HVAC

ENHANCED VENTILATION FOR PACKAGED HVAC

SWHC023-01

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MEASURE NAME

Enhanced Ventilation for Packaged HVAC

STATEWIDE MEASURE ID

SWHC023-01

TECHNOLOGY SUMMARY

This measure pertains the addition of a variable frequency drive (VFD) to an existing packaged single-zone direct expansion (DX) HVAC unit with 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.

MEASURE CASE DESCRIPTION

The measure case is defined as the addition of a variable frequency drive (VFD) 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.

The measure offerings (below) specify the addition of 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.

Measure Offerings

Statewide Measure Offering ID	Measure Offering Description
SWHC023A	AC unit with Gas Heat, Add VFD
SWHC023B	AC unit with Gas Heat, Add VFD and NEMA
SWHC023C	AC unit with Gas Heat, Add VFD and PMM
SWHC023D	AC unit only, Add VFD
SWHC023E	AC unit only, Add VFD and NEMA
SWHC023F	AC unit only, Add VFD and PMM
SWHC023G	Heat Pump, Add VFD
SWHC023H	Heat Pump, Add VFD and NEMA
SWHC023I	Heat Pump, Add VFD and PMM
SWHC023J	AC unit with Gas Heat, Add VFD and ADEC
SWHC023K	AC unit with Gas Heat, Add VFD, NEMA, and ADEC
SWHC023L	AC unit with Gas Heat, Add VFD, PMM, and ADEC
SWHC023M	AC unit only, Add VFD and ADEC
SWHC023N	AC unit only, Add VFD, NEMA, and ADEC
SWHC023O	AC unit only, Add VFD, PMM, and ADEC
SWHC023P	Heat Pump, Add VFD and ADEC
SWHC023Q	Heat Pump, Add VFD, NEMA, and ADEC
SWHC023R	Heat Pump, Add VFD, PMM, and ADEC

Statewide Measure Offering ID	Measure Offering Description
SWHC023S	AC unit with Gas Heat, HVAC Enhanced Vent, CO2 Sensor, Add VFD and ADEC
SWHC023T	AC unit with Gas Heat, HVAC Enhanced Vent, CO2 Sensor, Add VFD, NEMA, and ADEC
SWHC023U	AC unit with Gas Heat, HVAC Enhanced Vent, CO2 Sensor, Add VFD, PMM, and ADEC
SWHC023V	Heat Pump, HVAC Enhanced Vent, CO2 Sensor, Add VFD and ADEC
SWHC023W	Heat Pump, HVAC Enhanced Vent, CO2 Sensor, Add VFD, NEMA, and ADEC
SWHC023X	Heat Pump, HVAC Enhanced Vent, CO2 Sensor, Add VFD, PMM, and ADEC

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	Not applicable.
Industry Standard Practice	Not applicable.

This fan motor and control upgrade for existing units is an add-on equipment application, meaning the unit energy savings (UES) values provided are developed for an existing system without a two-speed fan as the baseline. There are no above-code savings, as the 2016 California Building Energy Efficiency Standards (Title 24)[1] §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.

BASE CASE DESCRIPTION

The base case is defined as the existing single-zone direct expansion (DX) HVAC unit with a function economizer without a variable frequency drive (VFD).

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 roof top unit (RTU) supply fans, are less susceptible to motor failures due to overheating at low

[1] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. CEC-400-2015-037-CMF.

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 manufacturer 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.

CODE REQUIREMENTS

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 the HVAC system. However, Title 24 2016 provides economizer control and general ventilation requirements that are considered to be best practice and are listed below for reference.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20 (2016)	None.	
CA Building Energy Efficiency Standards – Title 24 (2016)	Table 140.4-B: High limit shut-off control requirements by device type and climate zone §120.1: Minimum ventilation requirements	January 1, 2017
Federal Standards	None.	

NORMALIZING UNIT

Per ton cooling capacity (Cap-ton)

PROGRAM REQUIREMENTS

Measure Implementation Eligibility

All combinations of measure application type, delivery type, and sector that are established for this measure are specified below. Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial incentives or other services) is targeted. This table also designates the broad market sector(s) that are applicable for this measure.

Note that some of the implementation combinations below may not be allowed for some measure offerings by all program administrators.

Implementation Eligibility

Measure Application Type	Delivery Type	Sector
Add-on equipment	DnDeemed	Com
Add-on equipment	DnDeemDI	Com
Add-on equipment	DnDeemed	Ind
Add-on equipment	DnDeemDI	Ind

Eligible Products

This measure requires field documentation of the existing conditions that verify the measure was necessary and that the measure was successfully applied.

