Work Paper PGECOHVC168

**Revision 2**

**Pacific Gas & Electric Company**

**Customer Energy Solutions**

**Demand Controlled Ventilation for Single Zone Packaged HVAC**

**For Work Paper Reviewer Use Only**

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

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

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| --- | --- |
| **Measure Codes** | HV026, HV027, HV028, HV029, HV030, HV031 |
| **Measure Description** | Add Demand Controlled Ventilation (DCV) to an existing packaged single zone direct expansion (DX) HVAC unit with an economizer. |
| **Base Case Description** | Fixed position ventilation corresponding to Title 24 2016 requirement or 20% of supply air, whichever is greater |
| **Units** | Per ton cooling capacity, Cap-Tons. |
| **Energy Savings** | Refer to Excel Calculation Attachment |
| **Full Measure Cost ($/unit)** | Add ADEC and CO2 sensor: $141.17/Ton |
| Add CO2 sensor to unit having ADEC: $64.69/Ton |
| **Incremental Measure Cost ($/unit)** | N/A |
| **Effective Useful Life** | Source: DEER 5 Years |
| **Measure Installation Type** | Retrofit Add-On (REA) |
| **Net-to-Gross Ratio** | 0.6 (DEER NTGR ID: Com-Default>2yrs) |
| **Important Comments** | This work paper has a complementary Ex Ante Database data set that will be provided in a separate submission to the California Public Utilities Commission (CPUC). |

# Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Rev** | **Date** | **Author** | **Summary of Changes** |
| Revision 0 | 04/09/2014 | Sherry Hu (PG&E); Benjamin Lipscomb (PECI) | Demand Controlled Ventilation  PGECOHVC168 R0.doc  Original workpaper |
| Revision 1 | 03/01/2016 | Sherry Hu (PG&E) | Ex Ante Data Spreadsheet formatting update. |
| Revision 2 | 12/3/2019 | Tai Voong (PG&E); Phil Jordan (CLEAResult) | * Updated savings estimates using DEER prototype updates released with DEER2015 and DEER2017 * Measure cost analysis was updated to use current information for ADEC pricing * Work paper content was updated according to Resolution E-4818 existing conditions * Work paper format was updated to match latest template |

# Commission Staff and Cal TF Comments

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

# Section 1. General Measure & Baseline Data

## 1.1 Measure Description & Background

***Catalog Description –***

Add Demand Controlled Ventilation (DCV) to an existing packaged single zone direct expansion (DX) HVAC unit with an economizer. The specific DCV application uses a carbon dioxide (CO2) sensor to inform economizer outside air damper position. HV026, HV028, and HV030 are for adding an Advanced Digital Economizer Controller (ADEC) with DCV capability as well as a CO2 sensor. HV027, HV029, and HV031 are for adding a CO2 sensor only assuming a DCV-enabling digital controller is already installed. The three measure codes for each case distinguish between cooling units with gas heat, cooling only units, and heat pumps, respectively. The ADEC must have the capability to control the damper in response to a CO2 sensor signal.

**Base, Standard, and Measure Cases**

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measures | 1) Add ADEC and CO2 Sensor to AC with Gas Heat, AC-only, or HP unit.  2) Add CO2 Sensor to AC with Gas Heat, AC-only, or HP unit. |
| Existing Condition | 1) AC with Gas Heat, AC-only, or HP unit without ADEC or DCV capability.  2) AC with Gas Heat, AC-only, or HP unit with ADEC but no DCV capability. |
| Code/Standard | N/A |
| Industry Standard Practice | N/A |

Measures and Codes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Codes** | | | | **Measure Name** |
| SCG | SDG&E | SCE | PG&E |
|  |  |  | HV026 | Add ADEC and CO2 Sensor to AC unit with Gas Heat |
|  |  |  | HV027 | Add CO2 Sensor to AC unit with Gas Heat with ADEC |
|  |  |  | HV028 | Add ADEC and CO2 Sensor to AC only unit |
|  |  |  | HV029 | Add CO2 Sensor to AC only unit with ADEC |
|  |  |  | HV030 | Add ADEC and CO2 Sensor to HP |
|  |  |  | HV031 | Add CO2 Sensor to HP with ADEC |

***Program Restrictions and Guidelines***

The target market for DCV is spaces in commercial buildings served by packaged single zone DX HVAC units, sometimes referred to as rooftop units (RTU) and split systems.

