Work Paper SCE17HC023.0

**Revision 0**

**Southern California Edison**

**Quality Installation for Residential Split Systems and System Upgrade**

# At-a-Glance Summary

|  |  |
| --- | --- |
| **Measure Codes** | AC-19538, AC-19539, AC-19540, AC-19541, AC-19542, AC-19543, AC-9544, AC-19545, AC-19546, AC-19547, AC-19548, AC-19549, AC-9551, AC-19552, AC-19553, AC-19554, AC-19555, AC-19556 |
| **Measure Description** | This work paper includes two categories of measures:  **Non-DEER Measures:**  Quality Installation plus Efficiency Upgrade of residential HVAC units.  **DEER Measures:**  The measure cases include SEER Rated Residential AC, SEER Rated Residential Heat Pump, AFUE Rated Residential Gas Furnace |
| **Base Case Description** | The base cases for Quality Installation plus Efficiency Upgrade of HVAC units are Title 20 compliant units following standard installation processes, AFUE 80% gas furnace and 14 SEER or 8.2 HSPF and 14 SEER Heat pump, HVAC unit. The base cases for HVAC units include residential split HVAC units, both A/C units and heat pumps |
| **Units** | kWh/ton, kW/ton, Therm/ton |
| **Energy Savings** | Refer to Excel Calculation Attachment |
| **Full Measure Cost ($/unit)** | Refer to Excel Calculation Attachment |
| **Incremental Measure Cost ($/unit)** | Refer to Excel Calculation Attachment |
| **Effective Useful Life** | 15 years - HV-ResAC |
| **Measure Installation Type** | Replace on Burnout (ROB) |
| **Net-to-Gross Ratio** | 0.7 - DEER NTGR ID: All-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).  This work paper incorporates the following updates: (a) DEER 2015 update for 2011 Federal for Standards effective January 1, 2015 affecting all DEER HVAC measures based on SEER-rated equipment efficiency (b) cost update per modified 2010-2012 WO-017 Ex Ante Measure Cost Study findings, and (c) Updated input parameters for estimating QI measure per CPUC’s HVAC Impact Evaluation Study – WO32. |

# Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Rev** | **Date** | **Author** | **Summary of Changes** |
| 0 | 03/07/17 | Eli Caudill/Clearesult;  Andres Fergadiotti/SCE | * Incorporates findings from WO032 into modeled results * Includes DEER 2017 values for existing measures * Incorporates manufacturer data for air conditioner and heat pump efficiencies due to changes in airflow and fan power |

# 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 work paper details the quality installation of standard (Title 20) and higher efficiency residential split HVAC units, both air conditioning (A/C) units and heat pumps. Quality installation is defined by Energy Star [C] as having properly sized units, properly matched components, refrigerant charge, airflow, and sealed ducts. Given the magnitude of refrigerant charge loss required to impact the unit performance, the refrigerant charge is considered adequate in both the base and measure case units for the purposes of this work paper.

The savings reported are based on the impact of properly sizing the unit, sealing the ducts, meeting the airflow (cfm/ton) standards, and confirming that the total duct system static pressure meets installation standards. The kWh, kW and natural gas savings for Quality Installation in this work paper are provided per ton of air conditioning.

Base, Standard, and Measure Cases

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measure (Non-DEER) | Quality Installation + Efficiency Upgrade- Split Air Conditioner Replacing Standard Unit  Quality Installation + Efficiency Upgrade-Split Heat Pump Replacing Standard Unit  This work paper details the quality installation of standard (Title 20) and higher efficiency residential split HVAC units, both air conditioning (A/C) units and heat pumps. |
| Measure (DEER) | Installation of Split Air Conditioner SEER 15, 16, and 17 |
| Measure (DEER) | Installation of Split Heat Pump SEER 15, 16, and 17 |
| Existing Condition |  |
| Code/Standard |  |
| Industry Standard Practice | Standard Installation of Title 20 compliant Standard Split Air Conditioner  Standard Installation of Title 20 compliant Standard Split Heat Pump  Standard Installation of Title 20 compliant Standard Gas Furnace |

