**Work Paper SCE13HC038**

Revision 2

**Southern California Edison**

**VFD Demand Control System Retrofit to Parking Structure Exhaust Fan**

# At-a-Glance Summary

|  |  |
| --- | --- |
| Measure Codes | AC-29603, AC-30912, AC-45381 |
| Measure Description | VFD Demand Control System Retrofit to Parking Structure Exhaust Fan <10HP to 100 HP |
| Base Case Description | No VFD |
| Units | Per HP |
| 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 | HVAC-RedcOverVent: 10 years EUL, 3.3 years RUL |
| Measure Installation Type | Retrofit Add-on (REA) |
| Net-to-Gross Ratio | 0.6 (DEER NTGR ID: Com-Default>2yrs) |
| 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 | 5/31/12 | Lionel Metchop/Lincus, Inc. | - In Section 2, revised the savings calculations to include VFD Efficiency parameter in the formula. Updated annual energy savings tables accordingly  - In Section 1.1b, updated delivery and incentive mechanism  - Updated calculation table Cost NTG values  - Updated paper to the template version: SP&TS Work Paper Template 2013 v0.1 (based on previous version WPSCNRHC0038)   * In Section 1.1a, Updated entire table and spreadsheet with new solution codes * In Section 1.1c, updated the measures requirement * In Section 1.5, updated the NTG for new measures not otherwise addressed * In Section 2, updated the calculations to include Demand Reduction * In Section 3, updated building types * In Section 4, revised the cost estimates based on RS Means as a reference * In Section 1.5, updated the language and the table according to DEER2011\_NTGR\_2012-05-16 * Updated the entire paper to include “Residential – Multi-Family” building type   Section 2, All tables: Modified table headers to match equation parameter labels |
| 1 | 3/18/16 | Yun Han/SCE | * New template update for 2016 program year * Removed SCE building types * No value modifications |
| 2 | 4/28/16 | Jay Bhakta/SCE | * Replaced Misc-Commercial, Health/Medical - Clinic with Office Small |

# 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

This work paper details the retrofit installation of carbon monoxide sensors and variable frequency drive (VFD) exhausts fans for parking structures (parking structures). The base case is an existing constant speed exhaust fan within an existing parking structure either operated on a time schedule or allowed to run 24 hours per day 7 days a week. The measure case is a variable speed exhaust fan equipped with a variable frequency drive that will be controlled by carbon monoxide (CO) sensors located throughout the parking structure.

**Base, Standard, and Measure Cases**

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measure | VFD Demand Control System Retrofit to Parking Structure Exhaust Fan <10HP to 100 HP |
| Existing Condition | No VFD |
| Code/Standard | N/A |
| Industry Standard Practice | N/A |

**Measures and Codes**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Codes** | | | | **Measure Name** |
| SCG | SDG&E | SCE | PG&E |
|  |  | AC-29603 |  | VFD Demand Control System Retrofit to Parking Structure Exhaust Fan: < 10HP |
|  |  | AC-30912 |  | VFD Demand Control System Retrofit to Parking Structure Exhaust Fan: 10HP to 40HP |
|  |  | AC-45381 |  | VFD Demand Control System Retrofit to Parking Structure Exhaust Fan: 41HP to 100HP |

The target market participants for this measure are Residential Multi-family, Office, Education, Health, Lodging, Retail, and Commercial structures which have enclosed parking structures. See section 3 for a full list of the building types included in this work paper.

This work paper only applies to enclosed parking structures. Exhaust is not required for open parking structures, as defined by the Title 24, Part 2, California Building Code Section 406.3, or for parking structures smaller than 1000 square feet in area or storing 5 or fewer motor vehicles.

## 1.2 Technical Description

VFD Demand Control System saves energy by modulating the amount of exhaust air for the parking structure based on demand which will reduce the energy usage of the exhaust fan.

