Work Paper PGE3PHVC160

**Revision 2**

**Pacific Gas & Electric**

**Refrigerant Charge Adjustment (RCA)**

# At-a-Glance Summary

|  |  |
| --- | --- |
| **Measure Codes** | HV314, HV315, HV316, HV317, HV318, HV319, HV320, HV321, HV322, HV323, HV324, HV325, HV330, HV331, HV332, HV333 |
| **Measure Description** | Adjust refrigerant charge to meet manufacturer specifications |
| **Base Case Description** | Refrigerant charge does not meet manufacturer specifications |
| **Units** | Per ton cooling capacity, Cap-Tons. |
| **Energy Savings** | Refer to Excel Calculation Attachment |
| **Full Measure Cost ($/unit)** | $36.70 / ton |
| **Incremental Measure Cost ($/unit)** | $36.70 / ton |
| **Effective Useful Life** | 10 years (DEER EUL ID: HVAC-RefChg) |
| **Measure Installation Type** | Retrofit Add-on (REA) |
| **Net-to-Gross Ratio** | 0.73 (DEER NTGR ID: NonRes-sAll-mHVAC-RCA) |
| **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 | 06/01/2012 | Tai Voong (PG&E) | At-A-Glance Measure List: Changed Building Vintage from “AV” to “Any” and Unit Definition from “Ton” to “Cap-Tons”. |
| Revision 0 | 08/28/2012 | Tai Voong (PG&E) | * Revised savings, NTG, and ISR to comply with ED’s Disposition on the HVAC Quality Maintenance/AirCare Plus Workpapers dated on the March 2, 2013 and May 16, 2013 disposition. * Only the PG&E executive summary savings template was updated. Workpaper language will be updated later. * For updated Savings values, see file PGE3PHVC160 R1\_RCA(chl7v2).xlsx |
| Revision 1 | 7/11/2013 | Christopher Li (PG&E) | At-A-Glance Measure List: Changed Building Vintage from “AV” to “Any” and Unit Definition from “Ton” to “Cap-Tons”. |
| Revision 2 | 10-8-15 | Matt Tyler (CLEAResult), Sherry Hu (PG&E) | * Work paper was updated according to Workpaper Disposition for Nonresidential HVAC Rooftop Quality Maintenance3 and WO328. * Removed measure HA80 and added 16 new ones. |

# 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

This statewide work paper details refrigerant charge adjustment on existing nonresidential split-system and unitary HVAC equipment. This is one of eight work papers that cover specific HVAC Quality Maintenance (QM) treatments formerly combined into the measures described in the Revision 0 version of the June 26, 2012 Work Paper PGECOHVC138 Nonresidential HVAC RTU Quality Maintenance[[1]](#endnote-1) and the Revision 3 version of the December 26, 2014 Work Paper SCE13HC037 Comprehensive Commercial HVAC Rooftop Unit Quality Maintenance[[2]](#endnote-2). All HVAC QM treatments are now covered by the following work papers:

* Airflow Adjustment (To be completed in 2016)
* Condenser Coil Cleaning (PGE3PHVC156R2)
* Economizer Controls (PGE3PHVC152R3)
* Economizer Repair (PGE3PHVC151R2)
* Evaporator Coil Cleaning (PGE3PHVC158R2)
* Refrigerant Charge Adjustment (PGE3PHVC160R2)
* Unoccupied Fan Control (PGE3PHVC157R2)
* Programmable Thermostat (PGE3PHVC153R3)

Separation of this HVAC QM treatment into a statewide set of measures in this work paper was performed using guidance from the document WORKPAPER DISPOSITION FOR Non-Residential HVAC Rooftop Quality Maintenance[[3]](#endnote-3) and supplementary spreadsheet: 20132014-CommercialHVACMaintenance-SavingsValues-April2013-v1-2.xlsx[[4]](#endnote-4). Both are referenced in more detail later in this document.

