HVAC

DEMAND CONTROLLED VENTILATION FOR SINGLE ZONE HVAC

SWHC006-01

CONTENTS

MEASURE NAME

Demand Controlled Ventilation for Single Zone Packaged HVAC

STATEWIDE MEASURE ID

SWHC006-01

TECHNOLOGY SUMMARY

A constant volume single zone packaged HVAC system provides a fixed amount of outside air ventilation to a space, except for systems with airside economizers that are intended to provide up to 100% outside air for cooling when outside air conditions permit. When not economizing, most systems that do have economizers provide a fixed minimum amount of outside air. For systems that do not have the ability to adjust ventilation in response to occupancy, the California Building Energy Efficiency Standards (Title 24)[1] requires the minimum outside air to be determined based on the greater of:

1. The floor area-dependent ventilation rate required by Table 120.1-A (CFM/ ft^2)
2. 15 CFM per person using peak design occupancy for the space per §120.1(b)2

This requirement results in a safe and healthy level of ventilation supplied to the space during times of peak *occupancy but* may result in over-ventilation during times when the space has fewer occupants. When the occupant-dependent rate is greater than the floor-area dependent rate, *demand controlled ventilation (*DCV*)* may be used to reduce the minimum amount of ventilation that must be supplied to the space. DCV allows the system to provide additional ventilation up to the occupant-dependent rate only when necessary for periods of high occupancy.

The application of DCV included in this measure operates an existing economizer outside air damper based on measured CO_2 concentration in the space or return duct, which serves as a proxy for the occupant density in the space.[2] Implementation of DCV in this application requires installation of a CO_2 sensor in the zone or return duct (at a minimum). If an economizer controller with the ability to control the damper position based on a CO_2 sensor signal is already installed there are no additional hardware requirements beyond field wiring. For units that do not have a suitable economizer controller with DCV capability, an advanced digital economizer controller (ADEC) with DCV capability may be retrofit to the existing economizer.

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[1] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. CEC-400-2105-037-CMF.

[2] Other applications may use occupancy sensors, other types of gas concentration sensors, or other means to vary outside air damper position and/or total supply air and outside air flow rates. These other applications are outside the scope of this measure.

MEASURE CASE DESCRIPTION

The measure case is defined as the addition of demand controlled ventilation (DCV) to an existing packaged single zone direct expansion (DX) HVAC unit with an economizer. Measure offerings (below) distinguish between cooling units with gas heat, cooling only units, and heat pumps, respectively. The specific DCV application uses a carbon dioxide (CO_2) sensor to inform economizer outside air damper position. Measure offerings below also specify an advanced digital economizer controller (ADEC) with DCV capability as well as a CO_2 sensor. The ADEC must have the capability to control the damper in response to a CO_2 sensor signal.

Measures Offerings

Statewide Measure Offering ID	Measure Offering Description
SWHC006A	Add DCV, ADEC and CO2 Sensor, DX only
SWHC006B	Add DCV, ADEC and CO2 Sensor, DX Furnace
SWHC006C	Add DCV, ADEC and CO2 Sensor, Heat Pump
SWHC006D	Add DCV and CO2 Sensor, DX only with ADEC
SWHC006E	Add DCV and CO2 Sensor, DX Furnace with ADEC
SWHC006F	Add DCV and CO2 Sensor, Heat Pump with ADEC

Base, Standard, and Measure Cases

Case	Description of Typical Scenario
Measures	Add ADEC and CO_2 Sensor to AC with Gas Heat, AC-only, or HP unit. Add CO_2 Sensor to AC with Gas Heat, AC-only, or HP unit.
Existing Condition	AC with Gas Heat, AC-only, or HP unit without ADEC or DCV capability. AC with Gas Heat, AC-only, or HP unit with ADEC but no DCV capability.
Code/Standard	n/a
Industry Standard Practice	n/a

BASE CASE DESCRIPTION

The base case is defined as fixed position ventilation corresponding to the California Building Energy Efficiency Standards (Title 24) requirement or 20% of supply air, whichever is greater.

The California Building Energy Efficiency Standards (Title 24)[3] requires the minimum outside air to be determined based on the greater of:

1. The floor area-dependent ventilation rate required by Table 120.1-A (CFM/ ft^2)
2. 15 CFM per person using peak design occupancy for the space per §120.1(b)2

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[3] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. CEC-400-2105-037-CMF.