## 1.3 Installation Types and Delivery Mechanisms

The program/install type for the measures is:

* Retrofit Add-on (REA)

**Installation Type Descriptions**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Installation Type** | **Savings** | | **Life** | |
| 1st Baseline (BL) | 2nd BL | 1st BL | 2nd BL |
| Retrofit Add-on (REA) | Above Customer Existing | N/A | EUL | N/A |

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. |
| Partnership | The program implements projects through a partnership between the utility and an institutional, government, or community-based organization. |

**Incentive Method Descriptions**

|  |  |
| --- | --- |
| **Incentive Method** | **Description** |
| 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. |

## 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 | No |
| DEER Operating Hours | No |
| DEER eQUEST Prototypes | No |
| DEER Version | Non-DEER |
| Reason for Deviation from DEER | DEER does not contain this type of measure. |
| DEER Measure IDs Used | N/A |

**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 |
| Res-Default>2 | All other EEM with no evaluated NTGR; existing EEM with same delivery mechanism for more than 2 years | Res | Any | Any | .55 |

**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**

The EUL and RUL values were obtained using the DEER READI tool. DEER defines the RUL as 1/3 of the EUL value. The RUL value is only applicable to the first baseline period for an RET measure with an applicable code baseline. The relevant EUL and RUL values for the measures in this work paper are in the table below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| HVAC-RedcOverVent | Reducing Overventilation | Com | HVAC | 10 | 3.3 |

### 1.4.2 Codes and Standards Analysis

Title 24, Part 4, 2010 California Mechanical Code (CMC), Section 403.8 [A], requires exhaust of air flow for enclosed parking facilities, at a rate of 0.75 cubic feet/minute per square foot(CFM/ft2) , and accompanying makeup air from outside or from transfer.

Exhaust is not required for open parking structures, as defined by the Title 24, Part 2, California Building Code Section 406.3, or for parking structures smaller than 1000 square feet in area or storing 5 or fewer motor vehicles.

Section 403.8.2 of the 2010 CMC allows for an intermittently-operated exhaust system, where the system operates automatically upon detection of vehicle operation. Section 403.8.2.2 allows automatic carbon monoxide sensing devices to be employed to modulate the ventilation system to maintain a maximum average concentration of carbon monoxide of 50 parts per million during any eight-hour period, with a maximum concentration not greater than 200 parts per million for a period not exceeding one hour.

**Code Summary**

|  |  |  |
| --- | --- | --- |
| **Code** | **Reference** | **Effective Dates** |
| Title 24 (2010) | Title 24, Part 4, 2010 California Mechanical Code, Section 403.8 | 1/1/2010 |
| Title 24 (2010) | Title 24, Part 4, 2010 California Mechanical Code, Section 403.8.2 | 1/1/2010 |
| Title 24 (2010) | Title 24, Part 2, 2010 California Building Code, Section 406.3 | 1/1/2010 |

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

* N/A

## 1.6 Data Quality and Future Data Needs

N/A

# Section 2. Calculation Methodology

The Excel files used in this analysis are attached at the end of document. Energy savings and demand reduction for different building types and climate zones can be found in Attachment 1.

**Method 1: Education- Primary School & Secondary School, Large Office, Small Office and Residential Multi-Family**

Energy consumption of the base case enclosed parking structure fan exhaust system is based upon this system operating continuously at full speed for 6 days/week, 12 hours per day. The profile of contaminant generation within the space was based upon car movement profiles (Attachment 3) with 100% design Carbon Monoxide (CO) emissions from 7 – 9 AM and from 5 – 7 PM, and 15% design emissions from 9 AM – 5 PM.

Fans motors are operated at 90% of their nameplate horsepower. This assumption is consistent with the IDSM Online Application Tool (OAT). While the OAT does not feature savings calculations for VFD Demand Control System Retrofit to Parking Structure Exhaust Fan, it features a calculation for a measure that has the same baseline as VFD Demand Control System Retrofit to Parking Structure Exhaust Fan. That measure is “AC-32976 - Parking garage exhaust fan - on/off cycling” and it has the same baseline input as the measure under study in this work paper.

Refer to [Equation 1] for calculation of constant speed fan motor power, expressed per fan motor nominal horsepower (HP). Motor efficiencies are based upon NEMA Premium efficiencies as indicated in table below.

**[Equation 1]**



Refer to [Equation 2] for annual energy consumption of fans operating at constant speed for 12 hours per day, 6 days per week. The annual energy consumption is expressed per fan motor nominal horsepower.

