**Work Paper PGECOHVC143**

**Enhanced Ventilation and VFD**

**Revision # 1**

**Pacific Gas & Electric Company**

**Customer Energy Solutions**

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

**Measure Codes HV054 - HV071**

# At-a-Glance Summary

|  |  |
| --- | --- |
| **Applicable Measure Codes:** | HV054 - HV071 |
| **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. |
| **Energy Impact Common Units:** | per ton of cooling capacity. |
| **Base Case Description:** | An existing packaged single zone unit utilizing a constant speed motor for the supply fan. |
| **Base Case Energy Consumption:** | Source: DEER 2014 Prototype energy use with modifications described in §1.4.1. Varies by building type, climate zone, system type |
| **Measure Energy Consumption:** | Source: DEER 2014 Prototype energy use with modifications described in §1.4.1 Varies by building type, climate zone, system type |
| **Energy Savings**  **(Base Case – Measure):** | Source: Base Case – Measure (see above) Varies by building type, climate zone, system type. Averages: 412.4 kWh/ton, 6.24 therms/ton |
| **Costs Common Units:** | $ per ton of cooling capacity |
| **Base Case Equipment Cost ($/unit):** | $0 |
| **Measure Equipment Cost ($/unit):** | Source: Estimate, see §4.2 for estimate detail.  Add VFD control to existing motor: $109/ton  Add VFD and NEMA premium efficiency motor: $173/ton  Add VFD and PMM: $182/ton  Add ADEC and VFD control to existing motor: $207/ton  Add ADEC, VFD, and NEMA premium efficiency motor: $270/ton  Add ADEC, VFD, and PMM: $279/ton |
| **Gross Measure Cost ($/unit)** | Source: Estimate, see §4.3 for estimate detail.  Add VFD control to existing motor: $109/ton  Add VFD and NEMA premium efficiency motor: $173/ton  Add VFD and PMM: $182/ton  Add ADEC and VFD control to existing motor: $207/ton  Add ADEC, VFD, and NEMA premium efficiency motor: $270/ton  Add ADEC, VFD, and PMM: $279/ton |
| **Measure Incremental Cost ($/unit):** | Source: Estimate, see §4.3 for estimate detail.  Add VFD control to existing motor: $109/ton  Add VFD and NEMA premium efficiency motor: $173/ton  Add VFD and PMM: $182/ton  Add ADEC and VFD control to existing motor: $207/ton  Add ADEC, VFD, and NEMA premium efficiency motor: $270/ton  Add ADEC, VFD, and PMM: $279/ton |
| **Effective Useful Life (years):** | Source: DEER 5 Years |
| **Measure Application Type:** | Retrofit Add-On (REA) |
| **Net-to-Gross Ratios:** | Source: DEER |
| **Important Comments:** |  |

# Work Paper Approvals

The following Manager(s) approved this workpaper through the PG&E Electronic Data Routing System under Routing Requisition # \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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| --- |
|  |
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# Document Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Revision #** | **Date** | **Section by Section Description of Revisions** | **Author (Company)** |
| **Revision 0** | **06/01/2012** | **Enhanced Ventilation for Packaged AC** | **Janice Peterson (PECI)**  **Ben Lipscomb (PECI)**  **Judith Jennings (PG&E)** |
| **Revision 0** | **08/29/2012** | **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.** | **Judith Jennings (PG&E)** |
| **Revision 1** | **05/30/2014** | **All sections have been updated. DCV has been removed from the scope of this work paper. New measure codes were added.** | **Scott Jasinski (PECI)**  **Ben Lipscomb (PECI)**  **Sherry Hu (PG&E)** |

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# Section 1. General Measure & Baseline Data

## 1.1 Product 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 totally 18 measures, as in Table 1, 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.

Table 1 Measure List

|  |  |
| --- | --- |
| Measure Code | Measure |
| HV054 | Add VFD with AC unit with Gas Heat and ADEC |
| HV055 | Add VFD and NEMA motor with AC unit with Gas Heat and ADEC |
| HV056 | Add VFD and PMM with AC unit with Gas Heat and ADEC |
| HV057 | Add VFD with AC unit only and ADEC |
| HV058 | Add VFD and NEMA motor with AC unit only and ADEC |
| HV059 | Add VFD and PMM with AC unit only and ADEC |
| HV060 | Add VFD with Heat Pump and ADEC |
| HV061 | Add VFD and NEMA motor with Heat Pump and ADEC |
| HV062 | Add VFD and PMM with 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 with AC unit only |
| HV068 | Add VFD, PMM, and ADEC with 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 |

The rebate is downstream provided to the contractor at the time of installation upon receipt of application and invoice. This is a Direct Install program.