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, the 2016 California Building Energy Efficiency Standards (Title 24)[4] provides economizer control, general ventilation, and DCV requirements that are considered to be best practice and are specified below for reference.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	None	n/a
CA Building Energy Efficiency Standards – Title 24	Table 140.4-B: High limit shut-off control requirements by device type and climate zone. §120.1: Minimum ventilation requirements. §120.1(c)3 and 4: DCV ventilation and sensor requirements	January 1, 2017
Federal Standards	None	n/a

NORMALIZING UNIT

Cap-Tons

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.

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[4] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. CEC-400-2105-037-CMF.

Implementation Eligibility

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

Eligible Products

Existing System Requirements

The existing system must be packaged single zone DX cooling unit with gas heat, cooling only unit, or heat pump.

The existing system must ventilate continuously during occupied hours and may not have any other device previously installed that is intended to perform DCV such as an occupancy sensor that controls ventilation rate.

The measure shall only be applied where it will result in a reduction to the overall ventilation that is supplied for the space.

The existing system must have an operable airside economizer installed, and economizer high limit must be optimized for the climate per Title 24 2016[5] Table 140.4-B, adapted in the table below for reference.

Economizer High Limit Shut Off Control Requirements

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

Adapted from Title 24 2016 Table 140.4-B.

Verification and Data Requirements

The table below provides data required for calculation of energy savings estimates and incentives, and verification of installation and setup requirements.

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[5] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. CEC-400-2105-037-CMF.

Required Data

Required Data	Eligible Values
Actual or proxy building type	See Eligible Building Types below
Unit type	Packaged single zone DX - cooling unit with gas heat, cooling only unit, or heat pump
Nominal cooling capacity	Any
As-found minimum ventilation position	>0% open
As-found occupied fan operation	Continuous/ON
As-left minimum ventilation position	Less than as-found position
Sensor location	Wall in zone or return duct
CO_2 concentration high limit	1,000 ppm without direct measurement of outdoor air concentration or dynamically adjusted to 600 ppm above measured outdoor air concentration

Equipment used for the measure must meet the following qualifications for rebate eligibility. The requirements below draw on Title 24 2016 §120.1(a)4 requirements for DCV, although they deviate slightly in some respects since the application of retrofit controls on a packaged unit is not considered a code-triggering event. One primary deviation from Title 24 2016 requirements is that a return air duct-mounted CO_2 sensor is allowed whereas Title 24 2016 specifies that the sensor must be mounted in the zone and include a display. This allows for the measure to be installed more easily when site conditions or operational constraints are physically or cost-prohibitive to installation of a sensor in the zone.

1. To be eligible for CO_2 sensor-only rebate existing economizer control must be a digital type control and must have the capability to control the damper in response to a CO_2 sensor signal.
2. To be eligible for ADEC with CO_2 sensor rebate a program-qualifying ADEC or Enhanced Ventilation controller must be installed in addition to the CO_2 sensor. See bullet above for qualifying ADEC specification.
3. For each system with demand control ventilation, CO_2 sensors shall be installed in each room with no less than one sensor per 10,000 ft² of floor space. When a zone or a space is served by more than one sensor, signal from any sensor indicating that C CO_2 O2 is near or at the setpoint within a space, shall trigger an increase in ventilation to the space.
4. Upon detection of sensor failure, the system shall provide a signal which resets to supply the minimum quantity of outside air to the level required if DCV were not installed.
5. CO_2 sensors shall be certified by the manufacturer to be accurate within plus or minus 75 ppm at a 600 and 1,000 ppm concentration when measured at sea level and 25 °C, factory calibrated, and certified by the manufacturer to require calibration no more frequently than once every 5 years.

Eligible Building Types and Vintages

Building Types and Activity Area Types Simulated

Building Type Code	Activity Area Type	Weekly Occupied Hours	Peak Occupant Density (people per kSF)
Asm	Auditorium	98	95.2
EPr	Classroom / Lecture	69	33.4

