Work Paper PGECOHVC143

**Revision 3**

**Pacific Gas & Electric Company**

**Enhanced Ventilation and VFD for Packaged HVAC Units with Gas Heating and Packaged Heat Pumps**

**For Work Paper Reviewer Use Only**

**List all major comments that occurred during the review. This table may only be removed during management review.**

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| --- | --- | --- | --- |
| **Major Comment** | **Reviewer Name** | **Date** | **Outcome/Resolution** |
| E.g. Please remove measure LT-12345 (LD123) from this work paper because it is no longer eligible for incentives. | Reviewer 1 | 6/1/15 | E.g. Comment incorporated. LT-12345 was removed. |
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# At-a-Glance Summary

|  |  |
| --- | --- |
| **Measure Codes** | HV054 – HV071, SA07 – SA12 |
| **Measure Description** | * Retrofit a variable speed motor with controls to an existing motor on a packaged single zone direct expansion (DX) HVAC unit with an economizer with or without an advanced digital economizer controller (ADEC). * Retrofit the existing motor with a NEMA Premium Efficiency motor and variable frequency drive with or without an ADEC. * Retrofit the existing motor with a permanent magnet motor (PMM) and variable frequency drive with or without an ADEC. |
| **Base Case Description** | An existing packaged single zone unit utilizing a constant speed motor for the supply fan. |
| **Units** | Per ton of cooling capacity |
| **Energy Savings** | Refer to Excel Calculation Attachment |
| **Full Measure Cost ($/unit)** | Add VFD control to existing motor: $109.36/ton  Add VFD and NEMA premium efficiency motor: $172.56/ton  Add VFD and PMM: $182.12/ton  Add ADEC and VFD control to existing motor: $189.65/ton  Add ADEC, VFD, and NEMA premium efficiency motor: $252.85/ton  Add ADEC, VFD, and PMM: $262.41/ton |
| **Incremental Measure Cost ($/unit)** | Add VFD control to existing motor: $109.36/ton  Add VFD and NEMA premium efficiency motor: $172.56/ton  Add VFD and PMM: $182.12/ton  Add ADEC and VFD control to existing motor: $189.65/ton  Add ADEC, VFD, and NEMA premium efficiency motor: $252.85/ton  Add ADEC, VFD, and PMM: $262.41/ton |
| **Effective Useful Life** | 5 years (RUL of DEER EUL ID: HVAC-airAC) |
| **Measure Installation Type** | Retrofit Add-on (REA) |
| **Net-to-Gross Ratio** | 0.6 (DEER NTGR ID: Com-Default>2yrs) |
| **Important Comments** |  |

# Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Rev** | **Date** | **Author** | **Summary of Changes** |
| 0 | 6/1/2012 | Janice Peterson (PECI)  Ben Lipscomb (PECI)  Judith Jennings (PG&E) | Enhanced Ventilation & VFD PGECOHVC143 R0.doc  Original Workpaper |
| 0 | 8/29/2012 | Judith Jennings (PG&E) | Added OTR description in AAG summary and section 2. fixed ROB, units, vintages, grrs, cover and footnote dates, reformatted AAG measure list, fixed misc. errors. Removed embedded files. Updated table of contents and list of figures. |
| 1 | 5/30/2014 | Scott Jasinski (PECI)  Ben Lipscomb (PECI)  Sherry Hu (PG&E) | All sections have been updated. DCV has been removed from the scope of this work paper. New measure codes were added. |
| 2 | 4/1/2016 | Sherry Hu (PG&E) | Ex Ante Data Spreadsheet formatting update. |
| 3 | 12/3/2018 | Tai Voong (PG&E)  Phil Jordan (CLEAResult) | * Updated savings estimates using DEER prototype updates released with DEER2015 and DEER2017 * Measure cost analysis was updated to use current information for ADEC pricing * Work paper content was updated according to Resolution E-4818 existing conditions * Work paper format was updated to match latest template * Included “Enhanced Ventilation” measures (PG&E SA measure codes); per Rev 1 of this workpaper DCV has been removed from the scope of this workpaper, and the savings (and measure costs) for the “Enhanced Ventilation” measure codes are now determined by summing the savings (and measure costs) of the VFD measure (for adding VFD to a unit that already has ADEC) and the DCV + ADEC measure (for adding DCV and ADEC to a unit) from the PGECOHVC168 (Demand Controlled Ventilation) workpaper |
|  |  |  |  |

# Commission Staff and Cal TF Comments

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| --- | --- | --- | --- | --- | --- |
| **Rev** | **Party** | **Submittal Date** | **Comment Date** | **Comments** | **WP Developer Response** |
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Cal TF website: <http://www.caltf.org/>

# Section 1. General Measure & Baseline Data

## 1.1 Measure Description & Background

**Catalog Description**

Add a Variable Frequency Drive to an existing packaged single zone direct expansion (DX) HVAC unit with an economizer. The VFD operates at two discrete speeds based on ventilation and cooling or heating demand.

There are 18 measures total for adding one or more efficiency measures, including VFD, NEMA motor, permanent magnet motor (PMM), and Advanced Digital Economizer Controller (ADEC), to cooling units with gas heat, cooling only units, and heat pumps, respectively.

**Base, Standard, and Measure Cases**

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measure | Add VFD to single zone DX HVAC unit with an economizer |
| Existing Condition | Single zone DX HVAC unit with a functional economizer and no VFD |
| Code/Standard | NA |
| Industry Standard Practice | NA |