Table 1 Base, Standard, and Measure Cases

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measure | Adjust refrigerant charge to meet manufacturer specifications |
| Existing Condition | Refrigerant charge does not meet manufacturer specifications |
| Code/Standard | N/A |
| Industry Standard Practice | Standard 180-2008, Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems[[5]](#endnote-5) |

Table 2 Measures and Codes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Codes** | | | | **Measure Name** |
| SCG | SDG&E | SCE | PG&E |
|  |  |  | HV314 | Refrigerant Charge Adjustment on Single Stage AC Unit with Gas Heat |
|  |  |  | HV315 | Refrigerant Charge Adjustment on First Stage of Multi-Stage AC Unit with Gas Heat |
|  |  |  | HV316 | Refrigerant Charge Adjustment on Second or Higher Stage of Multi-Stage AC Unit with Gas Heat |
|  |  |  | HV330 | Refrigerant Charge Adjustment on First Stage and Second or Higher Stage of Multi-Stage AC Unit with Gas Heat |
|  |  |  | HV317 | Refrigerant Charge Adjustment on Single Stage AC Only Unit |
|  |  |  | HV318 | Refrigerant Charge Adjustment on First Stage of Multi-Stage AC Only Unit |
|  |  |  | HV319 | Refrigerant Charge Adjustment on Second or Higher Stage of Multi-Stage AC Only Unit |
|  |  |  | HV331 | Refrigerant Charge Adjustment on First Stage and Second or Higher Stage of Multi-Stage AC Only Unit |
|  |  |  | HV320 | Refrigerant Charge Adjustment on Single Stage Heat Pump |
|  |  |  | HV321 | Refrigerant Charge Adjustment on First Stage of Multi-Stage Heat Pump |
|  |  |  | HV322 | Refrigerant Charge Adjustment on Second or Higher Stage of Multi-Stage Heat Pump |
|  |  |  | HV332 | Refrigerant Charge Adjustment on First Stage and Second or Higher Stage of Multi-Stage Heat Pump |
|  |  |  | HV323 | Refrigerant Charge Adjustment on First Stage of Multi-Stage Variable Volume AC Unit with Gas Heat |
|  |  |  | HV324 | Refrigerant Charge Adjustment on Single Stage Variable Volume AC Unit with Gas Heat |
|  |  |  | HV325 | Refrigerant Charge Adjustment on Second or Higher Stage of Multi-Stage Variable Volume AC Unit with Gas Heat |
|  |  |  | HV333 | Refrigerant Charge Adjustment on First Stage and Second or Higher Stage of Multi-Stage Variable Volume AC Unit with Gas Heat |

This statewide work paper supports HVAC QM programs as well as HVAC tune-up programs in multiple programs and service territories. Refer to programs that offer the measure for specific restrictions and guidelines in addition to those described herein.

The target market for this measure is nonresidential buildings served by unitary DX and split systems that do not serve process or refrigeration loads. The measure is defined for all nonresidential building types and all 16 California climate zones. Savings are calculated for a weighted average of seven Database for Energy Efficient Resources (DEER15[[6]](#endnote-6)) vintages using utility-specific weightings.

Participating contractors must ensure the customer facility is physically located within the service territory of the Investor Owned Utility (IOU) administering the program and that the customer receives electric services from that IOU. Other terms and conditions are set by individual programs.

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

## 1.2 Technical Description

This measure involves refrigerant charge correction to nonresidential direct expansion (DX) air-cooled HVAC units. When an HVAC unit’s refrigerant charge does not meet the manufacturer recommended levels it results in a decrease in the unit’s energy efficiency ratio (EER).

Some units may be undercharged, which can result in decreased power draw but potentially longer run times. Other units may be overcharged, which can result in increased power draw but potentially shorter run times. In either case, energy savings can be achieved by correcting refrigerant charge to optimum levels based on the manufacturers’ specifications.

## 1.3 Installation Types and Delivery Mechanisms

The installation type describes the program scenario in which the measure is applied, thus guiding energy savings and measure cost methodology. These are summarized below in **Table 3**. The installation type for this measure is Retrofit Add-On (REA) since the baseline is the existing unit.

Table 3 Installation Type Descriptions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Installation Type** | **Savings** | | **Life** | |
| 1st Baseline (BL) | 2nd BL | 1st BL | 2nd BL |
| Replace on Burnout (ROB) | Above Code or Standard | N/A | EUL | N/A |
| New Construction (NEW/NC) | Above Code or Standard | N/A | EUL | N/A |
| Retrofit or Early Replacement (RET/ER) | Above Customer Existing | Above Code or Standard | RUL | EUL-RUL |
| Retrofit First Baseline Only (REF) | Above Customer Existing | N/A | EUL | N/A |
| Retrofit Add-on (REA) | Above Customer Existing | N/A | EUL | N/A |

A delivery mechanism is a delivery method paired with an incentive method. Delivery mechanisms are used by programs to obtain program participation and energy savings. See **Table 4** and **Table 5** below for descriptions of available delivery methods and incentive methods, respectively.