***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 2013 §140.4 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 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]
* 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 2013 Table 140.4-B[[1]](#endnote-1), adapted below in Table 2 for reference.
* Maintenance, and repairs to economizer should be completed prior to or in conjunction with this measure.

Table 2 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 2013 Table 140.4-B1. Refer to source for additional detail.

***Market Applicability:***

This upgrade measure for existing equipment provides a direct install rebate to contractors 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.

## 1.2 Product 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 2013. 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 of 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.[[2]](#endnote-2)

## 1.3 Measure Application Type

The DEER Measure Cost Data Users Guide found on [www.deeresources.com](http://www.deeresources.com) under *DEER2011 Database Format* hyperlink, DEER2011 for 13-14, spreadsheet *SPTdata\_format-V0.97.xls*, defines the terms as follows:

Table 3 Measure Application Type[[3]](#endnote-3)

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

|  |  |  |
| --- | --- | --- |
| Code | Description | Comment |
| REA | Retrofit Add-on | *Measure did not exist and was not requested by codes* |

This measure is replaces existing equipment and also adds controls for existing units it is an Early Retirement application, meaning 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 2013 §120.1 requires 2-speed fan control for single zone packaged units. The UES values are not appropriate for ROB or NC applications.

## 1.4 Product Base Case and Measure Case Data

## 1.4.1 DEER Base Case and Measure Case Information

Energy savings and demand reduction were estimated using eQUEST version 3.64[[4]](#endnote-4) energy modeling software. The DEER 2014[[5]](#endnote-5) prototypes for the customer average case of the Tech IDs shown in Table 4 were used with some modification to develop baseline energy use and demand estimates. All DEER prototypes were generated using MASControl v3.00.19[[6]](#endnote-6), and used the CZ2010 weather files[[7]](#endnote-7).

Table 4 DEER Prototype Tech ID by Measure

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

\* 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.

The DEER prototypes for the “110to134kBtuh” cooling capacity range were chosen as the representative prototypes for systems to which the measure would apply. Initially simulations included DEER prototypes for smaller and larger cooling capacities, but savings were not sensitive to small differences in performance for different capacity ranges. 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.

Based on the PGECOHVC168 Demand Controlled Ventilation R0 work paper analysis, the following modifications were necessary to estimate baseline energy use for Enhanced Ventilation and VFD.

1. A minimum outside air fraction of 20% was used instead of 0% due to emerging research (not yet published) 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) 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 2013 Table 140.4B.

To implement these modifications to the DEER prototypes the specific modifications to eQUEST keywords shown in Table 5 were performed for the baseline.

Table 5 Baseline modifications to eQuest keywords

|  |  |  |
| --- | --- | --- |
| eQuest Keyword | DEER Value | Modified Baseline Value |
| SYSTEM:MIN-OUTSIDE-AIR | Varies | 0.2 |
| SYSTEM:MAX-OA-FRACTION | 1.0 | 0.7 |
| SYSTEM:ECONO-LIMIT-T | Varies | Varies by climate zone from 69°F to 75°F depending on Title 24 2013 Table 140.4B requirement |

### Measure Simulations

To develop measure-case energy use and demand estimates the modified baseline files 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.

Table 6 Measure-case eQUEST keyword modifications

|  |  |  |
| --- | --- | --- |
| 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 |

### Effective Useful Life / 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. Table 7 provides DEER EUL and RUL data for packaged HVAC systems.

Table 7 Effective Useful Life: DEER Version and Impact IDs

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Building type | Bldg Vintage | Climate Zone | EUL (yrs) | RUL (yrs) | DEER Version | Impact IDs |
| **All** | **All** | **All** | **15** | **5** | **2014** | **HVAC-airHP,**  **HVAC-airAC** |

### In-service rate/first year installation rate:

Since this is a new measure with no available DEER or energy measurement and verification (EM&V) data available the In-service rate is 1.0.