Measures and Codes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Codes** | | | | **Measure Name** |
| SCG | SDG&E | SCE | PG&E |
|  |  |  | HV054 | Add VFD to AC unit with Gas Heat and ADEC |
|  |  |  | HV055 | Add VFD and NEMA motor to AC unit with Gas Heat and ADEC |
|  |  |  | HV056 | Add VFD and PMM to AC unit with Gas Heat and ADEC |
|  |  |  | HV057 | Add VFD to AC unit only and ADEC |
|  |  |  | HV058 | Add VFD and NEMA motor to AC unit only and ADEC |
|  |  |  | HV059 | Add VFD and PMM to AC unit only and ADEC |
|  |  |  | HV060 | Add VFD to Heat Pump and ADEC |
|  |  |  | HV061 | Add VFD and NEMA motor to Heat Pump and ADEC |
|  |  |  | HV062 | Add VFD and PMM to Heat Pump and ADEC |
|  |  |  | HV063 | Add VFD and ADEC to AC unit with Gas Heat |
|  |  |  | HV064 | Add VFD, NEMA motor, and ADEC to AC unit with Gas Heat |
|  |  |  | HV065 | Add VFD, PMM, and ADEC to AC unit with Gas Heat |
|  |  |  | HV066 | Add VFD and ADEC to AC unit only |
|  |  |  | HV067 | Add VFD, NEMA motor, and ADEC to AC unit only |
|  |  |  | HV068 | Add VFD, PMM, and ADEC to AC unit only |
|  |  |  | HV069 | Add VFD and ADEC to Heat Pump |
|  |  |  | HV070 | Add VFD, NEMA motor, and ADEC to Heat Pump |
|  |  |  | HV071 | Add VFD, PMM, and ADEC to Heat Pump |
|  |  |  | SA07 | HVAC ENHANCED VENT GAS HEAT, including adding ADEC, CO2 sensor, VFD to units with Gas Heat |
|  |  |  | SA08 | HVAC ENHANCED VENT NEMA GAS HEAT, including adding ADEC, CO2 sensor, VFD, NEMA motor to units with Gas Heat |
|  |  |  | SA09 | HVAC ENHANCED VENT PMM GAS HEAT, including adding ADEC, CO2 sensor, VFD, PMM motor to units with Gas Heat |
|  |  |  | SA10 | HVAC ENHANCED VENT HEAT PUMP, including adding ADEC, CO2 sensor, VFD to Heat Pump |
|  |  |  | SA11 | HVAC ENHANCED VENT NEMA HEAT PUMP, including Adding ADEC, CO2 sensor, VFD, NEMA motor to Heat Pump |
|  |  |  | SA12 | HVAC ENHANCED VENT PMM HEAT PUMP, including Adding ADEC, CO2 sensor, VFD, PMM motor to Heat Pump |

Program Restrictions and Guidelines

The target market for Enhanced Ventilation and VFD for Packaged HVAC Units with Gas Heating and Packaged Heat Pumps is spaces in commercial buildings served by packaged single zone HVAC units, sometimes referred to as rooftop units (RTUs). This fan motor and control upgrade for existing units is a Retrofit Add-on (REA) application, meaning Unit Energy Savings (UES) values provided are for an existing system without a 2-speed fan as the baseline. There are no above-code savings reported as Title 24 2016 §140.4[[1]](#endnote-1) requires that systems that include an air side economizer shall have a minimum of two speeds of fan control during economizer operation in most of the building types and activity area types considered. The UES values are not appropriate for Replace on Burnout (ROB) or New Construction (NC) applications.

The measures HV054 to HV071 described in this workpaper are available only for the below 17 DEER building types:

* Asm (Assembly),
* ECC (Education – Community College),
* EPr (Education – Primary School),
* ESe (Education – Secondary School),
* EUn (Education – University),
* Hsp (Health/Medical – Hospital),
* Htl (Lodging – Hotel),
* Nrs (Health/Medical – Nursing Home),
* MBT (Manufacturing Biotech),
* OfL (Office – Large),
* OfS (Office - Small),
* RFF (Restaurant – Fast Food),
* RSD (Restaurant – Sit-Down),
* Rt3 (Retail – Multistory Large ),
* RtL (Retail – Single-Story Large),
* RtS (Retail – Small),
* SCn (Storage – Conditioned).

Terms and Conditions:

* Existing system must be packaged single zone DX cooling unit with gas heat [HV063, HV064, HV065, HV054, HV055, HV056], cooling only unit [HV066, HV067, HV068, HV 057, HV058, HV059], or heat pump [HV069, HV070, HV071, HV060, HV061, HV062, DA10]
* Existing system must have a constant volume supply fan.
* Existing system must have an operable airside economizer installed, and economizer high limit must be optimized for the climate per Title 24 2016 Table 140.4-B, adapted below in Table 2 for reference.
* Maintenance, and repairs to economizer should be completed prior to or in conjunction with this measure.

Economizer High Limit Shut Off Control Requirements\*

|  |  |  |
| --- | --- | --- |
| **Device Type** | **Climate Zones** | **Economizer High Limit Equation (economizer off when)** |
| Fixed Dry Bulb | 1, 3, 5, 11-16 | Toa>75°F |
| 2, 4, 10 | Toa>73°F |
| 6, 8, 9 | Toa>71°F |
| 7 | Toa>69°F |
| Differential Dry Bulb | 1, 3, 5, 11-16 | Toa>Tra°F |
| 2, 4, 10 | Toa>Tra-2°F |
| 6, 8, 9 | Toa>Tra-4°F |
| 7 | Toa>Tra-6°F |
| Fixed Enthalpy + Fixed Dry Bulb | All | Hoa>28Btu/lb or Toa>75°F |

\*Adapted from Title 24 2016 Table 140.4-B. Refer to source for additional detail.

## 1.2 Technical Description

The base case for each measure is either a single zone constant volume packaged HVAC unit with direct expansion cooling with or without a natural gas furnace or a single zone packaged heat pump. The base case also has an outdoor air economizer to provide cooling when conditions permit.

“Single zone” means that the system is controlled by a single thermostat and does not employ zone dampers, bypass dampers, or any other means of air volume control required for multiple spaces.

Implementation of Enhanced Ventilation requires proper setup of the damper limits and fan speeds in order to provide ventilation in accordance with Title 24 2016. Total unit airflow must be verified for at least one of the fan speeds. The percentage of outdoor air must be verified for each of the unit’s operating modes, including heating and cooling for each stage as well as the ventilation only mode.

The measures are described below with the abbreviated measure names that will be used throughout the work paper.

**Base Measure (standard motor)**

Due to motor reliability concerns at lower speeds, the minimum fan speed modeled for this measure is 40% of the rated motor speed when applied to a standard induction motor. Reliability concerns for induction motors controlled by VFDs are related to high voltage spikes, which can result in winding failure, in addition to overheating due to reduced cooling at very low speeds. Voltage spikes can be mitigated by maintaining short cable lengths and applying capacitance and/or inductance filters when necessary. Minimum speed recommendations for non-inverter-duty rated standard efficiency induction motors range from 5% to 50% for variable torque applications. The 50% minimum recommendation was published by one VFD manufacturer and is suspected to be overly conservative based on the recommendations from motor manufacturers and other VFD manufacturers. All the recommendations by motor manufacturers range from 5% to 20% minimum speed for new standard duty, standard efficiency induction motors. Variable torque applications, such as centrifugal fans used for RTU supply fans, are less susceptible to motor failures due to overheating at low speeds because of the low torque requirement at low speeds, which reduces the cooling requirement. Because this measure is intended for applications on existing motors, the 40% minimum speed was chosen as a conservative minimum speed for existing motors.