**SCE Delivery Mechanism:** Financial Supportpaired withDirect Install, Down-Stream Incentive – Deemed, or Mid-Stream Incentive

**PG&E Delivery Mechanism:** Financial Support paired with Direct Install or Mid-Stream Incentive

Table 4 Delivery Method Descriptions

|  |  |
| --- | --- |
| **Delivery Method** | **Description** |
| Appliance Turn-in and Recycling | The program motivates customers, through financial incentives, to recycle appliances that are functional but inefficient. This prevents the continued use of those appliances, by both the current owner and potential future owners. |
| Audit/Information/Testing Services | The program performs a free assessment of a customer’s facility and provides the customer with information and guidance on energy efficiency opportunities. |
| Commissioning and Retrocommissioning | The program modifies or repairs existing equipment to ensure that it works as intended. |
| Financial Support | The program motivates customers, through financial incentives such as rebates or low interest loans, to implement energy efficient measures or projects. |
| Innovative Design | The program funds new ideas that meet reasonable scientific scrutiny for potential energy savings. These innovative measures typically have small market penetration (less than 5%) or are targeted toward relatively unreached market segments. |
| New Construction | The program offers financial incentives and/or design assistance to customers involved with new building construction. This is intended is to motivate customer to exceed Title 24 building energy efficiency requirements (residential or nonresidential). |
| Partnership | The program implements projects through a partnership between the utility and an institutional, government, or community-based organization. |
| Performance Based | The program offers financial incentives that vary based on the energy efficiency performance of specific projects. |
| Up-Stream Programs | See Up-Stream Incentive and Up-Stream Buy Down in the Incentive Method table. |

Table 5 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

The Database for Energy Efficient Resources (DEER) was referenced on November 19, 2015 for any 2016 updates that would impact this measure. No relevant updates were noted and a full Code Update for 2016 has not yet been presented on deeresources.com. This Measure is included in the Database for Energy Efficient Resources (DEER15). This work paper establishes new RCA unit energy savings (UES) values using existing DEER RCA savings methodology. Rationale for the change and updated modeling assumptions are described in Sections 2 and 2.1.

Table 6 DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Item** | **Used for Work Paper?** |
| Modified DEER methodology | Yes |
| 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 Section 2 |
| DEER Version | DEER 2015, READI v2.2.0 |
| Reason for Deviation from DEER | DEER does not contain this type of measure. DEER assumes single stage cooling and this measure includes multiple stages of cooling. |
| DEER Measure IDs Used | N/A |

**Net-to-Gross Ratio**

The Net-to-Gross Ratio (NTGR) was obtained using the DEER READI tool[[7]](#endnote-7). The relevant NTGR for the measures in this work paper is shown in **Table 7**.

Table 7 Measure Net-to-Gross Ratios

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **NTGR ID** | **Description** | **Sector** | **BldgType** | **Measure Delivery** | **NTGR** |
| NonRes-sAll-mHVAC-RCA | HVAC Maintenance: Refrigerant Charge Adjustment (RCA) | Com | Any | NonUpStrm | 0.73 |

**Spillage Rate**

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

**Installation Rate**

The installation rate (IR) values were obtained using the DEER READI tool. The relevant IR values for the measures in this work paper are in **Table 8** below. .

Table 8 Installation Rates

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **GSIA ID** | **Description** | **Sector** | **BldgType** | **ProgDelivID** | **GSIAValue** |
| Com-RCA-All | Commercial Refrigerant Charge & Airflow Adjustment; Annual Installation Rate | Com | Any | NonUpStrm | 0.638 |
| Com-RCA-PGE | Commercial Refrigerant Charge & Airflow Adjustment; Annual Installation Rate | Com | Any | NonUpStrm | 0.575 |
| Com-RCA-SCE | Commercial Refrigerant Charge & Airflow Adjustment; Annual Installation Rate | Com | Any | NonUpStrm | 0.67 |
| Com-RCA-SDG | Commercial Refrigerant Charge & Airflow Adjustment; Annual Installation Rate | Com | Any | NonUpStrm | 0.67 |

**Effective and Remaining Useful Life**

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 REA measure with an applicable code baseline. The relevant EUL and RUL values for the measures in this work paper are shown in **Table 9** below.