This 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 DCV as the baseline. There are no above-code savings reported as Title 24 2016 §120.1[[1]](#endnote-1) requires DCV 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 DCV measures described in this workpaper are available only for below 12 DEER building types: Asm (Assembly), EPr (Education – Primary School), ERC(Education - Relocatable Classroom), ESe(Education – Secondary School), EUn (Education – University), MBT (Manufacturing Biotech), OfS (Office - Small), RFF (Restaurant – Fast Food), RSD (Restaurant – Sit-Down), Rt3 (Retail – Multistory Large ), RtL(Retail – Single-Story Large), RtS (Retail – Small).

***Terms and Conditions:***

The following eligibility requirements must be satisfied prior to application of the measure:

* Existing system must be packaged single zone DX cooling unit with gas heat [HV026, HV027], cooling only unit [HV028, HV029], or heat pump [HV030, HV031]
* 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 1 for reference.
* 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.

**Table 1 Economizer High Limit Shut Off Control Requirements\***

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

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

Table 2 provides data required for calculation of energy savings estimates and incentives, and verification of installation and setup requirements.

**Table 2 Required Data**

|  |  |
| --- | --- |
| **Required Data** | **Eligible Values** |
| Actual or proxy building type | See Table 3 building type codes |
| 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 |
| CO2 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 CO2 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.

* To be eligible for CO2 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 CO2 sensor signal.
* To be eligible for ADEC with CO2 sensor rebate a program-qualifying ADEC or Enhanced Ventilation controller must be installed in addition to the CO2 sensor. See bullet above for qualifying ADEC specification.
* For each system with demand control ventilation, CO2 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 CO2 is near or at the setpoint within a space, shall trigger an increase in ventilation to the space.
* 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.
* CO2 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.

***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.

Savings estimation includes simulation of the measure in the specific building type and activity area combinations shown in Table 3, however the measure is applicable in any commercial building or activity area within where it reduces the overall amount of outside ventilation air that is supplied to the space. The UES estimates are provided by building type, and include savings for a mix of the activity area types for which the measure results in a reduction in the allowable minimum outside air ventilation required per Title 24 2016 §120.1[[2]](#endnote-2). The building type that contains activity areas that are closest to the actual application in terms of weekly occupied hours and peak occupant density shown in Table 3 shall be selected as a proxy for UES estimation. Values in Table 3 were extracted from default DEER prototype data. It is expected that some contractor discretion will be required when selecting proxy building types for building types that are not explicitly included, and the UES values shall not be considered in the decision. Rebates are not dependent on UES values, so there is not a monetary motivation for the contractor to select one building type proxy over another due to it having a higher UES value.

**Table 3 - 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 |
| 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 |

## 1.2 Technical Description

Constant volume single zone packaged HVAC systems provide a fixed amount of outside air ventilation to a space, with the exception of systems with airside economizers which 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, Title 24 2016 requires the minimum outside air to be determined based on the greater of:

1. The floor area-dependent ventilation rate required by Title 24 Table 120.1-A (CFM/sq. ft.)

2. 15 CFM per person using peak design occupancy for the space per Title 24 §120.1(b)2

This requirement results in a safe and healthy level of ventilation being 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, 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 particular application of DCV covered by this work paper operates an existing economizer outside air damper based on measured CO2 concentration in the space or return duct, which serves as a proxy for the occupant density in the space. 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 work paper.

Implementation of DCV in this application requires installation of a CO2 sensor in the zone or return duct at a minimum. If an economizer controller with the ability to control damper position based on a CO2 sensor signal is already installed there are no additional hardware requirements beyond field wiring. HV029, HV030, and HV031 provide rebates for this situation. For units that do not have a suitable economizer controller with DCV capability, an ADEC with DCV capability may be retrofit to the existing economizer. HV026, HV027, and HV028 provide rebates for the installation of ADEC with a CO2 sensor.