Building Type Code	Activity Area Type	Weekly Occupied Hours	Peak Occupant Density (people per kSF)
EPr	Dining Area	15	44.5
EPr	Exercising Center / Gym	55	13.3
ERC	Classroom / Lecture	69	33.3
ESe	Classroom / Lecture	69	33.3
ESe	Dining Area	59	44.5
ESe	Exercising Center / Gym	74	13.3
ESe	Classroom / Lecture (93%)	69	31.5
ESe	Computer (Instruc/PC Lab)	69	13.0
EUn	Classroom / Lecture	99	33.3
EUn	Dining Area	40	44.5
EUn	Computer (Instruc/PC Lab)	55	13.3
GRo	Retail Sales, Grocery	112	22.2
Hsp	Dining Area	168	44.3
Hsp	Laboratory, Medical	168	13.6
MBT	Conference Room	35	44.5
MBT	Dining	75	44.5
Nrs	Dining Area	77	44.5
OfS	Corridor	65	10.8
RFF	Dining Area	133	43.8
RFF	Lobby (Main Entry/Assem)	133	96.7
RFF	Restrooms	133	20.0
RSD	Dining Area	112	44.3
RSD	Lobby (Main Entry / Assem)	112	94.9
RSD	Restrooms	112	20.0
Rt3	Retail / Wholesale Showrm	94	19.4
RtL	Retail / Wholesale Showrm	98	22.2
RtS	Retail / Wholesale Showrm	88	22.2

Baseline and measure simulations used the new 3 DEER building vintages[6] described in the table below for both customer average and code prototypes.

Building Vintages

Vintage Code	Description	New "Era" Vintage
v75	Before 1978	Old
v85	1978 - 1992	Old

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[6] James J. Hirsch & Associates. (2014, March 18). DEER2014 Energy Impact Weights Tables v2. Retrieved from deeresources.com: http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EnergyImpact-Weights-Tables-v2.xlsx

Vintage Code	Description	New "Era" Vintage
v96	1993 - 2001	Old
v03	2002 - 2005	Ex
v07	2006 - 2009	Ex
v11	2010 - 2013	Ex
v15	2014 – 2016	Ex
V17	2017 – 2019	Rec
V20	After 2019	Rec
New	New Construction	New

Eligible Climate Zones

This measure is applicable in all California climate zones.

DATA COLLECTION REQUIREMENTS

Data collection requirements are to be determined.

USE CATEGORY

HVAC

ELECTRIC SAVINGS (kWh)

The electric unit energy savings (UES) of this measure were derived from building energy use simulation results and were calculated as the difference between the baseline and measure building energy use consumption.

Baseline and Measure Case Energy Use Simulation Models

Building energy use and demand were estimated using eQUEST version 3.65-7175 energy modeling software.[7] The 2020 Database for Energy Efficient Resources (DEER2020) base case prototypes of the Measure 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[8].

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[7] Pacific Gas & Electric Company (PG&E). 2019. "SWHC006-01 Model Files.zip."

[8] White Box Technologies, Inc. CZ2010 Weather Data. Developed for California Energy Commission. http://weather.whiteboxtechnologies.com/wd-CZ2010

Statewide Measure Offering IDs and DEER Prototype Measure IDs

Statewide Measure Offering ID	Measure Offering Description	DEER Energy Impact ID
SWHC006E	Add Demand Controlled Ventilation (DCV) and CO2 Sensors, DX Furnace with ADEC	NE-HVAC-airAC-SpltPkg-135to239kBtuh-11p5eer
SWHC006B	Add Demand Controlled Ventilation (DCV), ADEC and CO2 Sensors, DX Furnace	
SWHC006D	Add Demand Controlled Ventilation (DCV) and CO2 Sensors, DX only with ADEC	NE-HVAC-airAC-SpltPkg-135to239kBtuh-11p5eer
SWHC006A	Add Demand Controlled Ventilation (DVC), ADEC and CO2 Sensors, DX only	
SWHC006F	Add Demand Controlled Ventilation (DCV) and CO2 Sensors, Heat Pump with ADEC	NE-HVAC-airHP-SpltPkg-135to239kBtuh-11p5eer-3p2cop
SWHC006C	Add Demand Controlled Ventilation (DCV), ADEC and CO2 Sensors, Heat Pump	NE-HVAC-airHP-Pkg-55to65kBtuh-15p0seer-8p2hspf

The following modifications were made to the DEER prototypes to represent the base case for the DCV measures in this workpaper:

1. Hourly occupancy as a percentage of peak design occupancy was reduced to 90% for cases that the DEER occupancy schedule exceeded 90%. DCV savings are sensitive to occupancy, and most buildings do not reach 100% occupancy on a typical day. An average daily maximum occupancy percentage of 90% was determined to be appropriate in these cases.[9] The existing default DEER peak occupant densities were retained.
2. Economizer dry-bulb changeover temperatures were set in accordance with the 2019 California Building Energy Efficiency Standards (Title 24), Table 140.4-E.[10]

To implement these modifications to the DEER prototypes, modifications to eQUEST keywords were as follows:

Baseline eQUEST Keyword Modifications

eQUEST Keyword	DEER Value	Modified Baseline Value
DAY-SCHEDULE:VALUES[#] Only in daily schedules being used for space occupancy	If > 0.9	0.9 *

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[9] Professional judgement.