This measure must replace existing equipment with the addition of controls for existing units.

Contractors and technicians that implement these measures must ensure that the existing unit does not already have these measures.

Implementation requires proper setup of the damper limits and fan speeds in order to provide ventilation in accordance with Title 24 2016 (see Code requirements). 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 operating modes, including heating and cooling for each stage as well as the ventilation only mode.

Terms and conditions are noted below. Other terms and conditions are set by individual programs.

- The existing system must be packaged single zone DX cooling unit with gas heat, cooling only unit, or heat pump.
- The existing system must have a constant volume supply fan.
- The 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[2]

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

Eligible Building Types and Vintages

This measure is applicable for all nonresidential buildings served by unitary direct expansion (DX) and split systems that do not serve process or refrigeration loads. The target market for this measure includes commercial buildings served by packaged single zone HVAC units, sometimes referred to as rooftop units (RTUs).

Eligible Climate Zones

This measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

The UES values for this measure are not appropriate for normal replacement or new construction applications.

This measure does not apply if the rooftop unit (RTU) has a fully operational and/or non-snapdisc sensor and is adjusted to the appropriate changeover setpoint based on the number of thermostat stages available for cooling.

This measure does not apply if the unoccupied supply fan operation is already set to “Auto” or intermittent.

USE CATEGORY

HVAC

[2] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. CEC-400-2015-037-CMF. Table 140.4-B.

DATA COLLECTION REQUIREMENTS

Data requirements are to be determined.

ELECTRIC SAVINGS (kWh)

Energy savings and demand reduction were derived from baseline and measure case building energy use simulations using eQUEST version 3.65-7175 energy modeling software[3]. The Database for Energy Efficient Resources (DEER) 2020 basecase prototypes of the DEER Energy Impact IDs shown below were used to develop base and measure case energy use and demand estimates. DEER prototypes were generated using MASControl3 software. All modeling was performed using the CZ2010 weather files.

Statewide Measure Offering IDs and DEER Energy Impact IDs

Statewide Measure Offering ID	Measure Offering Description	DEER Energy Impact ID
SWHC023A	Add VFD to AC unit with Gas Heat and ADEC	NE-HVAC-airAC-SpltPkg-135to239kBtuh-11p5eer
SWHC023B	Add VFD and NEMA motor to AC unit with Gas Heat and ADEC	
SWHC023C	Add VFD and PMM to AC unit with Gas Heat and ADEC	
SWHC023D	Add VFD and ADEC to AC unit with Gas Heat	
SWHC023E	Add VFD, NEMA motor, and ADEC to AC unit with Gas Heat	
SWHC023F	Add VFD, PMM, and ADEC to AC unit with Gas Heat	
SWHC023G	Add VFD to AC unit only and ADEC	* NE-HVAC-airAC-SpltPkg-135to239kBtuh-11p5eer
SWHC023H	Add VFD and NEMA motor to AC unit only and ADEC	
SWHC023I	Add VFD and PMM to AC unit only and ADEC	
SWHC023J	Add VFD and ADEC to AC unit only	
SWHC023K	Add VFD, NEMA motor, and ADEC to AC unit only	
SWHC023L	Add VFD, PMM, and ADEC to AC unit only	
SWHC023M	Add VFD to Heat Pump and ADEC	NE-HVAC-airHP-SpltPkg-135to239kBtuh-11p5eer-3p2cop
SWHC023N	Add VFD and NEMA motor to Heat Pump and ADEC	
SWHC023O	Add VFD and PMM to Heat Pump and ADEC	
SWHC023P	Add VFD and ADEC to Heat Pump	
SWHC023Q	Add VFD, NEMA motor, and ADEC to Heat Pump	
SWHC023R	Add VFD, PMM, and ADEC to Heat Pump	

[3] Pacific Gas and Electric Company (PG&E). 2019. "SWHC023-01 Model Files.zip."

* 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 following modifications were made to the DEER prototypes to represent the base case for the DCV measure offerings:

1. Economizer dry-bulb changeover temperatures were set in accordance with Title 24 2019 Table 140.4-E.

To implement these modifications to the DEER prototypes the specific modifications to eQUEST keywords shown in Table 2 were performed.

Baseline eQUEST Keyword Modifications

eQUEST Keyword	DEER Value	Modified Baseline Value
SYSTEM:ECONO-LIMIT-T	Varies	Varies by climate zone from 69°F to 75°F depending on Title 24 2019 Table 140.4-E requirement

To develop measure-case energy use and demand estimates the baseline files (described 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 summarizes eQUEST keyword changes made.