Table 9 EUL and RUL

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| HVAC-RefChg | Refrigerant Charge - Commercial | Com | HVAC | 10 | 3.3 |

### 1.4.2 Codes and Standards Analysis

These maintenance measures are not governed by either state or federal codes and standards. The document Standard 180-2008, Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems5 may be used by QM programs as a guide for measure implementation. Only licensed California contractors will participate in the program. As required by the California State Licensing Board, contractors will be responsible for meeting all applicable codes. In general, maintenance and repairs do not require permits.

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

Two studies of significant importance to the measure development in this work paper are described in the following section.

### 1.5.1 WORKPAPER DISPOSITION FOR Non-Residential HVAC Rooftop Quality Maintenance3

Completion date: 5-2-2013

Author: California Public Utilities Commission, Energy Division

This Disposition outlines revision requirements to the existing work papers that cover discrete rooftop unit (RTU) QM service tasks and suites of service tasks for nonresidential QM programs. Three general directives outlined in the Disposition are:

1. Revise ex ante claims process to be based on actual service tasks completed as part of the QM process,
2. Revise All UES values to use staff recommended values, and
3. All IOUs should establish consistent savings estimate approach, preferably using eQuest.

The Disposition assumes use of DEER RCA UES values and does not direct any changes to RCA methodology. See §2.1 for reasoning behind re-modeling of RCA savings performed in this work paper.

### 1.5.2 HVAC Impact Evaluation FINAL Report WO32 HVAC – Volume 1: Report[[8]](#endnote-8)

Completion date: 1-28-2014

Author: DNV GL

This document (WO32) is a study of statewide, third-party, and local programs targeting unitary HVAC systems during the 2010-2012 program cycle, including Commercial Quality Maintenance (CQM). 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 highlights findings for key quality maintenance treatments (and parameters) including, but not limited to, recognition of typical damper leakage characteristics, non-functional economizer conditions and performance, and adjusting refrigerant charge.

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.

It was also stated in the Report that refrigerant charge testing methods (Fault detection & diagnostics (FDD), Title 24 testing protocol) that rely on temperature and pressure measurements “proved inaccurate based on field and laboratory findings” and are not a reliable testing method for calculating savings. It is recommended in the Report that using the weigh-in, weigh-out protocol should be used by program administrators for EM&V.

## 1.6 Data Quality and Future Data Needs

# Additional study of the impacts of refrigerant charge testing and adjustment protocols may be warranted. The improvements that RCA can bestow on HVAC system efficiency are highly dependent on the existing condition of the refrigeration system and determining the most accurate testing protocol would allow for a higher confidence in achieved savings.

# Section 2. Calculation Methodology

Energy savings and demand reduction for non-refrigeration models were estimated using eQUEST version 3.64.7130 energy modeling software and DOE-2.2R version 52h energy modeling simulation engine for refrigeration models. The DEER 2014 prototypes for the customer average (CAv) case of the Tech IDs shown in **Table 10** 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 v3.00.27[[9]](#endnote-9) for all prototypes applicable to the DEER 2015 Code Update and MASControl v3.00.20[[10]](#endnote-10) for the remaining DEER 2014 Code Update prototypes. All modeling was performed using default DEER hours and used the CZ2010 weather files[[11]](#endnote-11).

The two lowest available cooling capacity size ranges for each system type were determined to be an adequate representation of single stage or multi-stage in 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. Variable Volume AC units were not available in the “55to64kBtuh” or “110to134kBtuh” ranges and were created using “240to759kBtuh” and “gte760kBtuh” ranges.

With the exception of motel building type and education relocatable classroom building type with heat pumps, DEER prototypes for AC and heat pump measures were created using the “55to64kBtuh” and “110to134kBtuh” cooling capacity range. These capacity ranges allowed us to simulate single and multiple stage HVAC systems for the widest range of building types.