## 1.3 Installation Types and Delivery Mechanisms

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.

**Installation Type Descriptions**

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

Because this measure is a control upgrade for existing units it is a Retrofit Add-on (REA) application, meaning UES values provided are for an existing system without DCV as the baseline. There are no above-code savings reported as Title 24 2016 §120.11 requires DCV in most of the building type and activity area types where DCV is beneficial. The UES values are not appropriate for ROB or NC applications.

**Delivery Method Descriptions**

|  |  |
| --- | --- |
| **Delivery Method** | **Description** |
| Commissioning and Retrocommissioning | The program modifies or repairs existing equipment to ensure that it works as intended. |
| Financial Support | The program motivates customers, through financial incentives such as rebates or low interest loans, to implement energy efficient measures or projects. |
| Innovative Design | The program funds new ideas that meet reasonable scientific scrutiny for potential energy savings. These innovative measures typically have small market penetration (less than 5%) or are targeted toward relatively unreached market segments. |
| New Construction | The program offers financial incentives and/or design assistance to customers involved with new building construction. This is intended is to motivate customer to exceed Title 24 building energy efficiency requirements (residential or nonresidential). |
| Partnership | The program implements projects through a partnership between the utility and an institutional, government, or community-based organization. |
| Performance Based | The program offers financial incentives that vary based on the energy efficiency performance of specific projects. |
| Up-Stream Programs | See Up-Stream Incentive and Up-Stream Buy Down in the Incentive Method table. |

**Incentive Method Descriptions**

|  |  |
| --- | --- |
| **Incentive Method** | **Description** |
| Direct Install | The program implements energy efficiency measures for qualifying customers, at no cost to the customer. |
| Down-Stream Incentive | The customer installs qualifying energy efficient equipment and submits an incentive application to the utility program. Upon application approval, the utility program pays an incentive to the customer. Such an incentive may be deemed or customized. |
| Mid-Stream Incentive | The program gives a financial incentive to a midstream market actor, such as a retailer or contractor, to encourage the promotion of efficient measures. The incentive may or may not be passed on to the end-use customer. |
| Up-Stream Incentive | The program gives a financial incentive to an upstream market actor, such as a manufacturer or distributor, to encourage the manufacture, provision, or distribution of an efficient measure. The incentive may or may not be passed on to the end-use customer. |
| Up-Stream Buy Down | The program gives a financial incentive to an upstream market actor, such as a manufacturer or distributor, with specific requirements to pass down the incentive to the end use customer. Such an incentive buys-down the cost of an efficient measure for the end-use customer by at least the amount of the financial incentive. |
| Giveaway | The program provides customers with energy efficiency equipment or services for free. |
| Exchange/Replacement | The utility program holds events where customers can trade functional equipment for similar but more energy efficient equipment, free of charge. |
| On-bill Finance/Loan | The program offers financing for the cost an efficient measure as part of the utility bill. This can be an add-on option to an existing program or can serve as an organizing principle for its own program. |

## 1.4 Measure Parameters

### 1.4.1 DEER Data

DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Item** | **Used for Workpaper?** |
| Modified DEER methodology | No |
| Scaled DEER measure | No |
| DEER Base Case | No |
| DEER Measure Case | No |
| DEER Building Types | Yes |
| DEER Operating Hours | Yes |
| DEER eQUEST Prototypes | Yes, with modifications; see §2 |
| DEER Version | DEER 2015 and DEER 2017 (ERC airHP), READI v2.2.0 |
| Reason for Deviation from DEER | DEER does not contain this type of measure. |
| DEER Measure IDs Used | None |

**Net-to-Gross Ratio**

The NTG values were obtained using the DEER READI tool. The relevant NTG values for the measures in this work paper are in the table below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **NTGR ID** | **Description** | **Sector** | **BldgType** | **Measure Delivery** | **NTGR** |
| Com-Default>2yrs | All other EEMs with no evaluated NTGR; existing EEM in programs with same delivery mechanism for more than 2 years | Com | Any | Any | 0.6 |

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

**Spillage Rate**

Spillage rates are not tracked in work papers; they are tracked in an external document which will be supplied to the Commission Staff.