DEER2020 Grocery building prototypes are run using the DOE2.2R refrigeration engine, which differs slightly from the DOE2.3 engine that other building prototypes use. The enhanced ventilation model for other building types was simulated as a two-speed fan control with staged volume for HVAC packaged units. DOE2.2R does not support the SYSTEM: AIR/TEMP-CONTROL keyword STAGE-VOLUME for HVAC packaged units. Thus, the enhanced ventilation measure was simulated using two-speed fan control only. The cooling load for the HVAC system serving the sales area was analyzed and it was found that the HVAC system compressors were operating for a minimal amount of time. The majority of the cooling load was handled by the commercial refrigeration system. The HVAC systems fans were operational at low speeds for a majority of hours to maintain minimum ventilation requirements. Therefore, using two-speed fan control was deemed reasonable. Refer to the table below for details on the Grocery model baseline and measure value changes.

Furthermore, non-grocery measures adopted DCV savings from previous PG&E workpaper PGECOHVC168[4]. The PGECOHVC168 workpaper did not include savings for Grocery building types because DOE2.2R has limitations in modelling of DCV measures. Thus, the methodology for modelling DCV from PGECOHVC168 was modified for grocery measures to accommodate for the limitations of DOE2.2R engine. The changes are stated in the table below.

[4] Pacific Gas and Electric (PG&E). 2018. "PGECOHVC168 R2 Demand Controlled Ventilation.docx".

Measure eQUEST Keyword Modifications

eQUEST Keyword	Baseline Value (except GRO)	Measure Value (except GRO)	Grocery Baseline Value	Grocery Measure Value
SYSTEM:FAN-EIR-FPLR	One-speed_basecase Fan EIR fPLR	Two-speed_standard Fan EIR fPLR Two-speed_NEMA Fan EIR fPLR Two-speed_PMM Fan EIR fPLR	One-speed_basecase Fan EIR fPLR	Two-speed_standard Fan EIR fPLR Two-speed_NEMA Fan EIR fPLR Two-speed_PMM Fan EIR fPLR
SYSTEM:AIR/TEMP-CONTROL	VARIABLE	STAGED-VOLUME	Unable to implement in DOE2.2R	Unable to implement in DOE2.2R
SYSTEM:COOL-STAGES	n/a	0.99	Unable to implement in DOE2.2R	Unable to implement in DOE2.2R
SYSTEM:HEAT-STAGES	n/a	0.99	Unable to implement in DOE2.2R	Unable to implement in DOE2.2R
SYSTEM:MIN-FLOW-RATIO	1	0.4 (Standard Motor) 0.3 (NEMA) 0.2 (PMM)	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)	1	0.4 (Standard Motor) 0.3 (NEMA) 0.2 (PMM)
SYSTEM:MIN-SUPPLY-T	50 °F	50 °F	50 °F	50 °F
SYSTEM:MAX-SUPPLY-T	180 °F	180 °F	180 °F	180 °F
ZONE:OA/FLOW-PER	n/a	n/a	n/a	Set Minimum Outside Air to 0.2 CFM/sfm for Kitchen and Sales Floor areas based on 2019 T24 Table 120.1-A. These values were verified to be acceptable based on

				ASHRAE 62.1 2016[5] minimum air flows.

Vintage Weighted Average

The baseline and measure case building energy use simulations used the DEER building vintages[6] (below) for both customer average and code prototypes.

DEER Building Vintage Codes and Descriptions

DEER Vintage Code	Description
Ex	Non-Mobile Homes 2002 - 2016; default vintage for existing buildings
V03	Existing building stock built between 2002 and 2005
V07	Existing building stock built between 2006 and 2009
V11	Existing building stock built between 2010 and 2013
V15	Existing building stock built between 2014 and 2016
2020 (New)	New Construction (not yet built)

DEER 2020 vintage weighting tables and procedures were used to appropriately weight the unit energy savings and demand reduction for each measure offering, according to each vintage per IOU, building type, and climate zone. The following equation describes the DEER 2014 weighting methodology.

$$final\ weighted\ value = \frac{\sum_{i=75}^{7} W_i \times V_i}{\sum_{i=75}^{7} Wi}$$

final weighted value =	*Reported energy savings value (kWh/ton, kW/ton, or therms/ton)*
i =	*Vintage*
W =	*Weight for a given vintage i*
V =	*Unit energy savings value for a given vintage (kWh/ton, kW/ton, or therms/ton)*

[5] ANSI/ASHRAE Standard 62.1-2016. 2016. “Ventilation for Acceptable Indoor Air Quality.” Table 6.2.2.1 Minimum Ventilation Rates in Breathing Zone.

[6] James J. Hirsch & Associates. 2014. “DEER2014-EnergyImpact-Weights-Tables-v2.xlsx.”