Table 10 DEER Prototype Tech ID by Measure

|  |  |
| --- | --- |
| **Measure** | **DEER Prototype Tech ID** |
| RCA on Single Stage AC Unit with Gas Heat | **Single Stage, Non-Motel**: D08-NE-HVAC-airAC-PkgEcono-55to64kBtuh-15p0seer-8p2hspf MASControl v3.00.27  **Single Stage, Motel**: D08-NE-ILtg-Power-Exit-60pct  MASControl v3.00.20 |
| RCA on First Stage of Multi-Stage AC Unit with Gas Heat | **Multi-Stage, Non-Motel:** D08-NE-HVAC-airAC-SpltPkg-110to134kBtuh-11p5eer-3p4cop MASControl v3.00.27  **Multi-Stage, Motel:** D08-NE-ILtg-Power-Exit-60pct  MASControl v3.00.20 |
| RCA on Second or Higher Stage of Multi-Stage AC Unit with Gas Heat |
| RCA on First Stage and Second or Higher Stage of Multi-Stage AC Unit with Gas Heat |
| RCA on Single Stage AC Only Unit | **Single Stage, Non-Motel**: D08-NE-HVAC-airAC-PkgEcono-55to64kBtuh-15p0seer-8p2hspf MASControl v3.00.27  **Single Stage, Motel**: D08-NE-ILtg-Power-Exit-60pct  MASControl v3.00.20 |
| RCA on First Stage of Multi-Stage AC Only Unit | **Multi-Stage, Non-Motel:** D08-NE-HVAC-airAC-SpltPkg-110to134kBtuh-11p5eer-3p4cop MASControl v3.00.27  **Multi-Stage, Motel:** D08-NE-ILtg-Power-Exit-60pct  MASControl v3.00.20 |
| RCA on Second or Higher Stage of Multi-Stage AC Only Unit |
| RCA on First Stage and Second or Higher Stage of Multi-Stage AC Only Unit |
| RCA on Single Stage Heat Pump | **Single Stage**: D08-NE-HVAC-airHP-PkgEcono-55to64kBtuh-15p0seer-8p2hspf MASControl v3.00.27 |
| RCA on First Stage of Multi-Stage Heat Pump | **Multi-Stage, Non-Education Relocatable Classroom:** D08-NE-HVAC-airHP-SpltPkg-110to134kBtuh-11p5eer-3p4cop MASControl v3.00.20  **Multi-Stage, Education Relocatable Classroom:** D08-NE-HVAC-airHP-PkgEcono-55to64kBtuh-15p0seer-8p2hspf MASControl v3.00.27 |
| RCA on Second or Higher Stage of Multi-Stage Heat Pump |
| RCA on First Stage and Second or Higher Stage of Multi-Stage Heat Pump |
| RCA on Single Stage Variable Volume AC Unit with Gas Heat | **All:** D08-NE-HVAC-airAC-PVAV-240to759kBtuh-10p8eer  MASControl v3.00.27 |
| RCA on First Stage of Multi-Stage Variable Volume AC Unit with Gas Heat | **All:** D08-NE-HVAC-airAC-PVAV-gte760kBtuh-10p8eer MASControl v3.00.27 |
| RCA on Second or Higher Stage of Multi-Stage Variable Volume AC Unit with Gas Heat |
| RCA on First Stage and Second or Higher Stage of Multi-Stage Variable Volume AC Unit with Gas Heat |

## 2.1 DEER Prototype Modifications: Damper Leakage

Modifications were made to the DEER prototypes to simulate outside air damper leakage and return air damper leakage and exhaust re-entrainment. These modified DEER prototypes were then used to develop the Base and Measure case eQUEST models as described in §2.2 and §2.3 below. Rationale for the damper leakage modifications is described below.

In the course of developing *Demand Controlled Ventilation for Single Zone Packaged HVAC,*[[12]](#endnote-12)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 (was not yet published) that indicates return air damper leakage and exhaust air re-entrainment for packaged HVAC systems are higher than previously thought, leading to inability of most systems to provide 100% outside air.

Review of *WO328* 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 **Table 11** were performed.

**Table 11 Baseline Modifications to eQUEST Keywords**

|  |  |  |
| --- | --- | --- |
| **eQUEST Keyword** | **DEER Value** | **Modified Baseline Value** |
| SYSTEM:MIN-OUTSIDE-AIR | Varies | 0.2 |
| SYSTEM:MAX-OA-FRACTION | 1.0 | 0.7 |
| 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. |

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).

These modified DEER prototype models are referred to as the “Damper Leakage” prototypes in the remainder of this Work Paper.

## 2.2 Base Case

The base case methodology begins with Damper Leakage prototypes and alters the models to simulate faults representing HVAC units in an as-found condition. **Table 12** describes the modeled faults covered by the Refrigerant Charge Adjustment Measure.