**[Equation 2]**

*Baseline Annual Energy Consumption =Baseline Power Demand x 12 hours/day x 6 days/week x 52 weeks/year*

Fans controlled by variable frequency drives (VFDs) may be reduced to a minimum of 25% of full speed. Calculations for the measure case are based upon parking structure exhaust fans operating @ 100% speed for 4 hours/day, and 25% speed for 8 hours/day. This assumption is in line with ASHRAE based on two hours in the morning and two hours in the evening for a total of four hours. The fan energy required is proportional to the cube root of the fan speed. For example, the power required to operate a fan at 25% of full speed is 0.253, or 0.016 of the power to operate that fan at full speed.Refer to [Equation 3] and [Equation 4] respectively for variable speed fan annual energy consumption and peak demand. VFD efficiency values for drives of various nominal motor horsepower ratings and different motor loads are found in the US Department of Energy’s Motor Tip Sheet #11 (Attachment 4) . The efficiency values are rated as a percent of drive rated power output. The [Equation 3]calculates the Measure Annual Energy Consumption, also expressed per Fan Motor Nominal HP:

**VFD Efficiency Variation with Load**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable Frequency Drive HP Rating** | **Load, Percent of Drive Rated Power Output** | | | | | | |
| 2% | 13% | 25% | 42% | 50% | 75% | 100% |
| **VFD Efficiency, %** | | | | | | |
| 3 | 31% | 77% | 86% | 90% | 91% | 93% | 94% |
| 5 | 35% | 80% | 88% | 91% | 92% | 94% | 95% |
| 10 | 41% | 83% | 90% | 93% | 94% | 95% | 96% |
| 20 | 47% | 86% | 93% | 94% | 95% | 96% | 97% |
| 30 | 50% | 88% | 93% | 95% | 95% | 96% | 97% |
| 50 | 46% | 86% | 92% | 95% | 95% | 96% | 97% |
| 60 | 51% | 87% | 92% | 95% | 95% | 96% | 97% |
| 75 | 47% | 86% | 93% | 95% | 96% | 97% | 97% |
| 100 | 55% | 89% | 94% | 95% | 96% | 97% | 97% |
| 200 | 61% | 91% | 95% | 96% | 96% | 97% | 97% |
| 400 | 61% | 91% | 95% | 96% | 96% | 97% | 97% |
| **Average** | **48%** | **86%** | **92%** | **94%** | **95%** | **96%** | **96%** |
| **Normalized** | **50%** | **90%** | **96%** | **98%** | **99%** | **100%** | **100%** |



Figure 1 Average VFD Efficiency Variation with Drive Loading

**[Equation 3****]**

*Measure Annual Energy Consumption = Measure Fan kWh/day x 6 days/week x 52 weeks/year*

Where:

*Measure Fan kWh/day =*

*(Baseline Power Demand x 4 hr/day + 0.253x Baseline Power Demand x 8 hours/day) /VFD Efficiency*

Figure above provides typical variations in VFD efficiencies with drive loading. This variation in efficiency has been accounted for in the calculations.

Refer to [Equation 4] for annual fan energy savings resulting from the measure, expressed per fan motor nominal HP.

**[Equation 4]**

*Annual Energy Savings = Baseline Annual Energy Consumption- Measure Annual Energy Consumption*

Table below summarizes the annual energy savings for Education Primary and Secondary Schools, Large Office, Small Office, Residential Multi-Family and Miscellaneous Commercial building types. The Base Case and Measure Annual Energy Consumption are expressed per nominal Fan Motor HP.

The VFD efficiency of the 40 HP motor was found by interpolation using the efficiencies of the VFDs at 30 HP and at 50 hp. As a result, both the 30 HP and the 40 HP case respectively have both the same motor efficiency and the same VFD efficiency. Consequently, when expressing the Base Case and Measure Annual Energy Consumption per nominal Fan Motor HP, 30 HP and the 40 HP case have the same values. It is also noticeable that the 75 HP and 100 HP cases have the same motor efficiency and the same VFD efficiency and as a result they both have the same value of Base Case and Measure Annual Energy Consumption when expressed per Fan Motor Nominal HP.