HVAC Type

DXGF (Packaged DX with Gas Furnace)

Case Options

Description	Code	Modeled
Customer Average	CAv	Yes
2005 Code/Standard	C05	No
2008 Code/Standard	C08	No
2013 Code/Standard	C13	No
Market Average	MAv	No
Measure	Msr	Yes

Base Case Energy Use Simulation

Several modifications to the DEER prototypes were necessary to estimate baseline energy use for the VFD measure. Appropriate baseline assumptions and resulting modifications to the DEER prototypes and the following modifications were agreed upon with the Energy Division Ex-Ante Review Team:

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.

The HVAC Impact Evaluation conducted by DNV GL (2014)[7] 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.

[7] DNV GL. 2014. *HVAC Impact Evaluation FINAL Report. WO032 HVAC – Volume 1: Report.* Prepared for the California Public Utilities Commission (CPUC). January 28.

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 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.

Measure Case Energy Use Simulation

To develop measure-case energy use and demand estimates the 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. Keyword changes were not applied to systems that served more than one zone.

DEER2020 Grocery building prototypes are run using the DOE2.2R refrigeration engine, which differs slightly from the DOE2.3 engine that other building prototypes use. The enhanced ventilation model for other building types was simulated as a two-speed fan control with staged volume for HVAC packaged units. DOE2.2R does not support the SYSTEM: AIR/TEMP-CONTROL keyword STAGE-VOLUME for HVAC packaged units. Thus, the enhanced ventilation measure was simulated using two-speed fan control only.

The table below summarized eQuest keyword changes made.

eQUEST Keyword	Baseline Value	Measure Value (except GRO)	Grocery Baseline Value	Grocery 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	One-speed_basecase Fan EIR fPLR	Two-speed_standard Fan EIR fPLR Two-speed_NEMA Fan EIR fPLR Two-speed_PMM Fan EIR fPLR
SYSTEM:AIR/TEMP-CONTROL	VARIABLE	STAGED-VOLUME	Unable to implement in DOE2.2R	Unable to implement in DOE2.2R
SYSTEM:COOL-STAGES[1]	n/a	0.99	Unable to implement in DOE2.2R	Unable to implement in DOE2.2R
SYSTEM:HEAT-STAGES[1]	n/a	0.99	Unable to implement in DOE2.2R	Unable to implement in DOE2.2R
SYSTEM:MIN-FLOW-RATIO	1	0.4 (Standard Motor) 0.3 (NEMA) 0.2 (PMM)	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)	1	0.4 (Standard Motor) 0.3 (NEMA) 0.2 (PMM)
SYSTEM:MIN-SUPPLY-T	50°F	50°F	50 °F	50 °F
SYSTEM:MAX-SUPPLY-T	180°F	180°F	180 °F	180 °F
ZONE:OA/FLOW-PER	n/a	n/a	n/a	Set Minimum Outside Air to 0.2 CFM/sf for Kitchen and Sales Floor areas based on 2019 T24 Table 120.1-A. These values were verified to be acceptable based on ASHRAE 62.1 2016 [8] minimum air flows.

[8] ANSI/ASHRAE Standard 62.1-2016. 2016. “Ventilation for Acceptable Indoor Air Quality.” Table 6.2.2.1 Minimum Ventilation Rates in Breathing Zone.

eQUEST Keyword	Baseline Value	Measure Value (except GRO)	Grocery Baseline Value	Grocery Measure Value

Electric Unit Energy Savings Calculation

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

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 specified for this measure, or for units serving a space type that is inconsistent with the building type, the building type for which the 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.

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 building vintage and for each of the building types listed. In order to model the large volume of discrete cases considered, eQUEST batch processing was used.

The following tables describe the building types, building vintages and climate zones modeled.

Building Description and Used Models

Building Type	Building Type Code	Modeled
Assembly	Asm	Yes
Primary School	EPr	Yes
Secondary School	ESe	Yes
Community College	ECC	Yes
University	EUn	Yes
Grocery	Gro	Yes
Hospital	Hsp	Yes
Nursing Home	Nrs	Yes
Hotel	Htl	Yes
Motel	Mtl	No
Bio/Tech Manufacturing	MBT	Yes
Light Industrial Manufacturing	MLI	No
Large Office	OfL	Yes
Small Office	OfS	Yes
Sit-Down Restaurant	RSD	Yes
Fast-Food Restaurant	RFF	Yes

Building Type	Building Type Code	Modeled
Department Store	Rt3	Yes
Big Box Retail	RtL	Yes
Small Retail	RtS	Yes
Conditioned Storage	SCn	Yes
Unconditioned Storage	SUn	No
Refrigerated Warehouse	WRf	No