**Installation Rate**

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.

The IR values were obtained using the DEER READI tool. The relevant IR values for the measures in this work paper are in the table below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **GSIA ID** | **Description** | **Sector** | **BldgType** | **ProgDelivID** | **GSIAValue** |
| Def-GSIA | Default GSIA values | Any | Any | Any | 1 |

**Effective and Remaining Useful Life**

Since this measure is a retrofit on an existing system the RUL of the existing system is used as the EUL for the measure. The EUL for the measure is 5 years. The EUL and RUL values were obtained using the DEER READI tool. DEER defines the RUL as 1/3 of the EUL value. The RUL value is only applicable to the first baseline period for an RET measure with an applicable code baseline. The relevant EUL and RUL values for the measures in this work paper are in the table below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| HVAC-airHP, HVAC-airAC | Air Conditioners (air-cooled, split and unitary) | Com | HVAC | 15 | 5 |

### 1.4.2 Codes and Standards Analysis

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

Code Summary

|  |  |  |
| --- | --- | --- |
| **Code** | **Reference** | **Effective Dates** |
| Title 24 2016 | Table 140.4-B: High limit shut-off control requirements by device type and climate zone |  |
| Title 24 2016 | §120.1: Minimum ventilation requirements |  |
| Title 24 2016 | §120.1(c)3 and 4: DCV ventilation and sensor requirements |  |
|  |  |  |
|  |  |  |

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

A study of significant importance to the measure development in this work paper is described in the following section. Per Resolution E-4818 the default measure-level baseline shall be existing conditions for add-on equipment measures, which encompasses the measures in this work paper. DEER prototypes for the customer average (CAv) case of the Tech IDs shown in Table 4 were used as a starting point for defining existing conditions for the measures in this work paper; a search was done to identify any gaps between DEER and current research regarding existing conditions. Beyond the WO32 document described below no such additional studies were found that would impact the existing conditions for the measures in this work paper.

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

Completion date: 1-28-2014

Author: California Public Utilities Commission, Energy Division

This document (WO32[[3]](#endnote-3)) is a study of statewide, third-party, and local programs targeting unitary HVAC systems during the 2010-2012 program cycle). WO32 study evaluated gross energy savings and installation rates through activities including on-site field evaluations, sampling and monitoring the performance and energy use of units enrolled in the programs before and after CQM maintenance, and additional laboratory testing of existing HVAC units. The study includes recognition of typical damper leakage characteristics.

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

## 1.6 Data Quality and Future Data Needs

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

# Section 2. Calculation Methodology

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

READI Data Used

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

Energy savings and demand reduction for non-refrigeration models were estimated using eQUEST version 3.64.7130 energy modeling software. The DEER 2014, DEER 2015, and DEER 2017 prototypes for the customer average (CAv) case of the Tech IDs shown in the table below were used with some modification (as described in §2.1) to develop base and measure case energy use and demand estimates. DEER prototypes were generated using MASControl v3.00.29[[4]](#endnote-4) for the heat pump relocatable classroom prototypes, MASControl v3.00.27[[5]](#endnote-5) for all remaining prototypes applicable to the DEER 2015 Code Update, and MASControl v3.00.20[[6]](#endnote-6) for the remaining DEER 2014 Code Update prototypes. All modeling was performed using default DEER hours and the CZ2010 weather files[[7]](#endnote-7).