[10] California Energy Commission (CEC). 2018. *2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. CEC-400-2018-020-CMF.

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

* This modification was achieved by modifying the eQ_Lib.dat file included with MASControl3 to limit space occupancy day schedule hourly values to 0.9.

To develop measure case energy use and demand estimates the modified baseline files were further modified to simulate application of DCV to each system for which DCV would result in the benefit of reduced ventilation supplied to the space. To determine the specific systems and zones for which DCV would provide a benefit it was necessary to determine the minimum ventilation rate that could be supplied for each zone, based on the maximum of:

1. 20% of the supply airflow (assumed physical limitation of dampers)
2. Title 24 Table 120.1-A Minimum Ventilation Rate (code-required minimum)

Wherever this value resulted in a lower value than the minimum outdoor air flow rate for the baseline the DCV measure was simulated. For these areas the zone minimum outside airflow was adjusted to the minimum rate that could be supplied. eQUEST includes built-in functionality to simulate DCV by varying outside air flow rate based on the maximum of the rate required for the area and the rate required for the number of occupants in a given hour as described in the DOE-2.3 dictionary.[11] Specific keywords modified to represent the measure are shown in the table below. All other keywords remained consistent from the baseline to the measure.

Measure eQUEST Keyword Modifications

eQUEST Keyword	Baseline Value	Modified Baseline Value
ZONE:OA-FLOW/AREA	DEER prototype value	Set such that ZONE:OA-FLOW/AREA x Zone Area = Maximum of: 1. 0.2 x Supply Air Flow Rate 2. Title 24 Table 120.1-A Minimum Ventilation Rate
SYSTEM:MIN-OA-METHOD	FRACTION-OF-HOURLY-FLOW	DCV-ZONE-SENSORS

Unit Energy Savings Calculation

As an add-on equipment measure, a single baseline calculation is required. The calculation of the electric UES from the first baseline is represented below.

$$UES_{kWh/ton} = \frac{UEC_{base} - UEC_{measure}}{cooling\ tons}$$

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[11] Lawrence Berkeley National Laboratory (LBNL) and James J. Hirsch & Associates. 2017. *DOE-2.3 Building Energy Use and Cost Analysis Program Volume 2: Dictionary.* January. Pp. 416-418.

$UES_{kWh/ton} =$ Annual unit energy savings (kWh/ton)

$UEC_{base} =$ Annual building energy consumption of customer average baseline

$UEC_{measure} =$ 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)

Sample Calculation

This sample calculation represents a 1985 vintage assembly (Asm) prototype using AC with gas heat located in climate zone 11 is provided below.

The DEER Asm prototype consists of five zones total as depicted below. The four smaller zones in the corners of the building represent office spaces with peak occupant densities of under seven people per 1,000 ft^2. The central zone represents an auditorium space with a peak occupant density of over 95 people per 1,000 ft^2. For assembly buildings it was determined that DCV could be used to reduce the minimum ventilation rate required for the central auditorium zone, but that DCV could not be used effectively in the corner office zones. The DCV measure was therefore simulated only on the central auditorium zone, and the savings were divided by the cooling capacity in tons of the system that serves only that zone.
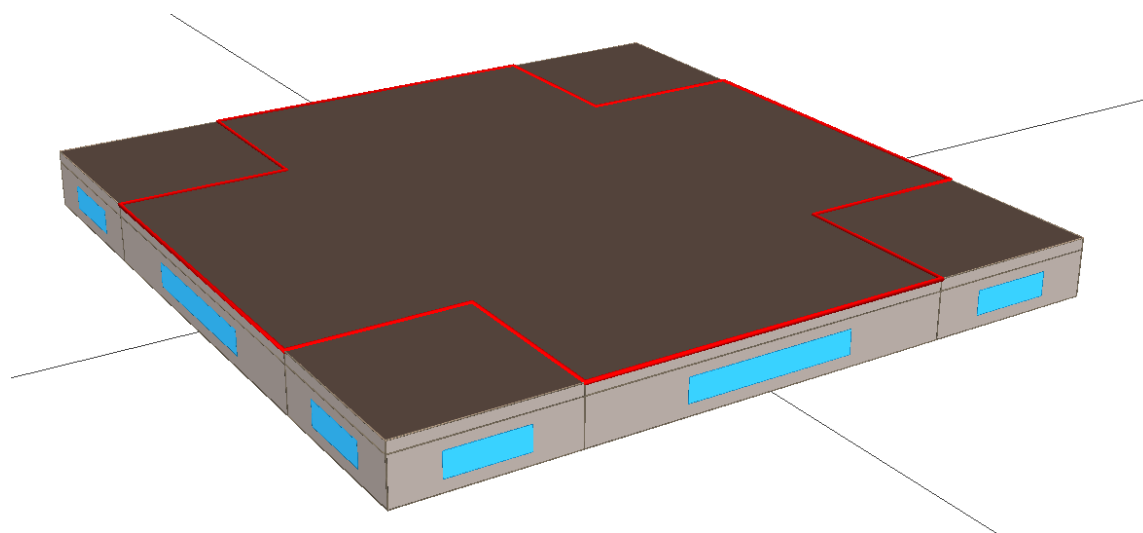
DEER Asm Prototype with DCV Zone Outlined