Climate Zone

Climate Zone	Climate Zone Description	Modeled
1	Arcata Area (CZ01)	Yes
2	Santa Rosa Area (CZ02)	Yes
3	Oakland Area (CZ03)	Yes
4	Sunnyvale Area (CZ04)	Yes
5	Santa Maria Area (CZ05)	Yes
6	Los Angeles Area (CZ06)	Yes
7	San Diego Area (CZ07)	No
8	El Toro Area (CZ08)	Yes
9	Pasadena Area (CZ09)	Yes
10	San Bernardino Area (CZ10)	Yes
11	Red Bluff Area (CZ11)	Yes
12	Sacramento Area (CZ12)	Yes
13	Fresno Area (CZ13)	Yes
14	China Lake Area (CZ14)	Yes
15	Blythe Area (CZ15)	Yes
16	Mount Shasta Area (CZ16)	Yes

The DEER prototypes are used as the reference models for the measure case buildings and are unmodified.

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.

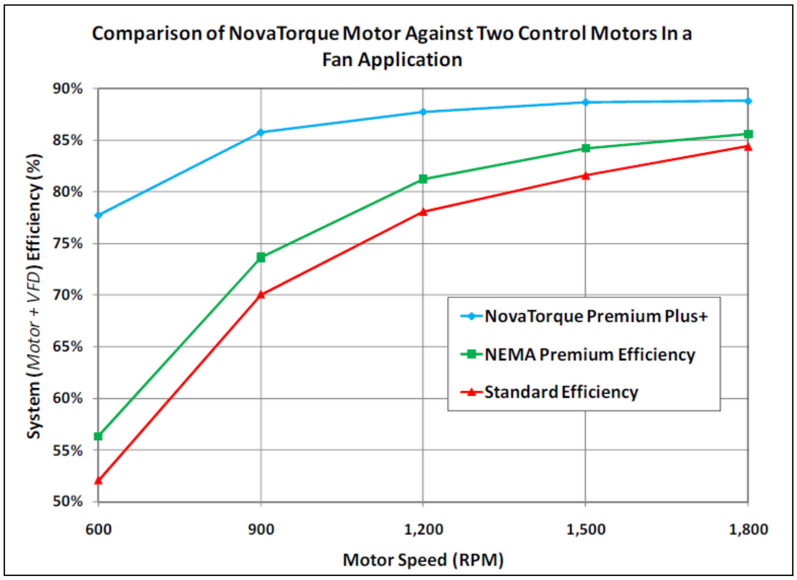
VFD Fan Control with Motor Power Interaction

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 for the Sacramento Municipal Utility District (SMUD).[9] 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 hp motor size is

[9] ADM Associates. 2010. *NovaTorque Brushless Permanent Magnet Motor Bench Test Final Report*. Prepared for the Sacramento Municipal Utility District (SMUD).

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 below depicts combined motor and VFD efficiency in a fan application.