## 1.4.2 Codes & Standards Requirements Base Case and Measure Information

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 2013 provides economizer control and general ventilation that are considered to be best practice and are provided here for reference.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Title 24 Std. Description | Base or Measure Case | Value | Units | Code Source or Reference |
| Economizer high limit control | Base Case | High limit shut-off control requirements by device type and climate zone | °F, Btu/lb | Title 24 2013 Table 140.4-B |

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

Data currently being finalized in Work Order 32 EM&V[[8]](#endnote-8) research of HVAC programs informed assumptions for economizer minimum and maximum outside air rate assumptions discussed in 1.4.1.

## 1.4.4 Assumptions and Calculations from other sources—Base and Measure Cases

There are no further data or calculations provided for the support of the measures in this workpaper.

***1.4.5 Time-of-Use Adjustment Factor***

CPUC decision 06-06-063 dated June 29, 2006 requires time-of-use (TOU) adjustment factors on residential A/C and commercial A/C (packaged and split-system direct-expansion cooling) measures only. Additionally, if a measure is assigned a DEER08 load shape, i.e. the load shape starts with “DEER:” the TOU assigned to that measure should also be zero. Since these measures are assigned a DEER08 load shape, the TOU assigned to the measures is zero as shown in Table 8 below.

Table 8 TOU Adjustment Factors

|  |  |  |  |
| --- | --- | --- | --- |
| Measure | kWAC | kWTotal | % |
| Add VFD with AC unit with Gas Heat and ADEC | 0 | 0 | 0 |
| Add VFD and NEMA motor with AC unit with Gas Heat and ADEC | 0 | 0 | 0 |
| Add VFD and PMM with AC unit with Gas Heat and ADEC | 0 | 0 | 0 |
| Add VFD with AC unit only and ADEC | 0 | 0 | 0 |
| Add VFD and NEMA motor with AC unit only and ADEC | 0 | 0 | 0 |
| Add VFD and PMM with AC unit only and ADEC | 0 | 0 | 0 |
| Add VFD with Heat Pump and ADEC | 0 | 0 | 0 |
| Add VFD and NEMA motor with Heat Pump and ADEC | 0 | 0 | 0 |
| Add VFD and PMM with Heat Pump and ADEC | 0 | 0 | 0 |
| Add VFD and ADEC to AC unit with Gas Heat | 0 | 0 | 0 |
| Add VFD, NEMA motor, and ADEC to AC unit with Gas Heat | 0 | 0 | 0 |
| Add VFD, PMM, and ADEC to AC unit with Gas Heat | 0 | 0 | 0 |
| Add VFD and ADEC to AC unit only | 0 | 0 | 0 |
| Add VFD, NEMA motor, and ADEC with AC unit only | 0 | 0 | 0 |
| Add VFD, PMM, and ADEC with AC unit only | 0 | 0 | 0 |
| Add VFD and ADEC to Heat Pump | 0 | 0 | 0 |
| Add VFD, NEMA motor, and ADEC to Heat Pump | 0 | 0 | 0 |
| Add VFD, PMM, and ADEC to Heat Pump | 0 | 0 | 0 |

***1.5 Summary of Inputs for Savings Calculations***

The following table provides references to sections that document the inputs for calculation:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Input Variable** | **Variations** | **Base Case 1 Average Value** | **Base Case 2 Average Value** | **Measure Case Average Value** | **Reference Section** |
| **Electric Savings** | CZ, BT, Utility | 0 | 0 | 412.4 kWh/ton | Section 1.4.1 |
| **Gas Savings** | CZ, BT, Utility | 0 | 0 | 6.24 therms/ton | Section 1.4.1 |
| **Hours of operation** | BT | 88 | 88 | 88 | Section 1.4.1 |
| **Full Cost** | Measure Code | 0 | 0 | varies, $109 - $279 per ton | Section 4.3 |
| **Incremental Cost** | Measure Code | 0 | 0 | varies, $109 - $279 per ton | Section 4.3.2 |
| **EUL /RUL** | One | 5 | 15 | 5 | Section 1.4.1 |
| **NTG** | One | TBD | TBD | TBD | Section 1.4.1 |
| **ISR** | Yes | 1 | 1 | 1 | Section 1.4.1 |
| **TOU Factor** | One | 0 | 0 | 0 | Section 1.4.5 |

# Section 2. Calculation Methods

Table 9 Baseline by Measure Application Type

|  |  |  |  |
| --- | --- | --- | --- |
| ****Measure Application Type**** | ****Measure Life Basis**** | ****First Baseline Period: Energy Savings Baseline**** | ****Second Baseline Period: Energy Savings Baseline**** |
| REA (retrofit add-on) | **RUL** | Existing/Customer Average Baseline | N/A |

Notes:

* For REA measures, First Baseline is the baseline for the RUL. There is no second baseline.