**Annual Energy Savings**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fan Motor Nominal HP** | **Motor Efficiency %** | **VFD Efficiency %** | **Baseline Annual Energy Consumption [kWh/HP]** | **Measure Annual Energy Consumption [kWh/ HP]** | **Annual Energy Savings [kWh/ HP]** |
| 10 | 91.7% | 95.2% | 2741.24 | 1014.56 | 1726.68 |
| 15 | 93.0% | 95.7% | 2702.93 | 995.15 | 1707.77 |
| 20 | 93.0% | 96.2% | 2702.93 | 989.98 | 1712.95 |
| 25 | 93.6% | 96.2% | 2685.60 | 983.63 | 1701.97 |
| 30 | 94.1% | 96.2% | 2671.33 | 978.41 | 1692.92 |
| 40 | 94.1% | 96.2% | 2671.33 | 978.41 | 1692.92 |
| 50 | 94.5% | 96.2% | 2660.02 | 974.26 | 1685.76 |
| 60 | 95.0% | 96.2% | 2646.02 | 969.14 | 1676.89 |
| 75 | 95.4% | 97.0% | 2634.93 | 956.62 | 1678.31 |
| 100 | 95.4% | 97.0% | 2634.93 | 956.62 | 1678.31 |

Refer to [Equation 5] for measure peak demand and to [Equation 6] for peak demand reduction, both expressed per fan motor nominal horsepower.

**[Equation 5]**

*Measure Power Demand = 0.253x Baseline Power Demand*

**[Equation 6]**

*Peak Demand Reduction = Baseline Power Demand- Measure Power Demand*

Table below summarizes the demand reduction for Education-Primary School & Secondary School, Large Office, Small Office, Residential Multi-Family and Miscellaneous Commercial building types. The Base Case and Measure Fan Demand are per expressed nominal Fan Motor HP. The motor efficiencies similarities and VFD efficiencies similarities between 30 HP and 40 HP cases in one side, and between the 75 HP and the 100 HP cases on the other side is the reason why the kW demand values expressed per Fan Motor Nominal HP are respectively the same.

**Peak Demand Reduction**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fan Motor Nominal HP** | **Motor Efficiency %** | **VFD Efficiency %** | **Baseline Power Demand [kW/ HP]** | **Measure Power Demand [kW/ HP]** | **Peak Demand Reduction [kW/ HP]** |
| 10 | 91.7% | 95.2% | 0.73217 | 0.02173 | 0.71044 |
| 15 | 93.0% | 95.7% | 0.72194 | 0.02132 | 0.70062 |
| 20 | 93.0% | 96.2% | 0.72194 | 0.02120 | 0.70073 |
| 25 | 93.6% | 96.2% | 0.71731 | 0.02107 | 0.69624 |
| 30 | 94.1% | 96.2% | 0.71350 | 0.02096 | 0.69254 |
| 40 | 94.1% | 96.2% | 0.71350 | 0.02096 | 0.69254 |
| 50 | 94.5% | 96.2% | 0.71048 | 0.02087 | 0.68961 |
| 60 | 95.0% | 96.2% | 0.70674 | 0.02076 | 0.68598 |
| 75 | 95.4% | 97.0% | 0.70377 | 0.02049 | 0.68328 |
| 100 | 95.4% | 97.0% | 0.70377 | 0.02049 | 0.68328 |

The measures are grouped by nominal fan motor horsepower for program offer purposes. The three groups created are per solution code: The savings values for the < 10HP group (Solution code AC-29603) is the savings value for the 10HP motor. The savings value for the 10HP to 40HP group (Solution code AC-30912) is average of the 15, 20, 25, 30, and 40HP motors. The savings value for the 41HP to 100HP group (Solution code AC-45381) is the average of the 50, 60, 75, and 100HP motors. Table below shows the savings values.

**Peak Demand Reduction & Annual Energy Savings by Groups**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Solution Code** | **Motor Efficiency %** | **Baseline Annual Energy Consumption [kWh/HP]** | **Measure Annual Energy Consumption [kWh/HP]** | **Annual Energy Savings [kWh/HP]** | **Baseline Power Demand [kW/HP]** | **Measure Power Demand [kW/HP]** | **Peak Demand Reduction [kW/HP]** |
| AC-29603 | 91.7% | 2741.24 | 1014.56 | 1726.68 | 0.73217 | 0.02173 | 0.71044 |
| AC-30912 | 93.6% | 2686.82 | 985.12 | 1701.71 | 0.71763 | 0.02110 | 0.69653 |
| AC-45381 | 95.1% | 2643.98 | 964.16 | 1679.82 | 0.70619 | 0.02065 | 0.68554 |

**Example**

100 HP Fan, serving enclosed parking structure, small office occupancy, CZ 6



*0.70377 kW/HP*

*Baseline Annual Energy Consumption =Baseline Power Demand x 12 hours/day x 6 days/week x 52 weeks/year =* 0.70377 kW/HP *x 12 hours/day x 6 days/week x 52 weeks = 2,634.93 kWh/HP*