**Base Measure with NEMA Premium Supply Fan Motor**

This measure includes the base measure in addition to replacement of the existing standard induction motor with a NEMA Premium efficiency motor, which has a higher overall operating efficiency. The minimum motor speed modeled was reduced to 30% for NEMA Premium motors. The 30% minimum was chosen as a conservative minimum speed for new NEMA Premium motors that may or may not be inverter-duty rated. A review of manufacturers’ recommendations indicated that inverter-duty rated motors may be operated at speeds as low as 0.1%. Motor manufacturer minimum speed recommendations for non-inverter-duty rated NEMA Premium motors range from 5% to 20% of the rated speed.

**Base Measure with Permanent Magnet Supply Fan Motor**

This measure includes the base measure in addition to replacement of the existing standard induction motor with a Permanent Magnet Motor (PMM), which has higher operating efficiency than both standard induction and NEMA Premium motors, especially at reduced speeds.

The minimum motor speed modeled was reduced to 20% for the PMM measure. The 20% minimum speed was based on engineering estimation of the lowest practical speed for an RTU fan application. According to the only known manufacturer of PMMs compatible with VFDs, there is no practical lower limit to how slowly their motors can be operated.

## 1.3 Installation Types and Delivery Mechanisms

The delivery method is Financial Support and the incentive method is downstream or direct installation with the rebate provided to the contractor or customer at the time of installation upon receipt of application and invoice.

This measure replaces existing equipment and adds controls for existing units, so it is a Retrofit Add-on installation type. UES values provided are for an existing system without 2-speed fan control as the baseline. There are no above-code savings reported as Title 24 2016 §140.4 requires 2-speed fan control for single zone packaged units. The UES values are not appropriate for ROB or NC applications.

Market Applicability:

This upgrade measure for existing equipment provides a direct install rebate to contractors or downstream rebate to customers participating in a utility rebate program. Commercial utility customers are the ultimate consumers of the measure. Contractors may use the rebate in any way they would like, including but not limited to passing through to customer, discounting cost to customer, increasing sales and marketing efforts related to the measure, et cetera.

UES values are applicable to any existing commercial utility customer building in any California climate zone and of any vintage. All California utilities may not provide a rebate for the measure, and rebate offerings may vary between those that do. Although some areas or specific customers for which the measure is available could be designated as hard-to-reach, this measure is not assigned a hard-to-reach designation.

**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 |
| 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 First Baseline Only (REF) | Above Customer Existing | N/A | EUL | N/A |
| Retrofit Add-on (REA) | Above Customer Existing | N/A | EUL | N/A |

**Delivery Method Descriptions**

|  |  |
| --- | --- |
| **Delivery Method** | **Description** |
| Appliance Turn-in and Recycling | The program motivates customers, through financial incentives, to recycle appliances that are functional but inefficient. This prevents the continued use of those appliances, by both the current owner and potential future owners. |
| Audit/Information/Testing Services | The program performs a free assessment of a customer’s facility and provides the customer with information and guidance on energy efficiency opportunities. |
| Commissioning and Retrocommissioning | The program modifies or repairs existing equipment to ensure that it works as intended. |
| Financial Support | The program motivates customers, through financial incentives such as rebates or low interest loans, to implement energy efficient measures or projects. |
| Innovative Design | The program funds new ideas that meet reasonable scientific scrutiny for potential energy savings. These innovative measures typically have small market penetration (less than 5%) or are targeted toward relatively unreached market segments. |
| New Construction | The program offers financial incentives and/or design assistance to customers involved with new building construction. This is intended is to motivate customer 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. |
| Performance Based | The program offers financial incentives that vary based on the energy efficiency performance of specific projects. |
| Up-Stream Programs | See Up-Stream Incentive and Up-Stream Buy Down in the Incentive Method 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 | The program gives a financial incentive to a midstream market actor, such as a 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. |
| Up-Stream Buy Down | The program gives a financial incentive to an upstream market actor, such as a manufacturer or distributor, with specific requirements to pass down the incentive to the end use customer. Such an incentive buys-down the cost of an efficient measure for the end-use customer by at least the amount of the financial incentive. |
| Giveaway | The program provides customers with energy efficiency equipment or services for free. |
| Exchange/Replacement | The utility program holds events where customers can trade functional equipment for similar but more energy efficient equipment, free of charge. |
| On-bill Finance/Loan | The program offers financing for the cost an efficient measure as part of the utility bill. This can be an add-on option to an existing program or can serve as an organizing principle for its own program. |

## 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 | Yes, with modifications; see §2 |
| DEER Version | DEER 2015 and DEER 2017 (ERC airHP), READI v2.2.0 |
| Reason for Deviation from DEER | DEER does not contain this type of measure. |
| DEER Measure IDs Used | None |

**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 |

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

**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**

Since this measure is a retrofit on an existing system the RUL of the existing system is used as the EUL for the measure. The EUL for the measure is 5 years.

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-airAC | Air Conditioners (air-cooled, split and unitary) | Com | HVAC | 15 | 5 |

### 1.4.2 Codes and Standards Analysis

This measure is a retrofit to an existing system and is not governed by either state or federal codes and standards as long as the project does not include other code-triggering activities such as replacement of HVAC systems. However, Title 24 2016 provides economizer control and general ventilation requirements that are considered to be best practice and are provided here for reference.

Code Summary

|  |  |  |
| --- | --- | --- |
| **Code** | **Reference** | **Effective Dates** |
| Title 24 2016 | Table 140.4-B: High limit shut-off control requirements by device type and climate zone |  |
| Title 24 2016 | §120.1: Minimum ventilation requirements |  |
|  |  |  |

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

A study of significant importance to the measure development in this work paper is described in the following section. Per Resolution E-4818 the default measure-level baseline shall be existing conditions for add-on equipment measures, which encompasses the measures in this work paper. DEER prototypes for the customer average (CAv) case of the Tech IDs shown in **Table 1** were used as a starting point for defining existing conditions for the measures in this work paper; a search was done to identify any gaps between DEER and current research regarding existing conditions. Beyond the WO32 document described below no such additional studies were found that would impact the existing conditions for the measures in this work paper.