## 2.1 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 six building vintages shown in Table 10, and for each of the building types listed in Table 11**.** Savings were calculated for each vintage and were weighted by the vintage weights in *DEER08 Building Weights.xls*.[[9]](#endnote-9) In order to model the large volume of discrete cases considered, eQUEST batch processing was used.

Table 10 DEER Prototype Building Vintages and Abbreviations

|  |  |
| --- | --- |
| **Vintage** | **Abbreviated Vintage Name** |
| Before 1978 | v75 |
| 1978 - 1992 | v85 |
| 1993 - 2001 | v96 |
| 2002 - 2005 | v03 |
| 2006 – 2009 | v07 |
| 2010 – 2011 | v11 |

Table 11 DEER Building Types Modeled

|  |  |
| --- | --- |
| **Building Type** | **Abbreviated Building Type** |
| Assembly | ASM |
| Education: Primary School | EPR |
| Education – Secondary School | ESE |
| Education – Community College | ECC |
| Education – University | EUN |
| Health/Medical – Hospital | HSP |
| Health/Medical – Nursing Home | NRS |
| Lodging – Hotel | HTL |
| Manufacturing – Bio/Tech | MBT |
| Large Office | OFL |
| Small Office | OFS |
| Restaurant – Fast Food | RFF |
| Restaurant – Sit-Down | RSD |
| Retail – 3-Story Large | RT3 |
| Retail – Large | RTL |
| Retail – Small | RTS |
| Storage – Conditioned | SCN |

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.

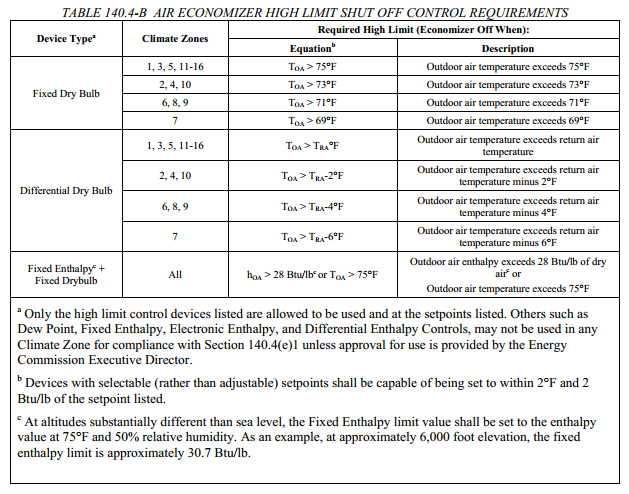
The assumptions and modeling methodologies used for the base case and each of the measures are detailed below. This section refers extensively to eQUEST/DOE-2 keywords, which are defined and detailed in the *DOE-2 Dictionary*.[[10]](#endnote-10)

### Base Case

The base case models are the DEER “customer average” building prototypes. They were modified to update the weather file from Typical Meteorological Year Version 2 (TMY2) to TMY3 weather data in an effort to use the most recent and relevant weather data available.

Besides the weather file modification, all of the Vintage 75 prototypes were modified to include economizer operation with a fixed outdoor air dry bulb temperature limit in accordance with Title 24 as shown in Figure 1 below**.** 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 in accordance with Title 24. 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.