**Table 4 DEER Prototype Tech ID by Measure**

|  |  |
| --- | --- |
| **Measure** | **DEER Prototype Tech ID** |
| Add Demand Controlled Ventilation (DCV) (Non-ADEC) on AC Unit with Gas Heat  Add Demand Controlled Ventilation (DCV) (ADEC) on AC Unit with Gas Heat | D08-NE-HVAC-airAC-SpltPkg-110to134kBtuh-11p5eer  MASControl v3.00.27 |
| Add Demand Controlled Ventilation (DCV) (Non-ADEC) on AC Only Unit  Add Demand Controlled Ventilation (DCV) (ADEC) on AC Only Unit | D08-NE-HVAC-airAC-SpltPkg-110to134kBtuh-11p5eer  MASControl v3.00.27 |
| Add Demand Controlled Ventilation (DCV) (Non-ADEC) on Heat Pump  Add Demand Controlled Ventilation (DCV) (ADEC) on Heat Pump | **Non-Education Relocatable Classroom:**  D08-NE-HVAC-airHP-SpltPkg-110to134kBtuh-11p5eer-3p4cop  MASControl v3.00.20 |
| **Education Relocatable Classroom:**  D08-NE-HVAC-airHP-PkgEcono-55to64kBtuh-15p0seer-8p2hspf  MASControl v3.00.29 |

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

## 2.1 Base Case Simulations

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

1. A minimum outside air fraction of 20% was used instead of 0% due to emerging research (not yet published at the time of the meeting) that indicates closed damper leakage for packaged HVAC systems are higher than previously thought.
2. A maximum outside air fraction of 70% was used instead of 100% due to emerging research (not yet published at the time of the meeting) that indicates return air damper leakage and exhaust air re-entrainment for packaged HVAC systems are higher than previously thought, leading to inability of most systems to provide 100% outside air.
3. Hourly occupancy as a percentage of peak design occupancy was reduced to 90% in cases where the DEER occupancy schedule exceeded 90%. DCV savings are sensitive to occupancy, and work paper authors and other collaborators recognized that most buildings do not reach 100% occupancy on a typical day. Parties involved came to the consensus that an average daily maximum occupancy percentage of 90% would be appropriate in these cases. The existing default DEER peak occupant densities were retained.
4. Economizer dry-bulb changeover temperatures were set in accordance with Title 24 2016 Table 140.4B.

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

|  |  |  |
| --- | --- | --- |
| **eQUEST Keyword** | **DEER Value** | **Modified Baseline Value** |
| SYSTEM:MIN-OUTSIDE-AIR | Varies | 0.2 |
| SYSTEM:MAX-OA-FRACTION | 1.0 | 0.7 |
| ZONE:OA/FLOW-PER | Varies | Set such that ZONE:OA-FLOW/PER x Peak Occupancy # of People  is between:   1. 0.2 x Supply Air Flow Rate 2. 0.7 x Supply Air Flow Rate   This modification ensures the first two keywords are not overwritten. |
| DAY-SCHEDULE:VALUES[#]  Only in daily schedules being used for SYSTEM:MIN-AIR-SCH | 0.001 for unoccupied periods, -999 for occupied periods | Modify 0.001 to 0.2 during unoccupied periods.  This modification ensures that unit operation during scheduled unoccupied periods will properly simulate damper leakage. |
| 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. |
| DAY-SCHEDULE:VALUES[#]  Only in daily schedules being used for space occupancy | If >0.9 | 0.9 |
| SYSTEM:ECONO-LIMIT-T | Varies | Varies by climate zone from 69°F to 75°F depending on Title 24 2016 Table 140.4B requirement |

## 2.2 Measure Case Simulations

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. Table 3 lists the building types and activity area types within each building where this condition was met. 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-2.2 dictionary pp. 362-363[[8]](#endnote-8). Specific keywords modified to represent the measure are shown in the table below. All other keywords remained consistent from the baseline to the measure.

|  |  |  |
| --- | --- | --- |
| **eQUEST Keyword** | **Baseline Value** | **Modified Baseline Value** |
| ZONE:OA-FLOW/AREA | 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 3. 15 CFM/person\* x Peak Occupancy # of People | 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-DESIGN | DCV-ZONE-SENSORS |

\*Outside air ventilation rate per person required by Title 24 2016 §120.1(b)2B

## 2.2 Electric Energy Savings Estimation Methodologies

As an add-on measure, a single baseline calculation is required. The electric energy savings from the first baseline are represented in the calculations below.

*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)*

A sample calculation using 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 in Figure 1. The four smaller zones in the corners of the building represent office spaces with peak occupant densities of under 7 people per 1,000 square feet. The central zone represents an auditorium space with a peak occupant density of over 95 people per 1,000 square feet. 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.