### 1.5.1 HVAC Impact Evaluation FINAL Report WO32 HVAC – Volume 1: Report

Completion date: 1-28-2014

Author: California Public Utilities Commission, Energy Division

This document (WO32 ) is a study of statewide, third-party, and local programs targeting unitary HVAC systems during the 2010-2012 program cycle. WO32 study evaluated gross energy savings and installation rates through activities including on-site field evaluations, sampling and monitoring the performance and energy use of units enrolled in the programs before and after CQM maintenance, and additional laboratory testing of existing HVAC units. The study includes recognition of typical damper leakage characteristics.

The economizer damper leakage observed during laboratory testing suggests that existing economizers are generally allowing 15% outdoor airflow with closed dampers, 20% outdoor airflow with the commonly applied “finger open” methodology for minimum ventilation, and 62% outdoor airflow with dampers completely open. The damper leakage findings can greatly vary energy savings results and have been incorporated into building energy modeling methodology as described in §2.1.

## 1.6 Data Quality and Future Data Needs

While WO32 is useful in quantifying outdoor airflow and characterizing non-functional economizer conditions, additional data would be helpful in corroborating and further characterizing the findings. For example, the laboratory testing referenced in WO32 was conducted on one 7.5-ton two-compressor commercial packaged unit; this could be expanded to encompass packaged units from other manufacturers for additional data points to quantify outdoor airflow at varying damper positions. Regarding further characterization of existing non-functional economizer conditions, WO32 provides the fault distribution for economizers failing closed or partially open but could be broken down further into each typical setting (i.e., 1-finger, 2-finger, 3-finger, fully open).

# Section 2. Calculation Methodology

No measures are taken directly from or created with the DEER READI tool.

READI Data Used

|  |  |  |
| --- | --- | --- |
| **Measure Code** | **Measure Name** | **READI Data** |
| NA | NA | NA |

Energy savings and demand reduction for non-refrigeration models were estimated using eQUEST version 3.64.7130 energy modeling software. The DEER 2014 and 2015 prototypes for the customer average (CAv) case of the Tech IDs shown in the table below were used with some modification (as described in §2.1) to develop base and measure case energy use and demand estimates. DEER prototypes were generated using MASControl v3.00.29[[2]](#endnote-2) for the heat pump relocatable classroom prototypes, MASControl v3.00.27[[3]](#endnote-3) for all remaining prototypes applicable to the DEER 2015 Code Update, and MASControl v3.00.20[[4]](#endnote-4) for the remaining DEER 2014 Code Update prototypes. All modeling was performed using default DEER hours and the CZ2010 weather files[[5]](#endnote-5).

**Table 1 DEER Prototype Tech ID by Measure**

|  |  |  |
| --- | --- | --- |
| **Measure Code** | **Measure** | **DEER Prototype Tech ID** |
| HV054 | Add VFD to AC unit with Gas Heat and ADEC | D08-NE-HVAC-airAC-SpltPkg-110to134kBtuh-11p5eer |
| HV055 | Add VFD and NEMA motor to AC unit with Gas Heat and ADEC |
| HV056 | Add VFD and PMM to AC unit with Gas Heat and ADEC |
| HV063 | Add VFD and ADEC to AC unit with Gas Heat |
| HV064 | Add VFD, NEMA motor, and ADEC to AC unit with Gas Heat |
| HV065 | Add VFD, PMM, and ADEC to AC unit with Gas Heat |
| HV057 | Add VFD to AC unit only and ADEC | \*D08-NE-HVAC-airAC-SpltPkg-110to134kBtuh-11p5eer |
| HV058 | Add VFD and NEMA motor to AC unit only and ADEC |
| HV059 | Add VFD and PMM to AC unit only and ADEC |
| HV066 | Add VFD and ADEC to AC unit only |
| HV067 | Add VFD, NEMA motor, and ADEC to AC unit only |
| HV068 | Add VFD, PMM, and ADEC to AC unit only |
| HV060 | Add VFD to Heat Pump and ADEC | D08-NE-HVAC-airHP-SpltPkg-110to134kBtuh-11p5eer-3p4cop |
| HV061 | Add VFD and NEMA motor to Heat Pump and ADEC |
| HV062 | Add VFD and PMM to Heat Pump and ADEC |
| HV069 | Add VFD and ADEC to Heat Pump |
| HV070 | Add VFD, NEMA motor, and ADEC to Heat Pump |
| HV071 | Add VFD, PMM, and ADEC to Heat Pump |

\* for AC only units, the electric energy savings and demand reduction were assumed to be the same as values for AC units with Gas Heat. Gas energy savings for AC only units were set to zero

DEER prototypes for AC and Heat Pump measures were created using the “110to134kBtuh” cooling capacity range. This capacity range allows prototypes to be generated for the widest range of building types. Savings variation between the size ranges simulated was minimal, and results from a single size range were determined to be an adequate representation for all applicable system size ranges. In addition, larger systems generally operate less efficiently than systems in the selected size range. Savings for larger units of these types are therefore slightly conservative.

**2.1 Base Case Simulations**

Upon examination of the DEER prototypes it was found that several modifications were necessary to estimate baseline energy use for the VFD measure. Work paper authors met with a consultant (Kevin Madison) from the Energy Division Ex-Ante Review Team to develop appropriate baseline assumptions and resulting modifications to the DEER prototypes. The following modifications were agreed upon.

1. A minimum outside air fraction of 20% was used instead of 0% due to emerging research (not yet published at the time of the meeting) that indicates closed damper leakage for packaged HVAC systems are higher than previously thought.
2. A maximum outside air fraction of 70% was used instead of 100% due to emerging research (not yet published at the time of the meeting) that indicates return air damper leakage and exhaust air re-entrainment for packaged HVAC systems are higher than previously thought, leading to inability of most systems to provide 100% outside air.
3. Economizer dry-bulb changeover temperatures were set in accordance with Title 24 2016 Table 140.4B.