Table 12 Modeled and Represented As-Found Conditions

|  |  |
| --- | --- |
| **Modeled Faults** | **Represented As-Found Conditions** |
| Refrigeration System Undercharged by 0-20% | Packaged HVAC system found with refrigerant charge 0-20% below manufacture specifications |
| Refrigeration System Undercharged by >20% | Packaged HVAC system found with refrigerant charge greater than 20% below manufacture specifications |

DEER RCA methodology modifies the cooling system electric input ratio (EIR), or 1/(Coefficient of Performance), for the cooling unit at ARI rated conditions. For this analysis EIR adjustment factors were used to model the efficiency degradation associated with refrigerant undercharging as two faults: RCA 0-20% and RCA >20%. To implement the fault simulations listed in **Table 12** in the Damper Leakage prototypes, specific modifications to eQUEST keywords shown in **Table 13** were performed on all system types in accordance with existing DEER RCA calculation methodologies. The EIR adjustment factor were obtained from the 2008 DEER Update document “RCA\_DataForRefrigerantChange-CoolingOnly\_081004.xls” (included as Attachment 1). The values obtained in this document are the only EIR adjustment factors currently available from DEER. The DEER EIR adjustment factors are based on the level of refrigerant charge adjustment (0%-20% & 20+%) required to meet manufacturer specifications. These EIR adjustment factors are available for both residential and commercial units; our analysis utilized the EIR adjustment factors for commercial units.

**Table 13 Baseline Modifications to eQUEST Keywords**

|  |  |  |  |
| --- | --- | --- | --- |
| **Modeled Faults** | **eQUEST Keyword** | **DEER Value** | **Modified Baseline Value** |
| RCA 0-20% | SYSTEM:COOLING-EIR | Varies | Existing COOLING-EIR \* 1.152  Where 1.152 is the DEER RCA EIR adjustment factor |
| RCA > 20% | SYSTEM:COOLING-EIR | Varies | Existing COOLING-EIR \* 1.358  Where 1.358 is the DEER RCA EIR adjustment factor |

To verify the modified baseline assumptions, the DEER 2008 EIR adjustment values were compared to lab and field testing results given by Robert Mowris during a December 9, 2014 CPUC presentation titled “Overview of Field Observations and Laboratory Testing of Commercial HVAC Maintenance Faults” (included as Attachment 2 -CPUC-Presentation-CQM-20141209-RMA-DNVGL-1st-v11.ppt). The comparison revealed that the 2008 DEER EIR adjustment values for undercharged units were in line with current research and applying them in the base case modeling would result in accurate results.

Once the modeling was completed, a weighted comparison of the Single-Stage AC Unit with Gas Heat modeled savings versus the existing DEER and Non-DEER Ex Ante data for the 2013-14 Cycle values reported in the READI v.2.1.0 database was performed. The weighting assumptions shown in **Table 14** for both of the modeled RCA faults (RCA 0-20% & RCA >20%) were used to consolidate the modeled savings into a single savings value that was comparable with the existing DEER savings values.

For the majority of building types, the resulting modeled savings values are comparable with existing DEER savings values. There are noticeable differences in the Hotel (Htl) building type energy savings for all HVAC system types (**Figure 1**). Further analysis revealed that nearly 60% of the Htl’s HVAC system capacity is for the PTAC system type compared with 23% for Health/Medical - Hospital & 10% for Education – University. Exclusion of PTAC savings from this analysis brings the savings results back in line with existing DEER values. However, because this particular detail of DEER and Non-DEER Ex Ante RCA calculation methodology is unavailable, it is unknown if PTAC systems are included in existing DEER savings. For this work paper all of the building types are modeled using the same methodology and it is assumed the modeled energy savings for building types that contain PTACs are accurate.

Figure 1 – Energy Savings Comparison for Climate Zone 11

## The savings analysis assumes the savings for the first, second and higher stages of multi-stage systems are a proportion of the total savings for a multi-stage system model. eQUEST’s hourly reporting function was used to find the proportion of runtime attributable to each stage of operation. Specifically, the part-load cooling ratio (Var 61) and cooling output (Btu/hr) (Var 156) variables for the Office – Small building type were used to determine that the first stage operated 80% of the total runtime hours and the remaining 20% used a higher stage of cooling. The resulting proportion is applied during energy savings calculations in §2.4 and §2.5.