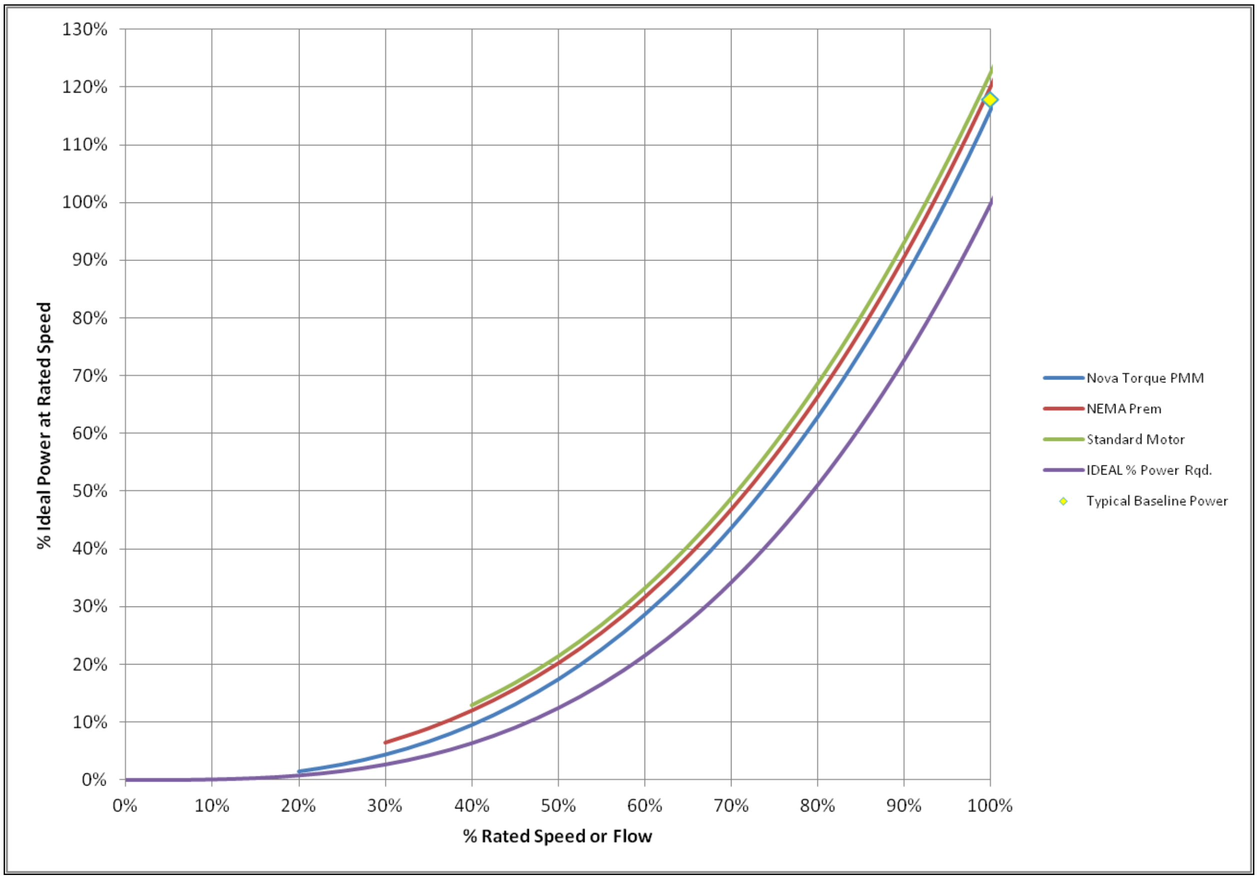
Combined Motor and VFD Efficiency for 3 HP Standard, Premium, and PMM Motors

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.[10]

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 below. The ideal fan power is included as a comparison to the three curves developed for this measure.[11]

[10] BC Hydro. "BC Hydro: Guides To Energy Management M310: Flexible Drives."

[11] Development of the three curves including belt efficiency is documented in the embedded workbook *Fan Power Curves.xls*.



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.

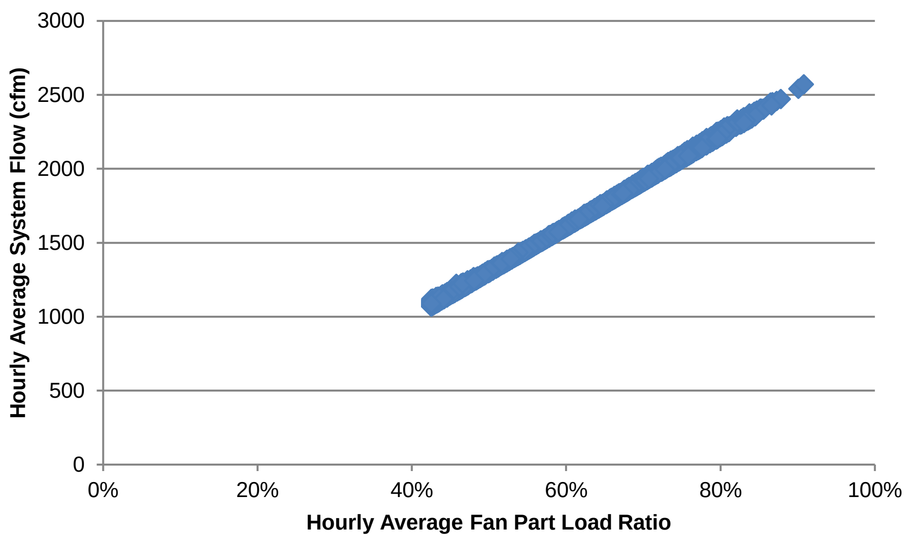
To simulate fan operation of 2-speeds, the STAGED-VOLUME capability of eQUEST was used. This function allows an air handling unit to operate at different flow rates depending on the heating and cooling demand. The modes that the unit will operate in are: floating (ventilation only), economizer cooling, 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.