The table below provides electric energy use and cooling capacity data for the baseline and measure case on the Asm prototype approximating a building constructed in 1986 in climate zone 11.

Asm cz11 v85 AC with Gas Heat Electric Energy Use and Cooling Capacity Data

	Baseline	Measure
Whole building energy use (kWh/yr)	710,604	692,824
System cooling capacity (Btu/h)	2,446,370	2,446,370

$$87.2 \left(\frac{kWh}{ton\ x\ year} \right) = \frac{710,604.0 \left(\frac{kWh}{year} \right) - 692,824.0 \left(\frac{kWh}{year} \right)}{2,446,370 \left(\frac{Btu}{h} \right) / 12,000 \left(\left(\frac{Btu}{h} \right) / ton \right)}$$

PEAK ELECTRIC DEMAND REDUCTION (KW)

The unit peak demand reduction of this measure was derived from building energy use simulation results and were calculated as the difference between the baseline and measure building average demand during the peak period of 4:00 p.m. to 9:00 p.m. on three specific weekdays and varies by climate zone.[12]

Baseline and Measure Case Energy Use Simulation Models

Building energy use and demand were estimated using eQUEST version 3.65-7175 energy modeling software.[13] The 2020 Database for Energy Efficient Resources (DEER2020) base case prototypes of the Measure 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[14].

See Electric Savings for a description of the base case and measure case building simulation models.

Peak Demand Reduction Calculation

Peak demand reduction was calculated similarly to electric energy savings but instead accounts for the difference between the baseline and measure case average hourly peak demand for the 15 hours of the peak period. The calculation of peak demand reduction per ton of cooling capacity is represented by the following equation:

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

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)

Sample Calculation

This sample calculation represents a 1985 vintage assembly (Asm) prototype using AC with gas heat located in climate zone 11. **Error! Reference source not found.** provides electric demand and cooling

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[12] California Public Utilities Commission (CPUC). 2018. *Resolution E-4952*. October 11. O.P.1.

[13] Pacific Gas & Electric Company (PG&E). 2019. "SWHC006-01 Model Files.zip."

[14] White Box Technologies, Inc. CZ2010 Weather Data. Developed for California Energy Commission. http://weather.whiteboxtechnologies.com/wd-CZ2010

capacity data for the baseline and measure case on the Asm prototype approximating a building constructed in 1986 in climate zone 11.

Asm cz11 v85 AC with Gas Heat Demand and Cooling Capacity Data

	Baseline	Measure
7/8 hour 15 demand (kW)	243.795	213.381
7/8 hour 16 demand (kW	271.600	258.211
7/8 hour 17 demand (kW)	277.581	270.279
7/9 hour 15 demand (kW	302.526	256.137
7/9 hour 16 demand (kW)	320.237	303.537
7/9 hour 17 demand (kW	319.755	310.777
7/10 hour 15 demand (kW)	346.646	287.656
7/10 hour 16 demand (kW	364.837	344.137
7/10 hour 17 demand (kW)	366.337	364.454
DEER Demand Average (kW)	**312.590**	**289.841**
System cooling capacity (Btu/h)	2,446,370	2,446,370

$$0.113 \left(\frac{kW}{ton} \right) = \frac{312.590(kW) - 289.841(kW)}{2{,}446{,}370 \left(\frac{Btu}{h} \right) / 12{,}000 \left(\left(\frac{Btu}{h} \right) / ton \right)}$$

GAS SAVINGS (THERMS)

The electric unit energy savings (UES) of this measure were derived from building energy use simulation results and were calculated as the difference between the baseline and measure building energy use consumption.