*Measure Annual Energy Consumption = (Baseline Power Demand x 4 hours/day + 0.253x Baseline Power Demand x 8 hours/day)/VFD Efficiency*

*Or*

*Measure Fan Energy Consumption = (*0.70377 *kW/HP x 4 hours/day + 0.028x* 0.70377 *kW/HP x 8 hours/day)/0.97 x 6 days/week x 52 weeks = 956.62 kWh/year*

*Annual Energy Savings = Baseline Annual Energy Consumption - Measure Annual Energy Consumption* ***=*** *2,634.9 – 956.6 = 1,678.3 kWh/HP*

*Measure Power Demand = (0.253x Baseline Power Demand)/VFD Efficiency = (0.253 x* 0.70377 *kW/HP)/54.9% =* 0.020 *kW/HP*

*Peak Demand Reduction = Baseline Power Demand- Measure Peak Demand =* 0.70377 *–* 0.020 *=* 0.683 *kW/HP*

**Method 2: Education - Community College & University, Health/Medical - Hospital, Health/Medical Nursing Home, Lodging Guest Rooms, Lodging Hotel & Motel, Retail Multistory & Single Story Large**

Energy consumption of the base case enclosed parking structure fan exhaust system is based upon this system operating continuously at full speed for 7 days/week, 24 hours per day.

As explained in the previous section (Method 1), it is assumed that fans motors are operated at 90% of their nameplate horsepower. Refer to [Equation 7] for calculation of constant speed fan motor power, expressed per fan motor nominal efficiency.

**[Equation 7]**



Refer to [Equation 8] for annual energy consumption of fans operating at constant speed for 24 hours per day, 7 days per week, expressed per fan motor nominal efficiency.

**[Equation 8]**

*Baseline Annual Energy Consumption = Baseline Power Demand x 24 hours/day x 7 days/week x 52 weeks/year*

Fans controlled by variable speed drives may be reduced in speed to a minimum of 25% of full speed. Calculations for the measure case are based upon parking structure exhaust fans operating at a speed equivalent to the hourly Mixed Use Occupancy Profiles shown in table below. The fan energy required is proportional to the cube root of the fan speed. For example, the power required to operate a fan at 25% of full speed is 0.253, or 0.016 of the power to operate that fan at full speed.The parking structure is operated seven (7) days per week. Refer to [Equation 9] and [Equation 10] for variable speed fan annual energy consumption.

**[Equation 9]**

*Measure Fan kWh/day= Sum over 24 hours of (Baseline Power Demand x 0.XX%3)*

Where 0.XX% is the hourly occupancy from table below, which varies depending on what day of the week it is.

**[Equation 10]**

*Measure Annual Energy Consumption = [(Measure Fan kWh/weekday x 5 days/week) + (Measure Fan kWh/Saturday x 1 day/week) + (Measure Fan kWh/Sunday x 1 day/week)]/VFD Efficiency x 52 weeks/year*

Where, VFD efficiency is based on Figure 1.

**Daily Occupancy Profile, Mixed Use Medium**

|  |  |  |  |
| --- | --- | --- | --- |
| **Source: Parking Garage LPA and Controls, 2013 Building Efficiency Standards, Draft of February 15, 2011, Figure 62** | | | |
| **Day** | **Occupancy (%)** | | |
| **Hour** | **Weekday** | **Saturday** | **Sunday** |
| 1:00 | 25% | 40% | 30% |
| 2:00 | 15% | 20% | 15% |
| 3:00 | 8% | 10% | 10% |
| 4:00 | 8% | 5% | 5% |
| 5:00 | 8% | 5% | 5% |
| 6:00 | 8% | 5% | 5% |
| 7:00 | 15% | 10% | 9% |
| 8:00 | 30% | 10% | 10% |
| 9:00 | 50% | 20% | 20% |
| 10:00 | 50% | 20% | 20% |
| 11:00 | 45% | 20% | 20% |
| 12:00 | 45% | 30% | 30% |
| 13:00 | 50% | 40% | 30% |
| 14:00 | 50% | 40% | 30% |
| 15:00 | 60% | 30% | 25% |
| 16:00 | 70% | 30% | 25% |
| 17:00 | 70% | 30% | 30% |
| 18:00 | 70% | 30% | 30% |
| 19:00 | 70% | 40% | 40% |
| 20:00 | 70% | 50% | 50% |
| 21:00 | 70% | 50% | 50% |
| 22:00 | 60% | 60% | 50% |
| 23:00 | 50% | 60% | 50% |
| 0:00 | 35% | 60% | 50% |

Table below summarizes measure annual energy savings for Education-Community College & University, Health, Lodging and Large Retail. Annual Energy Savings are formulated as the difference between Baseline Annual Energy Consumption and Measure Annual Energy Consumption. The motor efficiencies similarities and VFD efficiencies similarities between 30 HP and 40 HP cases in one side, and between the 75 HP and the 100 HP cases on the other side is the reason why the energy consumption values expressed per Fan Motor HP are similar.