Review of WO32 confirmed that these outside air assumptions are consistent with the best available laboratory data and were therefore used to adjust baseline assumptions for this work paper as well. To implement these modifications to the DEER prototypes the specific modifications to eQUEST keywords shown in the following table were performed.

|  |  |  |
| --- | --- | --- |
| **eQUEST Keyword** | **DEER Value** | **Modified Baseline Value** |
| SYSTEM:MIN-OUTSIDE-AIR | Varies | 0.2 |
| SYSTEM:MAX-OA-FRACTION | 1.0 | 0.7 |
| ZONE:OA/FLOW-PER | Varies | Set such that ZONE:OA-FLOW/PER x Peak Occupancy # of People  is between:   1. 0.2 x Supply Air Flow Rate 2. 0.7 x Supply Air Flow Rate   This modification ensures the first two keywords are not overwritten. |
| SYSTEM:OA-CONTROL | FIXED | OA-TEMP  Only in “v75” prototypes where some systems were not affected by DEER 2015 Code Update and could not be created with default economizer baseline. |
| SYSTEM:ECONO-LIMIT-T | Varies | Varies by climate zone from 69°F to 75°F depending on Title 24 2016 Table 140.4B requirement (see table in section 1.1) |

The SYSTEM modifications were applied to every DX-cooling HVAC system in the model except for packaged terminal air conditioners (PTACs) which are unlikely to have economizers and thus economizer damper leakage. The ZONE modification was applied to each conditioned zone served by the affected HVAC systems. The DAY-SCHEDULE modification was only applied to schedules being assigned to SYSTEM:MIN-AIR-SCH and avoids affecting PTAC units assigned to the same schedule by duplicating the DAY-SCHEDULE, renaming and assigning them to the PTAC systems, and only modifying original applicable DAY-SCHEDULE values. Hourly reports were verified to ensure that the keyword changes properly simulated the desired effects of damper leakage for both the occupied and unoccupied periods. The only three building types affected by the omission of PTACs were hospitals (Hsp), hotels (Htl), and universities (EUn).

All the vintage 75 prototypes were modified to include economizer operation with a fixed outdoor air dry bulb temperature limit in accordance with Title 24. The default prototypes for vintage 75 assume a fixed outdoor air damper, while all of the other prototypes use a high dry bulb economizer limit. The economizer adjustment to the vintage 75 prototypes reflects the assumption that the economizer of the unit in question was repaired and properly configured prior to installation of any of these measures.

**2.2 Measure Case Simulations**

To develop measure-case energy use and demand estimates the baseline files (described in section 2.1 above) were further modified to simulate application of a VFD to each system for which a VFD retrofit would result in the benefit of reduced air flow. Keyword changes were not applied to systems that served more than one zone. The table below summarized eQuest keyword changes made.

|  |  |  |
| --- | --- | --- |
| **eQUEST Keyword** | **Baseline Value** | **Measure Value** |
| SYSTEM:FAN-EIR-FPLR | One-speed\_basecase Fan EIR fPLR | * Two-speed\_standard Fan EIR fPLRTwo * Two-speed\_NEMA Fan EIR fPLR * Two-speed\_PMM Fan EIR fPLR |
| SYSTEM:AIR/TEMP-CONTROL | VARIABLE | STAGED-VOLUME |
| SYSTEM:COOL-STAGES[1] | n/a | 0.99 |
| SYSTEM:HEAT-STAGES[1] | n/a | 0.99 |
| SYSTEM:MIN-FLOW-RATIO | 1 | * 0.4 (Standard Motor) * 0.3 (NEMA) * 0.2 (PMM) |
| SYSTEM:MIN-FAN-RATIO | 1 | * 0.4 (Standard Motor) * 0.3 (NEMA) * 0.2 (PMM) |
| SYSTEM:MIN-SUPPLY-T | 50°F | 50°F |
| SYSTEM:MAX-SUPPLY-T | 180°F | 180°F |

**2.3 Electric Energy Savings Estimation Methodologies**

Energy savings and demand reductions were calculated by modeling a base case scenario and a measure case scenario for each of the measures using eQUEST. The savings is the difference in annual electric energy usage, annual gas energy usage, and peak electric power demand between the base case and the measure case.

Enhanced Ventilation and VFD savings may be applied to any unit that meets the program restrictions and guidelines. For units serving building types that are not explicitly included in this work paper, or for units serving a space type that is inconsistent with the building type, the building type whose occupant density and typical schedule most nearly represents it should be selected to estimate savings. For example, a fast food restaurant within a large retail building should claim savings for a fast food restaurant rather than for a large retail building. This ensures that the most accurate savings are applied for a given unit.

The savings calculations represent the average savings per ton of cooling capacity across the population of buildings of a certain type in a given climate zone.

DEER Prototype Models were developed to represent a “customer average” building for each building type, climate zone, and vintage. These models were extracted from the eQUEST DEER model database using the DEER batch processing capability in eQUEST.

Modeling was performed for all climate zones for the seven building vintages shown in the table below, and for each of the building types listed in Section 1.1. Savings were calculated for each vintage and were weighted by the vintage weights in the DEER2014 Energy Impact Weights Tables[[6]](#endnote-6). In order to model the large volume of discrete cases considered, eQUEST batch processing was used.

|  |  |
| --- | --- |
| **DEER Vintage Code** | **Description** |
| v75 | Before 1978 |
| v85 | 1978 - 1992 |
| v96 | 1993 - 2001 |
| v03 | 2002 - 2005 |
| v07 | 2006 - 2009 |
| v11 | 2010 - 2013 |
| v14 | 2014 - 2015 |

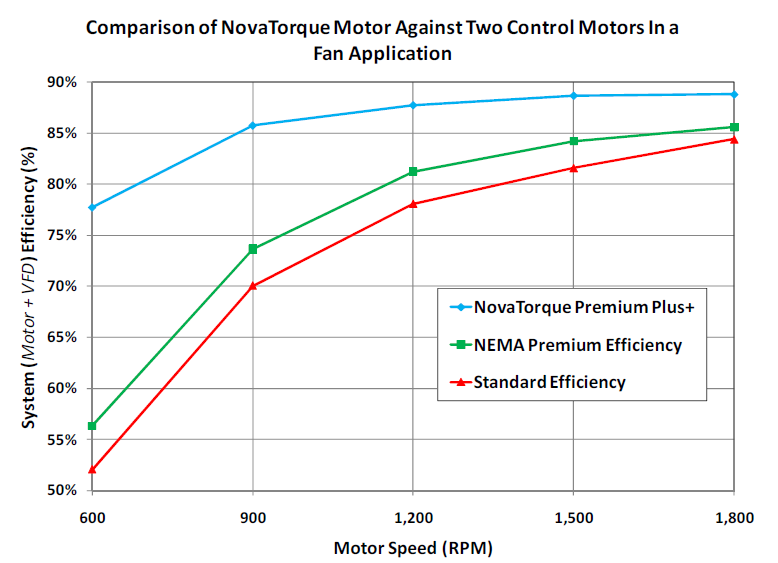
The modeled building types were chosen because they utilize packaged rooftop units. They also represent the majority of commercial buildings that use packaged rooftop units.