DEER2020 Grocery building prototypes are run using the DOE2.2R refrigeration engine, which differs slightly from the DOE2.3 engine that other building prototypes use. The enhanced ventilation model for other building types was simulated as a two-speed fan control with staged volume for HVAC packaged units. DOE2.2R does not support the SYSTEM: AIR/TEMP-CONTROL keyword STAGE-VOLUME for HVAC packaged units. Thus, the enhanced ventilation measure was simulated using two-speed fan control only. As the enhanced ventilation measure is mainly a fan measure, the fan only control modification based on the fan part load efficiency (SYSTEM:FAN-EIR-FPLR) was used. The cooling load for the HVAC system serving the sales area was analyzed and it was found that the HVAC system compressors were operating for a minimal amount of time. The majority of the cooling load was handled by the commercial refrigeration system. The HVAC systems fans were operational at low speeds for a majority of hours to maintain minimum ventilation requirements. Therefore, using two-speed fan control was deemed reasonable.

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 for this 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.

$$PLR_{fan\ averaged\ hour} = \left(\%hour_{float\ mode} \times PLR_{float\ mode}\right) + \left(\%hour_{econ\ mode} \times PLR_{econ\ mode}\right) + \left(\%hour_{clg/htg\ mode} \times PLR_{clg/htg\ mode}\right)$$

$$\%hour_{float\ mode} + \%hour_{econ\ mode} + \%hour_{clg/htg\ mode} = 1$$



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. The equation below shows the expected linear relationship between supply flow and fan part load ratio developed from simulation hourly reports.

$$\therefore Supply\ Flow_{averaged\ hour} = Flow_{float\ mode} + \%hour_{clg/htg\ mode}\left(Flow_{clg/htg\ mode} - Flow_{float\ mode}\right)$$

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 above.

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.

$$kWh\ per\ ton\ savings = \frac{baseline\ kWh - measure\ kWh}{cooling\ tons}$$

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)

PEAK ELECTRIC DEMAND REDUCTION (kW)

Peak demand reduction was derived using the same methodology to derive electric unit energy savings (UES). The peak demand reduction was estimated using energy modeling software, eQUEST version 3.65. The Database of Energy Efficient Resources (DEER) 2015 prototypes were developed for the CAv (Customer Average) case using MASControl v3.00.27, the .INP file was then imported into eQUEST and modifications were made to develop the base case and the measure case. (See Electric Savings.)

However, the DEER demand reduction estimation protocol requires using the average hourly peak demand for the 15 hours of the DEER peak period from 4:00 p.m. to 9:00 p.m. during the three consecutive weekday period within the dates of June 1 through September 30.[12]

[12] California Public Utilities Commission (CPUC). 2018. *Resolution E-4952.* October 11.

The following calculation determined the demand reduction per ton of cooling capacity was calculated as the different between the baseline and measure case demand, divided by cooling capacity.

$$kW\ per\ ton\ demand\ reduction = \frac{baseline\ kW - measure\ kW}{cooling\ tons}$$

$kW\ per\ ton\ savings = annual\ unit\ demand\ reduction$
$baseline\ kW = average\ demand\ during\ peak\ period,\ baseline$
$measure\ kW = average\ demand\ during\ peak\ period,\ measure\ case$
$cooling\ tons = cooling\ capacity\ of\ units\ measure\ was\ applied\ to\ (Btu/h)\ divided\ by\ 12{,}000\ (Btu/h\ per\ ton)$

GAS SAVINGS (THERMS)

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

$$therms\ per\ ton\ savings = \frac{baseline\ therms - measure\ therms}{cooling\ tons}$$

$therms\ per\ ton\ savings = annual\ unit\ energy\ savings$
$baseline\ therms = annual\ building\ energy\ consumption\ of\ customer\ average\ baseline$
$measure\ therms = annual\ building\ energy\ consumption\ of\ measure$
$cooling\ tons = cooling\ capacity\ of\ units\ measure\ was\ applied\ to\ (Btu/h)\ divided\ by\ 12{,}000\ (Btu/h\ per\ ton)$

Vintage Weighted Average

Baseline and measure simulations used the DEER building vintages[13] (below) for both customer average and code prototypes.

DEER Building Vintage Codes and Descriptions

DEER Vintage Code	Description
Ex	Non-Mobile Homes 2002 - 2016; default vintage for existing buildings
V03	Existing building stock built between 2002 and 2005
V07	Existing building stock built between 2006 and 2009
V11	Existing building stock built between 2010 and 2013
V15	Existing building stock built between 2014 and 2016
2020 (New)	New Construction (not yet built)

[13] James J. Hirsch & Associates. 2014. "DEER2014-EnergyImpact-Weights-Tables-v2.xlsx."