Figure 1 DEER Asm Prototype with DCV Zone Outlined

Table 5 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.

Table 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 |

## 2.3 Demand Reduction Estimation Methodologies

Demand reduction estimates must consider the DEER peak demand period. The peak period is defined as 2:00 PM to 5:00 PM on three specific weekdays and varies by climate zone as shown in the following table[[9]](#endnote-9):

|  |  |  |  |
| --- | --- | --- | --- |
| **Climate Zone** | **3-Weekday Period** | **Climate Zone** | **3-Weekday Period** |
| 1 | Sep 16 – Sep 18 | 9 | Sep 1 – Sep 3 |
| 2 | July 8 – July 10 | 10 | Sep 1 – Sep 3 |
| 3 | July 8 – July 10 | 11 | July 8 – July 10 |
| 4 | Sep 1 – Sep 3 | 12 | July 8 – July 10 |
| 5 | Sep 8 – Sep 10 | 13 | July 8 – July 10 |
| 6 | Sep 1 – Sep 3 | 14 | Aug 26 – Aug 28 |
| 7 | Sep 1 – Sep 3 | 15 | Aug 25 – Aug 27 |
| 8 | Sep 1 – Sep 3 | 16 | July 8 – July 10 |

Demand reduction is calculated similarly to electric energy savings, however DEER demand reduction estimation protocol requires using the average hourly peak demand for the 9-hours of the DEER peak period. 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)*

A sample calculation using a 1985 vintage assembly (Asm) prototype using AC with gas heat located in climate zone 11 is provided below. Table 6 provides electric demand and cooling capacity data for the baseline and measure case on the Asm prototype approximating a building constructed in 1986 in climate zone 11.

Table 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 | 271.6 | 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 |

## 2.4 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)*

A sample calculation using a 1985 vintage assembly (Asm) prototype using AC with gas heat located in climate zone 11 is provided below. Table 7 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.

Table 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 |

## 2.5 Vintage Weighted Average

Baseline and measure simulations used the 7 DEER building vintages[[10]](#endnote-10) described in the table below for both customer average and code prototypes.

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

DEER 2014 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.

Where:

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=energy savings value for a given vintage (kWh/ton, kW/ton, or therms/ton)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **WtSet** | **Vintage** | **DEER Weight** | **Savings**  **kWh/Ton** | **Demand Reduction**  **kW/Ton** | **Savings**  **Therms/Ton** |
| PGEAsmCZ11 | v75 | 0.39993 | 34.09 | 0.0445 | 18.27 |
| PGEAsmCZ11 | v85 | 0.25853 | 22.55 | 0.0288 | 12.12 |
| PGEAsmCZ11 | v96 | 0.15391 | 13.85 | 0.0174 | 7.68 |
| PGEAsmCZ11 | v03 | 0.07843 | 7.15 | 0.0090 | 3.95 |
| PGEAsmCZ11 | v07 | 0.04369 | 3.98 | 0.0050 | 2.20 |
| PGEAsmCZ11 | v11 | 0.04369 | 3.68 | 0.0047 | 2.20 |
| PGEAsmCZ11 | V14 | 0.02184 | 1.91 | 0.0028 | 1.18 |
| **Final Weighted Savings** | **Existing** |  | **87.21** | **0.1122** | **47.60** |

# Section 3. Load Shapes

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

The ideal load shape for net benefits estimates would represent the difference between the base case and measure case. The closest load shapes that are applicable to the measures in this work paper are listed in the table below.

Building Types and Load Shapes

|  |  |  |
| --- | --- | --- |
| **Building Type** | **Load Shape** | **E3 Alternate Building Type** |
| All | DEER:HVAC\_Split-Package\_AC, DEER:HVAC\_Split-Package\_HP | NON\_RES |

# Section 4. Costs

## 4.1 Base Case Cost

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

## 4.2 Measure Case Cost

To develop measure cost estimates a combination of retail, manufacturer suggested retail, and distributor costs were gathered for CO2 sensors. Estimates of installation time were developed based on author’s direct experience working with contractors to install DCV in field tests of the technology. A base labor rate of $86.93 per hour was used, and was adjusted to account for local variation. A weighted average cost for the state was developed based on the methodology used for the 2010-2012 WO017 Ex Ante Measure Cost Study Final Report[[11]](#endnote-11). 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.