**2.3.1 VFD Fan Control with Motor Power Interaction**

To simulate the addition of the variable frequency drive, a custom fan power curve was developed using data from a bench test of 3 horsepower (HP) versions of each of the three types of motors considered in this work paper. The bench test used was performed by ADM Associates[[7]](#endnote-7) for the Sacramento Municipal Utility District (SMUD).[[8]](#endnote-8) At the present time, the NovaTorque Premium Plus is the only PMM designed to operate with a belt driven fan and VFD. This report is particularly applicable since the 3HP motor size is often found on units from 7.5 to 12.5 tons, which is only slightly larger than the smallest units typically serviced in the HVAC Optimization program.

In the bench test report, a typical centrifugal fan curve was used to select the operating points from the bench test data for each of the three motors. The efficiency comparison graph shown in **Figure 1** depicts combined motor and VFD efficiency in a fan application.

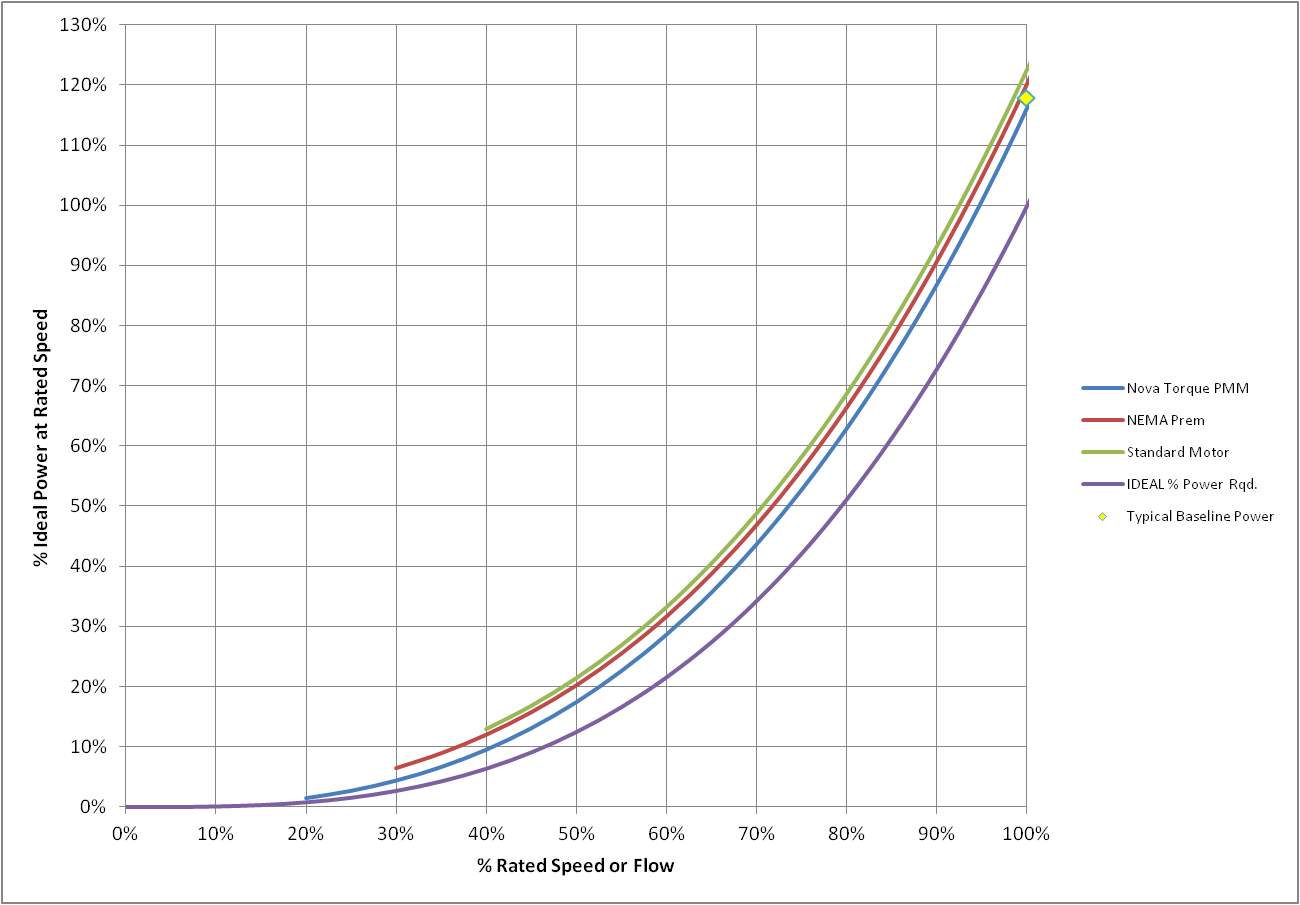
**Figure 1 Combined Motor and VFD Efficiency for 3 HP Standard, Premium, and PMM Motors**



These curves were fit with a cubic polynomial and combined motor and VSD efficiency as a function of percent motor speed. Belt efficiency was also considered, and an additional belt efficiency curve was developed based on data in the BC Hydro Guide to Flexible Drives.[[9]](#endnote-9)

The required percent motor power as a function of percent speed was then calculated by dividing the ideal motor power by the VFD and motor efficiency and V-Belt efficiency. This resulted in the three fan power curves shown in **Figure 2**. Ideal fan power is included as a comparison to the three curves developed for this work paper. Development of the three curves including belt efficiency is documented in the embedded workbook *Fan Power Curves.xls*.[[10]](#endnote-10)

**Figure 2 Fan Power Curves for Standard, Premium, and PMM Motors**

****

Note that the PMM curve extends down to 20% speed, the NEMA Premium to 30%, and the Standard to 40% speed. This reflects the recommended minimum turndown for each type of motor. The minimum recommended turndown was chosen as a conservative number to lower the risk of motor burnout. NovaTorque indicated that the PMM can be turned down to 10% speed with no risk of motor failure, so a 20% minimum was chosen to maintain a conservative savings estimate. These curves also reflect the additional power at full load introduced by the addition of the VFD. The yellow dot at the upper right indicates the base case motor power requirement at full speed for comparison to the three measure cases with the efficiency of the VFD included. The addition of a VFD raises the motor power required at 100% speed to levels higher than the baseline for the standard and NEMA Premium motors, but the improved efficiency of the PMM results in slightly reduced power consumption at full speed even with the addition of a VFD.