DEER 2020 vintage weighting tables and procedures were used to appropriately weight all measure electric and demand reduction savings according to each vintage per IOU, building type, and climate zone. The following equation describes the DEER 2014 weighting methodology.

$$final\ weighted\ value = \frac{\sum_{i=75}^{7} W_i \times V_i}{\sum_{i=75}^{7} Wi}$$

final weighted value =	*Reported energy savings value (kWh/ton, kW/ton, or therms/ton)*
i =	*Vintage 75, 85, 96, 03, 07, 11, 14*
W =	*Weight for a given vintage i*
V =	*Unit energy savings value for a given vintage (kWh/ton, kW/ton, or therms/ton)*

LIFE CYCLE

Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention not caused the replacement or alteration.

The methodology to calculate the RUL conforms with Version 5 of the Energy Efficiency Policy Manual, which recommends "one-third of the effective useful life in DEER as the remaining useful life until further study results are available to establish more accurate values."[14] This approach provides a reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced.[15] Further, as per Resolution E-4807, the California Public Utilities Commission (CPUC) revised add-on measures so that the EUL of the measure is equal to the lower of the RUL of the modified system or equipment or the EUL of the add-on component." [16]

The EUL and RUL for this measure are specified below.

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs)	15.0	California Public Utilities Commission (CPUC), Energy Division. 2003. *Energy Efficiency Policy Manual v 2.0.* Page 17.
RUL (yrs)	5.0	

BASE CASE MATERIAL COST ($/UNIT)

The base case is the existing equipment; therefore, the base case cost is equal to $0.

[14] California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 32.

[15] KEMA, Inc. 2008. "Summary of EUL-RUL Analysis for the April 2008 Update to DEER." Memorandum submitted to Itron, Inc.

[16] California Public Utilities Commission (CPUC). 2016. *Resolution E-4807.* December 16. Page 13.

MEASURE CASE MATERIAL & LABOR COST ($/UNIT)

The measure case material costs were derived from retail, manufacturer suggested retail, and distributor costs variable frequency drive (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*.[17] 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, the measure costs were 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[18] (Demand Controlled Ventilation).

BASE CASE LABOR COST ($/UNIT)

The base case is the existing equipment; therefore, the base case labor cost is equal to $0.

NET-TO-GROSS (NTG)

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. These NTG values are based upon the average of all NTG ratios for all evaluated 2006 – 2008 commercial and industrial programs, as documented in the 2011 DEER Update Study conducted by Itron, Inc. These sector average NTGs ("default NTGs") are applicable to all energy efficiency measures that have been offered through commercial and industrial sector programs for more than two years and for which impact evaluation results are not available.

Net-to-Gross Ratios

Parameter	Value	Source
NTG - commercial	0.60	Itron, Inc. 2011. *DEER Database 2011 Update Documentation.* Prepared for the California Public Utilities Commission. Page 15-4 Table 15-3.
NTG - industrial	0.60	

[17] Itron, Inc. 2014. *2010-2012 WO017 Ex Ante Measure Cost Study Final Report.* Prepared for the California Public Utilities Commission.

[18] Pacific Gas and Electric (PG&E). 2018. "PGECOHVC168 R2 Demand Controlled Ventilation.docx".

GROSS SAVINGS INSTALLATION ADJUSTMENT (GSIA)

The gross savings installation adjustment (GSIA) rate represents the ratio of the number of verified installations of the measure to the number of claimed installations reported by the utility. This factor varies by end use, sector, technology, application, and delivery method. This GSIA rate is the current "default" rate specified for measures for which an alternative GSIA has not been estimated and approved.

Gross Savings Installation Adjustment Rates

Parameter	Value	Source
GSIA -	1.0	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 31.

NON-ENERGY IMPACTS

Non-energy impacts for this measure have not been quantified.

DEER DIFFERENCES ANALYSIS

This section provides a summary of DEER-based inputs and methods, and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment / 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
DEER Version	DEER 2020
Reason for Deviation from DEER	DEER does not contain this type of measure.
DEER Measure IDs Used	n/a
NTG	Source: The NTG of 0.60 is associated with NTG ID: Com-Default>2yrs
GSIA	Source: DEER. The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: Source: The value of 15 years is associated with EUL ID: HVAC-VSD-DCV, RUL as 1/3=5 years

REVISION HISTORYMEASURE CHARACTERIZATION REVISION HISTORY

Revision Number	Revision Complete Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision
01	09/30/2018	Jennifer Holmes, Cal TF Staff	Draft of consolidated text for this statewide measure is based upon: PGE3PHVC157, Revision 2 (October 8, 2015)

			Consensus reached among Cal TF members.
	06/12/2019	Tai Voong (PG&E)	Updated the following: Savings estimates using DEER prototype updates released with DEER2020 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
	11/26/2019	Sergio Corona (TRC) Tai Voong (PG&E)	Added Grocery building type to workpaper.