Figure 1 Title 24 Economizer High Limit Requirements

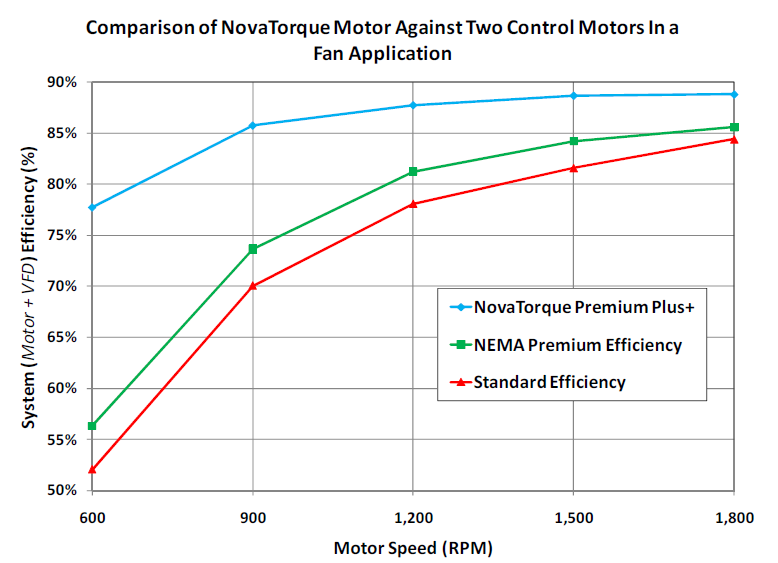


### VFD Fan Control with Motor Power Interaction

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[[11]](#endnote-11) for the Sacramento Municipal Utility District (SMUD).[[12]](#endnote-12) 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 2 depicts combined motor and VFD efficiency in a fan application.

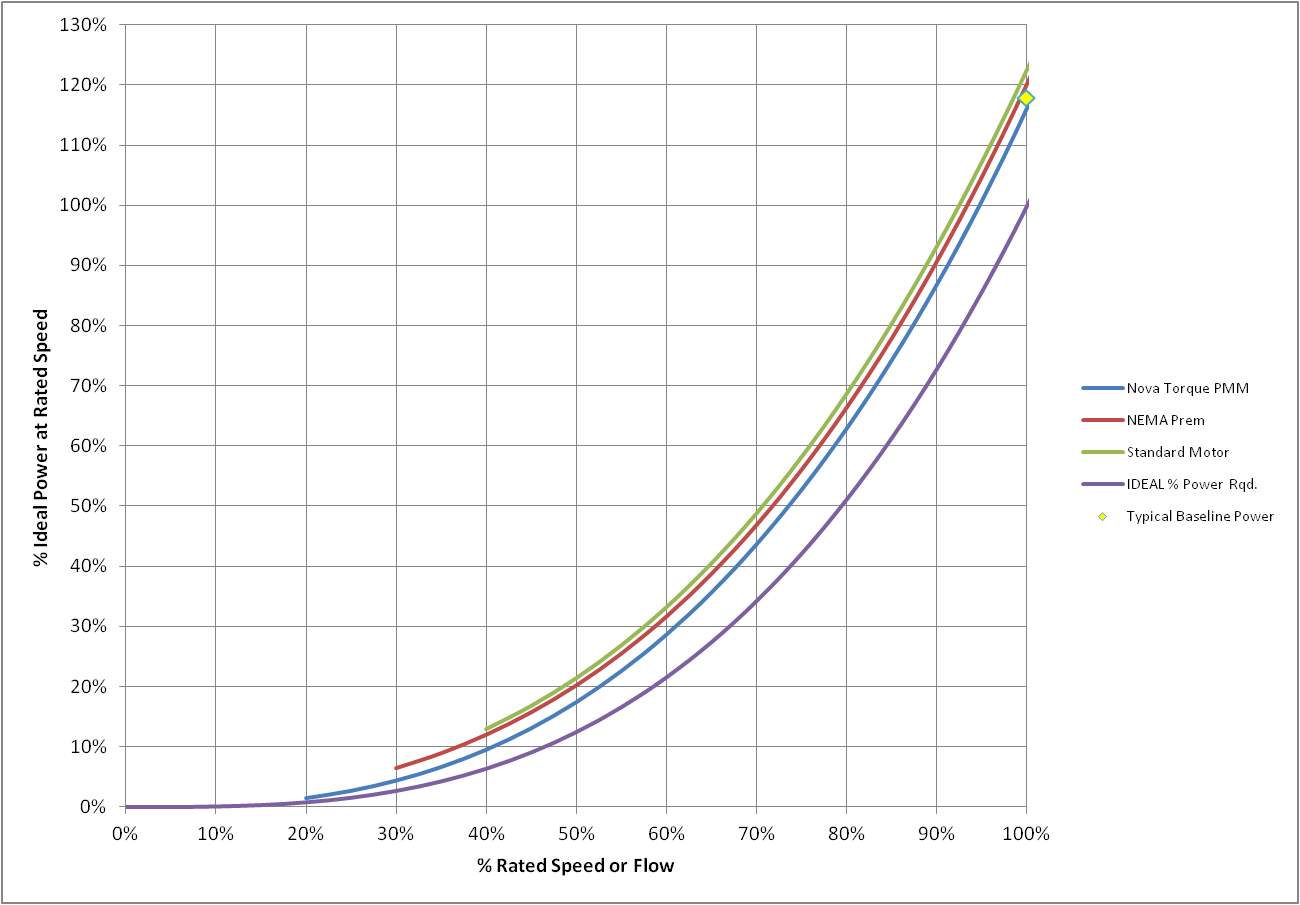
Figure 2 Combined Motor and VFD Efficiency for 3 HP Standard, Premium, and PMM Motors