In order to simulate fan operation of 2-speeds, the STAGED-VOLUME capability of eQUEST was used. This function allows an air handling unit to operate at different flow rates depending on the heating and cooling demand. The modes that the unit will operate in are: floating (ventilation only), economizer cooling, or full heating/cooling. This function allows the capability of staged capacities, but for the purpose of this measure, one stage of either heating or cooling was used. The energy calculations in eQUEST are on an hourly basis. The unit can operate in various modes during this hour. The calculations account for this through summation of each fraction of an hour per mode to meet space loads. For each mode the air flow and associated part load ratio for the fan will be different. The part load ratio is calculated based on the appropriate fan curve. Fan curves were developed from the PGECOHBC143R0 work paper. Instead of having to develop a fan curve that incorporated the 2-speed fan characteristics, the original fan curves could be used. Hourly reports were verified to ensure the model was operating at discrete flow rates. The following calculation is the method in which eQUEST calculates the part load fan ratio per hour.

**Figure 3: Supply Flow versus Part Load Fan Ratio**

There is a similar relationship for the system supply flow. To demonstrate, the economizing mode was disabled. Therefor the relationship between supply and part load fan ratio is linear. This is demonstrated by the following relationship. **Figure 3** shows the expected linear relationship between supply flow and fan part load ratio developed from simulation hourly reports.

Since the intent was not to simulate fan speed that varies continuously, but rather multiple discrete speed operation varying according to the operating mode of the unit, eQUEST/DOE-2 keywords were selected to limit the fan’s speed and power behavior to closely mimic the intended multiple speed operation. Cooling speed was set at a minimum of 90% speed or the speed that results in no less than 50 °F supply air temperature using the MIN-SUPPLY-T keyword. Heating speed was set at a minimum of 90% speed or the speed that results in no more than 180 °F supply air temperature using the MAX-SUPPLY-T keyword. The ventilation only speed, MIN-FLOW-RATIO, was set to the maximum of 40% for standard induction motors, 30% for NEMA Premium motors, and 20% for PMMs.

The custom fan power curves were used to simulate the three different motor types. Specifically, the cubic polynomial coefficients for the existing models were modified in the batch processor to reflect the coefficients for a cubic polynomial fitted to each fan power curve shown in **Figure 2**.

The following was used for per ton of cooling capacity electric savings calculations. For building types that had multiple system types, the cooling capacity corresponds to the total capacity of the only the systems that were changed.

*Where:*

*kWh per ton savings = annual unit energy savings*

*baseline kWh = annual building energy consumption of customer average baseline*

*measure kWh = annual building energy consumption of measure*

*cooling tons = cooling capacity of units measure was applied to (Btu/h) divided by 12,000 (Btu/h per ton)*

**2.4. Demand Reduction Estimation Methodologies**

Demand reduction is calculated similarly to electric energy savings, however there is an additional calculation step required to estimate peak demand reduction in accordance with DEER peak period definitions. The DEER demand reduction estimation protocol requires average hourly peak demand from a defined time period that varies by climate zone to be determined for the baseline and measure. The time period defined by climate zone is shown in Table 2[[11]](#endnote-11).

**Table 2 DEER 2014 Peak Demand Periods**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| CZ | start month | start day | end month | end day | start hour | end hour |
| 1 | 9 | 16 | 9 | 18 | 15 | 17 |
| 2 | 7 | 8 | 7 | 10 | 15 | 17 |
| 3 | 7 | 8 | 7 | 10 | 15 | 17 |
| 4 | 9 | 1 | 9 | 3 | 15 | 17 |
| 5 | 9 | 8 | 9 | 10 | 15 | 17 |
| 6 | 9 | 1 | 9 | 3 | 15 | 17 |
| 7 | 9 | 1 | 9 | 3 | 15 | 17 |
| 8 | 9 | 1 | 9 | 3 | 15 | 17 |
| 9 | 9 | 1 | 9 | 3 | 15 | 17 |
| 10 | 9 | 1 | 9 | 3 | 15 | 17 |
| 11 | 7 | 8 | 7 | 10 | 15 | 17 |
| 12 | 7 | 8 | 7 | 10 | 15 | 17 |
| 13 | 7 | 8 | 7 | 10 | 15 | 17 |
| 14 | 8 | 26 | 8 | 28 | 15 | 17 |
| 15 | 8 | 25 | 8 | 27 | 15 | 17 |
| 16 | 7 | 8 | 7 | 10 | 15 | 17 |

Hourly peak demand from the nine hours defined for each climate zone is averaged for each climate zone. The following equation is then used to determine demand reduction per ton of cooling capacity.

*Where:*

*kW per ton savings = annual unit demand reduction*

*baseline kW = average demand for DEER peak period of customer average baseline*

*measure kW = average demand for DEER peak period of measure*

*cooling tons = cooling capacity of units measure was applied to (Btu/h) divided by 12,000 (Btu/h per ton)*

**2.5 Gas Energy Savings Estimation Methodologies**

Gas energy savings are calculated similarly to electric energy savings. The gas energy savings from the first baseline are represented in the calculations below.

*Where:*

*therms per ton savings = annual unit energy savings*

*baseline therms = annual building energy consumption of customer average baseline*

*measure therms = annual building energy consumption of measure*

*cooling tons = cooling capacity of units measure was applied to (Btu/h) divided by 12,000 (Btu/h per ton)*

**2.6 Vintage Weighted Average**

Baseline and measure simulations used prototypes for the following seven DEER vintages: v75, v85, v96, v03, v07, v11, and v14. The weighted average electric and gas energy savings, and demand reduction for application of the measure to any vintage were then developed using DEER 2014 vintage weighting tables and procedures. The following equation provides the methodology used to apply the DEER 2014 weights.