## 4.3 Full and Incremental Measure Cost

**Full and Incremental Measure Cost Equations**

|  |  |  |  |
| --- | --- | --- | --- |
| **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| ROB | (MEC + MLC) – (BEC + BLC) | (MEC + MLC) – (BEC + BLC) | N/A |
| NEW/NC |
| RET/ER | (MEC + MLC) – (BEC + BLC) | MEC + MLC | (MEC + MLC) – (BEC + BLC) |
| REF | (MEC + MLC) – (BEC + BLC) | MEC + MLC | N/A |
| REA | MEC + MLC | MEC + MLC | N/A |

MEC = Measure Equipment Cost; MLC = Measure Labor Cost

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

**Full and Incremental Costs**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure** | **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| Add ADEC and CO2 sensor to existing system | REA | $79.34 + $65.64 = $144.98 | $79.34 + $65.64 = $144.98 | N/A |
| Add CO2 sensor to existing system with ADEC | REA | $32.48 + $32.21 = $64.69 | $32.48 + $32.21 = $64.69 | N/A |

# Attachments

# References

1. California Energy Commission. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24, Part 6).* Sacramento, California. June 2016. [↑](#endnote-ref-1)
2. James J. Hirsch & Associates. (2014, October 17). DEER2015 – Codes and Standards Update. Retrieved from deeresources.com: http://www.deeresources.com/index.php/deer-versions/deer2015-code-update [↑](#endnote-ref-2)
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4. James J. Hirsch & Associates. (2017, July 12). *MASControl 3.00.29*. Retrieved from deeresources.com:

   <http://deeresources.com/files/DEER2016/download/SetupMASControlX32_3_00_29.msi> and http://deeresources.com/files/DEER2019/download/Update-MASControl2016-June2017.zip [↑](#endnote-ref-4)
5. James J. Hirsch & Associates. (2014, October 31). *MASControl 3.00.27.* Retrieved from deeresources.com: http://www.deeresources.com/files/DEER2015/download/SetupMASControlX32\_3\_00\_27.msi [↑](#endnote-ref-5)
6. James J. Hirsch & Associates. (2013, September 9). *MASControl 3.00.20*. Retrieved from deeresources.com: http://www.deeresources.com/files/DEER2013codeUpdate/download/SetupMASControlX32\_3\_00\_20.msi [↑](#endnote-ref-6)
7. White Box Technologies, Inc. *CZ2010 Weather Data.* Developed for California Energy Commission. http://weather.whiteboxtechnologies.com/wd-CZ2010 [↑](#endnote-ref-7)
8. Lawrence Berkeley National Laboratory; James J. Hirsch & Associates. (2014, February). *DOE-2.2 Building Energy Use and Cost Analysis Program Volume 2: Dictionary*. Retrieved from DOE2.com: http://doe2.com/download/DOE-22/DOE22Vol2-Dictionary\_48r.pdf [↑](#endnote-ref-8)
9. James J. Hirsch & Associates. (2014, February 11). DEER2014 — Codes and Standards Update. Retrieved from deeresources.com: http://deeresources.com/files/DEER2013codeUpdate/download/DEER2014UpdateDocumentation\_2-12-2014.pdf. [↑](#endnote-ref-9)
10. James J. Hirsch & Associates. (2014, March 18). DEER2014 Energy Impact Weights Tables v2. Retrieved from deeresources.com: http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EnergyImpact-Weights-Tables-v2.xlsx [↑](#endnote-ref-10)
11. Itron. *2010-2012 WO017 Ex Ante Measure Cost Study Final Report.* San Francisco, CA (2014, May 27). Retrived from http://www.calmac.org/publications/2010-2012\_WO017\_Ex\_Ante\_Measure\_Cost\_Study\_-\_Final\_Report.pdf [↑](#endnote-ref-11)