## Measure Case

The Damper Leakage prototypes used as the reference models for the measure case buildings are unmodified.

## 2.4 Electric Energy Savings Estimation Methodologies

Because RCA is a Retrofit Add-on measure only a single baseline calculation is required. The electric energy savings from the first baseline are represented in the calculations below.

**Equation 1: Annual Energy Savings**

Where:

kWh per ton savings = annual unit energy savings

Weighted baseline kWh = annual building energy consumption from each modeled fault weighted by the frequency distribution the corresponding as-found condition, see **Table 14**

Measure kWh = annual building energy consumption of measure

Cooling tons = design cooling capacity of base case non-PTAC systems

Proportional savings factor (PSF) = Adjusts savings values based on unit type and stage, see **Table 15 Proportional Savings Factors**

Table 14 *Weightings for Savings Calculations*

|  |  |
| --- | --- |
| **Fault Distribution** | **Fault Weight** |
| RCA 0-20% | 0.95 |
| RCA > 20% | 0.05 |

Table 15 *Proportional Savings Factors*

|  |  |
| --- | --- |
| **System** | **Proportional Savings Factor** |
| Single Stage HVAC Unit | 1 |
| First Stage of Multi-Stage HVAC Unit | 0.8 |
| Second or Higher Stage of Multi-Stage HVAC Unit | 0.2 |
| First Stage and Second or Higher Stage of Multi-Stage HVAC Unit | 1 |

The fault weighting assumptions were determined from comparison between actual modeled energy savings using the DEER RCA calculation methodology and the DEER and Non-DEER Ex Ante data for the 2013-14 Cycle values reported in the READIv.2.1.0 database. A sample calculation using a 1996 vintage Office - Small (OfS) single-stage prototype with AC and Gas Heat located in climate zone 1 is provided. **Table 16** below displays modeling results for building energy use and cooling system tonnage. For building types that have PTAC systems, the cooling tonnage was calculated as the sum of all systems’ individual tonnages.

Table 16 OfS-w01-v96-airAC-55to64kBtus - Prototype Electric Energy Use and Cooling Capacity Data

|  |  |  |  |
| --- | --- | --- | --- |
|  | **RCA 0-20%** | **RCA >20%** | **Measure** |
| Whole building energy use (kWh/yr) | 105,470 | 105,764 | 105,251 |
| System cooling capacity (Btu/h) | 271,019 | 271,019 | 271,019 |

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

Table 17 DEER Peak Demand Periods

|  |  |  |  |
| --- | --- | --- | --- |
| **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 similar 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 demand reduction = annual unit demand reduction

Weighted baseline kW = average demand for DEER peak period of customer average from each modeled fault weighted by the frequency distribution the corresponding as-found condition, see Table 14

Measure kW = average demand for DEER peak period of measure

Cooling tons = design cooling capacity of all base case systems

Proportional savings factor (PSF) = Adjusts savings values based on unit type and stage, see **Table 15 Proportional Savings Factors**

A sample calculation using a 1996 vintage Office - Small (OfS) single-stage prototype located in climate zone 1 is provided here.

**Table 18** provides electric demand and cooling capacity data for the baseline and measure case on the OfS prototype approximating a building constructed in 1996 in climate zone 1.

**Table 18 OfS-w01-v96-airAC-55to64kBtus - Prototype Electric Demand Use and Cooling Capacity Data**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **RCA 0-20%** | **RCA >20%** | **Measure** |
| 9/16 2-3pm demand (kW) | 32.00 | 33.01 | 31.24 |
| 9/16 3-4pm demand (kW) | 31.66 | 32.74 | 30.86 |
| 9/16 4-5pm demand (kW) | 23.86 | 24.39 | 23.46 |
| 9/17 2-3pm demand (kW) | 29.79 | 30.41 | 29.33 |
| 9/17 3-4pm demand (kW) | 29.75 | 30.48 | 29.20 |
| 9/17 4-5pm demand (kW) | 23.00 | 23.37 | 22.71 |
| 9/18 2-3pm demand (kW) | 44.60 | 47.85 | 42.17 |
| 9/18 3-4pm demand (kW) | 42.90 | 45.98 | 40.61 |
| 9/18 4-5pm demand (kW) | 37.09 | 39.98 | 34.94 |
| **DEER Demand Average (kW)** | **32.74** | **34.25** | **31.62** |
| System cooling capacity (Btu/h) | 271,019 | 271,019 | 271,019 |

## Gas Energy Savings Estimation Methodologies

There are no natural gas energy savings associated with this measure.