**Annual Energy Savings**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fan Motor Nominal HP** | **Motor Efficiency %** | **VFD Efficiency %** | **Baseline Annual Energy Consumption [kWh/HP]** | **Measure Annual Energy Consumption [kWh/HP]** | **Annual Energy Savings [kWh/HP]** |
| 10 | 91.7% | 95.2% | 6413.81 | 899.03 | 5514.78 |
| 15 | 93.0% | 95.7% | 6324.15 | 881.85 | 5442.30 |
| 20 | 93.0% | 96.2% | 6324.15 | 877.29 | 5446.87 |
| 25 | 93.6% | 96.2% | 6283.62 | 871.67 | 5411.95 |
| 30 | 94.1% | 96.2% | 6250.23 | 867.03 | 5383.19 |
| 40 | 94.1% | 96.2% | 6250.23 | 867.03 | 5383.19 |
| 50 | 94.5% | 96.2% | 6223.77 | 863.36 | 5360.41 |
| 60 | 95.0% | 96.2% | 6191.01 | 858.82 | 5332.19 |
| 75 | 95.4% | 97.0% | 6165.06 | 851.69 | 5313.36 |
| 100 | 95.4% | 97.0% | 6165.06 | 851.69 | 5313.36 |

The equations below are used to determine the peak demand reduction.

**[Equation 11]**

*Measure Power Demand= Baseline Power Demand x (Peak Hours Occupancy)3/VFD Efficiency, w*here *Peak Hour Occupancy* is the average occupancy of the parking structure between 2:00 pm and 5:00 pm on weekdays as shown in Table - Daily Occupancy Profile, Mixed Use Medium.

Refer to [Equation 12] for peak demand reduction.

**[Equation 12]**

*Peak Demand Reduction = Baseline Power Demand- Measure Power Demand*

Table below summarizes the demand reduction for Education- Community College & University, Health, Lodging and Large Retail. The Base Power Demand and Measure Power Demand are expressed per fan motor nominal horsepower. The motor efficiencies similarities and VFD efficiencies similarities between 30 HP and 40 HP cases in one side, and between the 75 HP and the 100 HP cases on the other side is the reason why the peak demand values expressed per Fan Motor HP are similar.

**Peak Demand Reduction**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fan Motor Nominal HP** | **Motor Efficiency %** | **VFD Efficiency %** | **Baseline Power Demand [kW/ HP]** | **Measure Power Demand [kW/ HP]** | **Peak Demand Reduction [kW/ HP]** |
| 10 | 91.7% | 95.2% | 0.73217 | 0.18558 | 0.54659 |
| 15 | 93.0% | 95.7% | 0.72194 | 0.18203 | 0.53990 |
| 20 | 93.0% | 96.2% | 0.72194 | 0.18109 | 0.54085 |
| 25 | 93.6% | 96.2% | 0.71731 | 0.17993 | 0.53738 |
| 30 | 94.1% | 96.2% | 0.71350 | 0.17897 | 0.53452 |
| 40 | 94.1% | 96.2% | 0.71350 | 0.17897 | 0.53452 |
| 50 | 94.5% | 96.2% | 0.71048 | 0.17821 | 0.53226 |
| 60 | 95.0% | 96.2% | 0.70674 | 0.17728 | 0.52946 |
| 75 | 95.4% | 97.0% | 0.70377 | 0.17580 | 0.52797 |
| 100 | 95.4% | 97.0% | 0.70377 | 0.17580 | 0.52797 |

The measures are grouped by fan motor nominal horsepower for program offer purposes. The three groups created are per solution code: The savings values for the < 10HP group (Solution code AC-29603) is the savings value for the 10HP motor. The savings value for the 10HP to 40HP group (Solution code AC-30912) is average of the 15, 20, 25, 30, and 40HP motors. The savings value for the 41HP to 100HP group (Solution code AC-45381) is the average of the 50, 60, 75, and 100HP motors. See Table below for the savings values.