Baseline and Measure Case Energy Use Simulation Models

Building energy use and demand were estimated using eQUEST version 3.65-7175 energy modeling software.[15] The 2020 Database for Energy Efficient Resources (DEER2020) base case prototypes of the Measure 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[16].

See Electric Savings for a description of the base case and measure case building simulation models.

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[15] Pacific Gas & Electric Company (PG&E). 2019. "SWHC006-01 Model Files.zip."

[16] White Box Technologies, Inc. CZ2010 Weather Data. Developed for California Energy Commission. http://weather.whiteboxtechnologies.com/wd-CZ2010

Unit Energy Savings Calculation

Gas UES values were calculated similarly to electric energy savings. The calculation of gas energy savings from the first baseline is represented as.

$$UES_{therms/ton} = \frac{UEC_{base} - UEC_{measure}}{cooling\ tons}$$

$UES_{kWh/ton} =$	*Annual unit energy savings (therms/ton)*
$UEC_{base} =$	*Annual building energy consumption of customer average baseline*
$UEC_{measure} =$	*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)*

Sample Calculation

This sample calculation represents a 1985 vintage assembly (Asm) prototype using AC with gas heat located in climate zone 11. The table below provides gas energy use and cooling capacity data for the baseline and measure case on the Asm prototype approximating a building constructed in 1986 in climate zone 11.

Asm cz11 v85 AC with Gas Heat Gas Energy Use and Cooling Capacity Data

	Baseline	Measure
Whole building energy use (therms/yr)	21,847.2	12,286.4
System cooling capacity (Btu/h)	2,446,370	2,446,370

$$46.90 \left(\frac{therms}{ton\ x\ year}\right) = \frac{21{,}847.2 \left(\frac{therms}{year}\right) - 12{,}286.4 \left(\frac{therms}{year}\right)}{2{,}446{,}370 \left(\frac{Btu}{h}\right)/12{,}000 \left(\left(\frac{Btu}{h}\right)/ton\right)}$$

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."[17] This approach provides a reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced.[18] 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." [19]

The relevant EUL and RUL values for the measures in this work paper are specified below. Since this measure is classified as add-on equipment to an existing system, the RUL of the existing system is adopted as the EUL for the measure. The RUL value is only applicable to the first baseline period for an add-on equipment with an applicable code baseline.

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs) – existing HVAC system	15.0	California Public Utilities Commission (CPUC), Energy Division. 2014. "DEER2014-EUL-table-update_2014-02-05.xlsx"
RUL (yrs) – existing HVAC system = EUL of measure	5.0	

BASE CASE MATERIAL COST ($/UNIT)

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

MEASURE CASE MATERIAL COST ($/UNIT)

The measure case material cost was derived from a combination of retail, manufacturer suggested retail, and distributor costs for CO_2 sensors collected in 2019. As a controls upgrade, measure costs do not scale strongly with cooling capacity. To normalize costs an average capacity of 12.5 tons was assumed to be the average capacity to which the measure would be applied.

BASE CASE LABOR COST ($/UNIT)

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

MEASURE CASE LABOR COST ($/UNIT)

The measure case installation labor cost was derived from estimates provided by contractors in 2019 to install DCV in field tests of the technology. A weighted average cost for California was developed based

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

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

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

on the methodology used for the *2010-2012 WO017 Ex Ante Measure Cost Study* conducted by Itron, Inc.[20] The labor rate and adjustments to account for local variation are in alignment with the methodology presented in the Itron measure cost study.

Labor Cost Inputs

Parameter	Value	Source
Labor rate ($/hr)	$86.93	Contractor estimates.

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	

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

Parameter	GSIA	Source
GSIA - Default	1.00	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5.* Page 31.

NON-ENERGY IMPACTS

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

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

DEER DIFFERENCES ANALYSIS

This section provides a summary of inputs and methods based upon the Database of Energy Efficient Resources (DEER), and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment
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	None
NTG	Source: The NTG of 0.60 is associated with NTG ID: Com-Default>2yrs
GSIA	The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: The value of 15 years is associated with EUL ID: *HVAC-VSD-DCV*

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Complete Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision
01	06/14/2019	Adan Rosillo (PG&E)	Draft of statewide consolidated text based upon: PGECOHV168, Revision 2. Consensus of Cal TF Updated MAT and Building Vintage as per resolution E-4952 Updated energy savings and peak demand