## Vintage Weighted Average

Baseline and measure simulations used the seven DEER building vintages[[14]](#endnote-14) described in **Table 19** for both customer average and code prototypes.

**Table 19 DEER Building Vintage Codes and Descriptions**

|  |  |
| --- | --- |
| **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 UES value (kWh/ton, kW/ton, or therms/ton)

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

W = Weight for a given vintage

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

**Table 20** contains sample measure savings for a customer average Office - Small building in climate zone 4 and PG&E territory. The sample measure savings are shown by vintage and the resulting final weighted savings values after applying the DEER 2014 weighting methodology.

Table 20 Vintage Weighting Sample for PG&E OfS CZ04

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **WtSet** | **Vintage** | **DEER Weight** | **Savings**  **kWh/Ton** | **Demand Reduction**  **kW/Ton** |
| PGEOfSCZ04 | v75 | 9.2826 | 6.4 | 0.04 |
| PGEOfSCZ04 | v85 | 8.2469 | 6.4 | 0.04 |
| PGEOfSCZ04 | v96 | 3.6064 | 6.7 | 0.04 |
| PGEOfSCZ04 | v03 | 1.4606 | 6.0 | 0.04 |
| PGEOfSCZ04 | v07 | 0.9704 | 6.1 | 0.04 |
| PGEOfSCZ04 | v11 | 0.9704 | 5.0 | 0.04 |
| PGEOfSCZ04 | v14 | 0.4852 | 6.4 | 0.04 |
| **Final Weighted Savings** | **Existing** |  | **6.3** | **0.04** |

# 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 **Table 21** Building Types and Load Shapes.

Table 21 Building Types and Load Shapes

|  |  |  |
| --- | --- | --- |
| **Building Type** | **Load Shape** | **E3 Alternate Building Type** |
| Assembly | DEER:HVAC\_Split-Package\_AC, DEER:HVAC\_Split-Package\_HP | NON\_RES |
| Education - Primary School |
| Education - Secondary School |
| Education - Relocatable Classroom |
| Education - Community College |
| Education - University |
| Grocery |
| Health/Medical - Nursing Home |
| Health/Medical - Hospital |
| Lodging – Hotel |
| Lodging - Motel |
| Manufacturing – Bio/Tech |
| Manufacturing – Light Industrial |
|  |
| Office - Large |
| Office - Small |
| Restaurant - Fast-Food |
| Restaurant - Sit-Down |
| Retail - Multistory Large |
| Retail - Single-Story Large |
| Retail - Small |
| Storage - Conditioned |
| Warehouse - Refrigerated |

# Section 4. Costs

The 2010-2012 WO17 Ex Ante Measure Cost Study[[15]](#endnote-15) (Cost Study) provides refrigerant charge adjustment per-ton costs by leveraging a sample size of ten direct install (DI) primary price data points from utilities over the past two program cycles (2010-2012 and 2013-2014). The Cost Study does not specify how many of the ten DI costs in the sample are multiple stage or single stage RTUs. It is assumed that the per-ton costs should be applied to the combined capacity of all compressor stages in RTUs to which the measure is being applied. The DEER Measure Cost Data Users Guide[[16]](#endnote-16) was also referenced. As a Retrofit Add-on measure, the incremental cost for RCA is equal to the gross measure cost.

## 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

The Cost Study provides costs per ton cooling for RCA of $9.92 for materials and $26.78 for labor for a total cost of $36.70/ton.

## 4.3 Full and Incremental Measure Cost

Table 22 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

Table 23 Full and Incremental Costs

|  |  |  |  |
| --- | --- | --- | --- |
| **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| REA | $9.92 + $26.78 = $36.70 | $9.92 + $26.78 = $36.70 | N/A |

# Attachments

Attachment 1 – DEER RCA Analysis & Calculation Methodology- EIR Fac Values - RCA\_DataForRefrigerantChange-CoolingOnly\_081004.xls



Attachment 2 – CPUC Presentation - Robert Mowris – 12/9/2014 - Overview of Field Observations and Laboratory Testing of Commercial HVAC Maintenance Faults



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