**Annual Energy Savings by Solution Code**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Solution Code** | **Motor Efficiency %** | **Baseline Annual Energy Consumption [kWh/HP]** | **Measure Annual Energy Consumption [kWh/HP]** | **Annual Energy Savings [kWh/HP]** | **Baseline Power Demand [kW/HP]** | **Measure Power Demand [kW/HP]** | **Peak Demand Reduction [kW/HP]** |
| AC-29603 | 91.7% | 6413.81 | 899.03 | 5514.80 | 0.73217 | 0.18558 | 0.54659 |
| AC-30912 | 93.1% | 6319.19 | 879.37 | 5439.80 | 0.72137 | 0.18152 | 0.53985 |
| AC-45381 | 95.1% | 6186.22 | 856.39 | 5329.80 | 0.70619 | 0.17678 | 0.52941 |

# 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** |
| Education - Community College | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Education - Primary School | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Education - Secondary School | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Education - University | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Lodging - Guest Rooms | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Health/Medical - Hospital | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Lodging - Hotel | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Residential Multi-family | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Lodging - Motel | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Health/Medical - Nursing Home | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Office - Large | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Office - Small | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Retail - Multistory Large | Reduce\_Cooling\_Load-Ret | NON\_RES |
| Retail - Single-Story Large | Reduce\_Cooling\_Load-Ret | NON\_RES |

# Section 4. Costs

## 4.1 Base Case Cost

The base case equipment and labor cost is $0/unit because the base case refers to situations where there are no VFDs installed for the exhaust fans.

## 4.2 Measure Case Cost

The actual cost can vary by contractor, the date in which the work occurred, and by the volume of business. Costs are based on RS Means Handbook [B]. These are total project costs that include labor and materials for installation of VFD controller, CO Detector panel, and CO Detector sensor. A cost model was developed to include the variation in number of CO sensors installed according to the size of the parking structure (Attachment 2). The table below reports the estimated costs as a ratio of the fan motor nominal horsepower.

Measure Cost

|  |  |  |  |
| --- | --- | --- | --- |
| **Fan Motor Nominal HP** | **Material Cost [$/HP]** | **Labor Cost [$/HP]** | **Gross Measure Cost [$/HP]** |
| 10 | $ 887.00 | $ 103.65 | $ 990.65 |
| 15 | $ 768.33 | $ 98.90 | $ 867.23 |
| 20 | $ 750.25 | $ 82.28 | $ 832.53 |
| 25 | $ 748.80 | $ 85.66 | $ 834.46 |
| 30 | $ 731.67 | $ 76.78 | $ 808.45 |
| 40 | $ 743.00 | $ 67.04 | $ 810.04 |
| 50 | $ 701.60 | $ 66.11 | $ 767.71 |
| 60 | $ 688.75 | $ 65.14 | $ 753.89 |
| 75 | $ 697.33 | $ 59.31 | $ 756.65 |
| 100 | $ 659.45 | $ 55.67 | $ 715.12 |

Table below shows the costs for each solution code, reported as cost per nominal horsepower.

Measure Cost by Solution Code

|  |  |  |  |
| --- | --- | --- | --- |
| **Solution Code** | **Material Cost [$/HP]** | **Labor Cost [$/HP]** | **Gross Measure Cost [$/HP]** |
| AC-29603: < 10 HP | 887.00 | 990.65 | 1,877.65 |
| AC-30912: 10 HP to 40 HP | 748.41 | 830.54 | 1,578.95 |
| AC-45381: 41 HP to 100 HP | 686.78 | 748.34 | 1,435.12 |

## 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** |
| REA | MEC + MLC | MEC + MLC | N/A |

MEC = Measure Equipment Cost; MLC = Measure Labor Cost

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

**Full and Incremental Costs**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure** | **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| AC-29603 | REA | 1,877.65 | 1,877.65 | N/A |
| AC-30912 | REA | 1,578.95 | 1,578.95 | N/A |
| AC-45381 | REA | 1,435.12 | 1,435.12 | N/A |

# Attachments

1.  2. 3. 4.

# References



[A] http://www.energy.ca.gov/title24/

[B] RS Means 2009 Mechanical Cost Data Handbook