
| Restaurant - Sit-Down | DEER:Indoor\_Non-CFL\_Ltg | NON\_RES |
| Restaurant - Fast-Food | DEER:Indoor\_Non-CFL\_Ltg | NON\_RES |
| Retail - Multistory Large | DEER:Indoor\_Non-CFL\_Ltg | NON\_RES |
| Retail - Single-Story Large | DEER:Indoor\_Non-CFL\_Ltg | NON\_RES |
| Retail - Small | DEER:Indoor\_Non-CFL\_Ltg | NON\_RES |
| Warehouse - Refrigerated | DEER:Indoor\_Non-CFL\_Ltg | NON\_RES |

# Section 4. Costs

## 4.1 Base Case Cost

SCE17LC098\_00\_B001 through SCE17LC098\_00\_B015 are created. The material costs are from web search and captured in Attachment 9. The labor cost is derived from WO17 [475]. For a complete breakdown of base case costs, please refer to Attachment 1.

## 4.2 Measure Case Cost

SCE17LC098\_00\_M001 through SCE17LC098\_00\_M004 are created. The material costs are from web search and captured in Attachment 9. The labor cost is derived from WO17 [475]. For a complete breakdown of measure case costs, please refer to Attachment 1.

## 4.3 Full and Incremental Measure Cost

**Full and Incremental Measure Cost Equations**

|  |  |  |  |
| --- | --- | --- | --- |
| **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| ROB | (MEC + MLC) – (BEC + BLC) | (MEC + MLC) – (BEC + BLC) | N/A |
| RET/ER | (MEC + MLC) – (BEC + BLC) | MEC + MLC | (MEC + MLC) – (BEC + BLC) |

MEC = Measure Equipment Cost; MLC = Measure Labor Cost

BEC = Base Case Equipment Cost; BLC = Base Case Labor Cost

For a complete breakdown of full and incremental measure costs, please refer to Attachment 1.

**Full and Incremental Costs**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure** | **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| LT-17642 | RET | $97.21 | $256.02 | N/A |
| LT-20643 | RET | $89.13 | $256.02 | N/A |
| LT-30954 | RET | $100.24 | $256.02 | N/A |
| LT-49651 | RET | $90.62 | $242.38 | N/A |
| LT-58674 | RET | $86.80 | $242.38 | N/A |
| LT-65612 | RET | $92.87 | $242.38 | N/A |
| LT-69439 | RET | $86.28 | $274.19 | N/A |
| LT-75912 | RET | $89.18 | $242.38 | N/A |
| LT-78303 | RET | $80.72 | $274.19 | N/A |
| LT-79548 | RET | $137.42 | $333.63 | N/A |
| LT-80693 | RET | $94.47 | $274.19 | N/A |
| LT-84544 | RET | $72.56 | $274.19 | N/A |
| LT-89513 | RET | $86.41 | $256.02 | N/A |
| LT-93848 | RET | $137.42 | $333.63 | N/A |
| LT-97154 | RET | $89.13 | $256.02 | N/A |

# Attachments

1. SCE17LG098.0 A1 – Calculation Template\_Final.xlsx

2. SCE17LG098.0 A2 – App B Std Fixt Wattages.pdf

3. SCE17LG098.0 A3 - LED Disp Cases Fixt Specs.zip

4. SCE17LG098.0 A4 – Single Comp RI DIsp Case.pdf

5. SCE17LG098.0 A5 - 3&4ft. LEDs.zip

6. SCE17LG098.0 A6 – Vert LED.xlsx

7. SCE17LG098.0 A7 – Horiz LED 3ft.xlsx

8. SCE17LG098.0 A8 – Horiz LED 4ft.xls

9. SCE17LG098.0 A9 – Cost Calculations.xlsx

# References

1. References\_12122016\_100741.xlsx

[227], [456], [457], [475], [493], [496]

[E] SCE’s Analysis of Compressor Manufacturer Data for Reciprocating Compressors. 2004