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.[[13]](#endnote-13)

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 3. 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*.[[14]](#endnote-14)

Figure 3 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 4: 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 4 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 CMIN-FLOW-RATIO and MIN-SUPPLY-T keywords. 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 HMIN-FLOW-RATIO and MAX-SUPPLY-T keywords. 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 3.

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)*

## 2.2. 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 12[[15]](#endnote-15).

Table 12 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)*

## 2.3 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)*

## 2.4 Vintage Weighted Average

Baseline and measure simulations used prototypes for the following 6 DEER vintages: v75, v85, v96, v03, v07, and v11. 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, or 11*

*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*

## 3.1 Base Case Load Shapes

The difference between the base case load shape and the measure load shape would be the most appropriate load shape; however, only end-use profiles for some sectors are available. Therefore, the closest load shape chosen for this measure is the DEER:HVAC\_Eff\_AC load shape as shown in Table 13.

Table 13 Building Types and Load Shapes

|  |  |  |
| --- | --- | --- |
| **Building Type** | **E3 Alt. Building Type** | **Load Shape** |
| All | Non\_Res | DEER:HVAC\_Eff\_AC |

## 3.2 Measure Load Shapes

There are no measure case load shapes applicable to this(ese) measure(s). The base case shapes are to be used in the cost avoidance calculation.

# Section 4. Base Case & Measure Costs

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure Application Type** | **Measure Life Basis** | **First Baseline Period Gross Measure Cost (RUL)** | **Second Baseline Period Gross Measure Cost (EUL – RUL)** |
| ***NC (new construction)*** | EUL | Calculated as Incremental Measure Cost | N/A |
| ***ROB(replace on burnout)*** | EUL | Calculated as Incremental Measure Cost | N/A |
| ***ER (early retirement)*** | RUL/  EUL-RUL | Calculated as Full Gross Measure Cost | Calculated as Negative Full Gross Base Case Cost |
| ***REA(Retrofit Add-on)*** | RUL | Calculated as Full Measure Cost | N/A |

## 4.1 Base Case(s) Costs

The following Measure Application Types is are appropriate to these measures. The Base Case Costs are:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *Measure Codes* | Measure Application Type | Baseline | Equipment Cost ($) | Labor / Installation Cost ($) | Maintenance / Other Cost ($) | Total Base Case Cost ($) |
| HVC054 - 071 | REA | Existing | 0 | 0 | 0 | 0 |

*All costs are noted as $ per measure unit*

Since this is an REA application for a retrofit on existing equipment, the base case cost is zero.

## 4.2 Measure Case Costs

To develop measure cost estimates a combination of retail, manufacturer suggested retail, and distributor prices were gathered for ADEC, VFD controllers, and motors made by multiple manufacturers. Cost data related to ADEC was developed based on cost information from PGECOHVC168 Demand Controlled Ventilation R0. 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 Draft DEER Measure Cost Update[[16]](#endnote-16) The base labor rate and adjustments are in alignment with the methodology presented in the Draft DEER Measure Cost Update. 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. Detailed cost calculations are documented in *ENV\_VFD+ADEC cost data.xlsx[[17]](#endnote-17).*