*Where:*

*final weighted value=reported UES value (kWh/ton, kW/ton, or therms/ton)*

*i=vintage 75, 85, 96, 03, 07, 11, or 14*

*W=Weight for a given vintage i*

*V=UES Value for a given vintage (kWh/ton, kW/ton, or therms/ton)*

# Section 3. Load Shapes

Load shapes are used for portfolio lifecycle cost analysis. A load shape indicates the distribution of a measure’s energy savings over one year. A load shape is a set of fractions summing to unity, with one fraction per hour (or other time period). Multiplying a savings value by the load shape value for any particular hour yields the energy savings for that particular hour.

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** |
| All | DEER:HVAC\_Split-Package\_AC, DEER:HVAC\_Split-Package\_HP | NON\_RES |

# Section 4. Costs

## 4.1 Base Case Cost

The base case is the customer’s existing equipment; therefore, the base case cost is $0.00..

## 4.2 Measure Case Cost

To develop measure cost estimates a combination of retail, manufacturer suggested retail, and distributor costs were gathered for VFD controllers and motors made by multiple manufacturers. Cost data related to ADEC was developed based on cost information from PGE3PHVC151 Economizer Repair R4. A base labor rate of $86.93 per hour was used and was adjusted to account for local variation. A weighted average cost for the state was developed based on the methodology used for the 2010-2012 WO017 Ex Ante Measure Cost Study Final Report[[12]](#endnote-12). The base labor rate and adjustments are in alignment with the methodology presented in WO017. As a controls upgrade, measure costs do not scale strongly with cooling capacity. To reference cost with the same base unit as UES values (per ton) an average capacity of 12.5 tons was assumed to be the average capacity to which the measure would be applied. For the “Enhanced Ventilation” measures (PG&E SA measure codes), the measure costs are determined by summing the cost of each VFD measure (for adding a VFD to a unit that already has ADEC) and the “DCV + ADEC” measure (for adding DCV and ADEC to a unit) from the PGECOHVC168 (Demand Controlled Ventilation) workpaper.

## 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 |
| NEW/NC |
| RET/ER | (MEC + MLC) – (BEC + BLC) | MEC + MLC | (MEC + MLC) – (BEC + BLC) |
| REF | (MEC + MLC) – (BEC + BLC) | MEC + MLC | N/A |
| 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 Codes** | **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| HV054, HV057, HV060 | REA | $77.15 + $32.21 = $109.36 | $77.15 + $32.21 = $109.36 | N/A |
| HV055, HV058, HV061 | REA | $116.19 + $56.37 = $172.56 | $116.19 + $56.37 = $172.56 | N/A |
| HV056, HV059, HV062 | REA | $125.75 + $56.37 = $182.12 | $125.75 + $56.37 = $182.12 | N/A |
| HV063, HV066, HV069 | REA | $124.01 + $65.64 = $189.65 | $124.01 + $65.64 = $189.65 | N/A |
| HV064, HV067, HV070 | REA | $163.05 + $89.80 = $252.85 | $163.05 + $89.80 = $252.85 | N/A |
| HV065, HV068, HV071 | REA | $172.61 + $89.80 = $262.41 | $172.61 + $89.80 = $262.41 | N/A |
| SA07, SA10 | REA | $156.49 + $97.85 = $254.34 | $156.49 + $97.85 = $254.34 | N/A |
| SA08, SA11 | REA | $195.53 + $122.01 = $317.54 | $195.53 + $122.01 = $317.54 | N/A |
| SA09, SA12 | REA | $205.09 + $122.01 = $327.10 | $205.09 + $122.01 = $327.10 | N/A |

# Attachments

# References

1. California Energy Commission. 2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24, Part 6). Sacramento, California. June 2016 [↑](#endnote-ref-1)
2. James J. Hirsch & Associates. (2017, July 12). *MASControl 3.00.29*. Retrieved from deeresources.com:

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3. James J. Hirsch & Associates. (2014, October 31). *MASControl 3.00.27.* Retrieved from deeresources.com: http://www.deeresources.com/files/DEER2015/download/SetupMASControlX32\_3\_00\_27.msi [↑](#endnote-ref-3)
4. James J. Hirsch & Associates. (2013, September 9). *MASControl 3.00.20*. Retrieved from deeresources.com: http://www.deeresources.com/files/DEER2013codeUpdate/download/SetupMASControlX32\_3\_00\_20.msi [↑](#endnote-ref-4)
5. White Box Technologies, Inc. *CZ2010 Weather Data.* Developed for California Energy Commission. http://weather.whiteboxtechnologies.com/wd-CZ2010 [↑](#endnote-ref-5)
6. James J. Hirsch & Associates. (2014, March 18). DEER2014 Energy Impact Weights Tables v2. Retrieved from deeresources.com: http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EnergyImpact-Weights-Tables-v2.xlsx [↑](#endnote-ref-6)
7. ADM Associates, *NovaTorque Brushless Permanent Magnet Motor Bench Test Final Report*. Sacramento Municipal Utility District, 2010 [↑](#endnote-ref-7)
8. *Install/Program Type*(Courtesy of SCE Strategic Planning and Technical Services, from rev4 Install/Program Typedocument 11/8/11) [↑](#endnote-ref-8)
9. BC Hydro: Guides To Energy Management M310: Flexible Drives. BC Hydro [↑](#endnote-ref-9)
10. *Fan Power Curves.xls* – See Accompanying File [↑](#endnote-ref-10)
11. James J. Hirsch & Associates. (2014, February 11). *DEER2014 — Codes and Standards Update*. Retrieved from deeresources.com: http://deeresources.com/files/DEER2013codeUpdate/download/DEER2014UpdateDocumentation\_2-12-2014.pdf [↑](#endnote-ref-11)
12. Itron. *2010-2012 WO017 Ex Ante Measure Cost Study Final Report.* San Francisco, CA (2014, May 27). Retrived from http://www.calmac.org/publications/2010-2012\_WO017\_Ex\_Ante\_Measure\_Cost\_Study\_-\_Final\_Report.pdf [↑](#endnote-ref-12)