Table 14 Measure Cost Data

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Measure Codes | Measure | Measure Material Cost ($) | Labor Cost ($) | Measure Cost ($) | Avg. tonnage | Measure Material Cost ($/ton) | Labor Cost ($/ton) | Measure Cost ($/ton) |
| HV054, HV057, HV060 | Add VFD to unit with ADEC | $964.40 | $402.67 | $1,367.08 | 12.5 | $77.15 | $32.21 | $109.37 |
| HV055, HV058, HV061 | Add VFD and NEMA motor to unit with ADEC | $1,452.36 | $704.68 | $2,157.04 | 12.5 | $116.19 | $56.37 | $172.56 |
| HV056, HV059, HV061 | Add VFD and PMM to unit with ADEC | $1,571.89 | $704.68 | $2,276.57 | 12.5 | $125.75 | $56.37 | $182.13 |
| HV063, HV066, HV069 | Add VFD and ADEC to unit | $1,778.68 | $805.35 | $2,584.03 | 12.5 | $142.29 | $64.43 | $206.72 |
| HV064, HV067, HV070 | Add VFD, NEMA motor, and ADEC to unit | $2,266.63 | $1,107.36 | $3,373.99 | 12.5 | $181.33 | $88.59 | $269.92 |
| HV065, HV068, HV071 | Add VFD, PMM, and ADEC to unit | $2,386.16 | $1,107.36 | $3,494.52 | 12.5 | $190.89 | $88.59 | $279.48 |

## 4.3 Incremental & Full Measure Costs

Table 15 Incremental & Full Measure Costs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Measure Codes | Measure Application Type | Measure Cost | Base Case Cost | Incremental Measure Cost |
| HV054, HV057, HV060 | REA | $109.37 | $0 | $109.37 |
| HV055, HV058, HV061 | REA | $172.56 | $0 | $172.56 |
| HV056, HV059, HV061 | REA | $182.13 | $0 | $182.13 |
| HV063, HV066, HV069 | REA | $206.72 | $0 | $206.72 |
| HV064, HV067, HV070 | REA | $269.92 | $0 | $269.92 |
| HV065, HV068, HV071 | REA | $279.48 | $0 | $279.48 |

# *4.3.1 Gross Measure Cost*

Gross Measure Cost is the cost to install an energy efficient measure per the CPUC calculators. This definition implies a different meaning depending on the Measure Application type.

This measure’s Measure Application Type is REAfor the First baseline period only (RUL), so the Gross Measure Cost (GMC) is represented by the equation below:

GMC = Measure Equipment Cost + Measure Labor Cost

*GMC = $ per (unit) + $ per (unit) = $ per(unit)*

For **REA** in the second baseline period (EUL – RUL) period, there is no GMC needed.

\*Note: Various complicated price fluctuations are not addressed in these equations, such as future costs due to inflation in labor, future costs due to deflation in material cost, and other variables that cannot be accurately described at this time.

# *4.3.2 Incremental Measure Costs*

Incremental Measure Cost is the premium cost to install an energy efficient measure over a standard efficiency measure or code baseline measure. While IMC has a straightforward definition depending on the Measure Application type, the equation does vary.

This Measure Application Types is **REA.** There is no base case to which to compare the measure, so the Incremental Measure Cost (IMC) is represented by the equation below:

IMC = Measure Equipment Cost + Measure Labor Cost

*IMC = $ per (unit)+ $ per (unit) = $ per (unit)*

Table 16 Summary Table for Section 4

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Measure ID | Measure Application Types | Base Case Total Cost ($) | Measure Case Total Cost ($) | Gross Measure Case Cost ($) | Incremental Measure Cost ($) |
| HV054, HV057, HV060 | REA | 0 | $109.37 | $109.37 | $109.37 |
| HV055, HV058, HV061 | REA | 0 | $172.56 | $172.56 | $172.56 |
| HV056, HV059, HV061 | REA | 0 | $182.13 | $182.13 | $182.13 |
| HV063, HV066, HV069 | REA | 0 | $206.72 | $206.72 | $206.72 |
| HV064, HV067, HV070 | REA | 0 | $269.92 | $269.92 | $269.92 |
| HV065, HV068, HV071 | REA | 0 | $279.48 | $279.48 | $279.48 |

# References

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2. Personal communication (phone call) with Shams Shaikh of NovaTorque, Inc. [↑](#endnote-ref-2)
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14. *Fan Power Curves.xls* – See Accompanying File [↑](#endnote-ref-14)
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