Measures and Codes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Codes** | | | | **Measure Name** |
| SCG | SDG&E | SCE | PG&E |
|  |  | AC-19538 |  | Quality Installation + Efficiency Upgrade- Split Air Conditioner SEER 15.0 Replacing SEER 14.0 |
|  |  | AC-19539 |  | Quality Installation + Efficiency Upgrade- Split Air Conditioner SEER 16.0 Replacing SEER 14.0 |
|  |  | AC-19540 |  | Quality Installation + Efficiency Upgrade- Split Air Conditioner SEER 17.0 Replacing SEER 14.0 |
|  |  | AC-19541 |  | Quality Installation + Efficiency Upgrade-Split Heat Pump SEER 15.0 Replacing SEER 14.0 |
|  |  | AC-19542 |  | Quality Installation + Efficiency Upgrade-Split Heat Pump SEER 16.0 Replacing SEER 14.0 |
|  |  | AC-19543 |  | Quality Installation + Efficiency Upgrade-Split Heat Pump SEER 17.0 Replacing SEER 14.0 |
|  |  | AC-19544 |  | RE-HV-ResAC-lt45kBtuh-15S |
|  |  | AC-19545 |  | RE-HV-ResAC-lt45kBtuh-16S |
|  |  | AC-19546 |  | RE-HV-ResAC-lt45kBtuh-17S |
|  |  | AC-19547 |  | RE-HV-ResAC-45to65kBtuh-15S |
|  |  | AC-19548 |  | RE-HV-ResAC-45to65kBtuh-16S |
|  |  | AC-19549 |  | RE-HV-ResAC-45to65kBtuh-17S |
|  |  | AC-19551 |  | RE-HV-ResHP-15p0S-8p7H |
|  |  | AC-19552 |  | RE-HV-ResHP-16p0S-9p0H |
|  |  | AC-19553 |  | RE-HV-ResHP-17p0S-9p4H |
|  |  | AC-19554 |  | Res-GasFurnace-AFUE90 |
|  |  | AC-19555 |  | Res-GasFurnace-AFUE92 |
|  |  | AC-19556 |  | Res-GasFurnace-AFUE94 |

These measures are limited to Single Family Residential buildings served by the HVAC systems described by each measure variation. The measures are defined for all 16 California climate zones and savings are calculated for vintage 2015 and a weighted average of 5 Database for Energy Efficient Resources (DEER17) thermostats using utility-specific weightings – See Attachment SCE17HC023.01 A1

For eligibility for incentives, qualified contractors with appropriate duct sealing, HVAC sizing, and/or Quality Installation training shall be used. HVAC equipment installation shall comply with all latest applicable Energy Standards – Title 20, Title 24, and Codes. Refer to programs that offer these measures for specific restrictions and guidelines in addition to those described herein. 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 or natural gas services from that IOU.

## 1.2 Technical Description

This work paper includes Quality Installation plus Efficiency Upgrade of HVAC units. The measure and base cases for Residential Quality Installation (RQI) are based on the recommendations of Work Order 32 – See Attachment SCE17HC023.01 A2. Measure cases include Title 20 (SEER 15, 80 AFUE) and higher efficient residential split and packaged HVAC units, both A/C units and heat pumps. A properly installed unit includes the unit being properly sized, sealing the ducts, meeting the airflow (cfm/ton) standards, confirming that the total duct system static pressure meets installation standards, and confirming appropriate refrigerant charge. The table above includes measure names and their respective solution codes.

The measure base case for Quality Installation plus Efficiency Upgrade of HVAC units is a system installed following standard processes and meeting equipment efficiency requirements of Title 20 (14 SEER, 80% AFUE). The base cases include residential split and packaged HVAC units, both A/C units and heat pumps. A unit installed following standard processes may be over-sized, may contain ducts that are not properly sealed, may have less than appropriate airflow, may have a total duct system static pressure that is too high, and may have inappropriate refrigerant charge. Please see Section 2 for more information.

This work paper additionally includes DEER2017 measures addressing system upgrade on gas furnace, split-system air conditioner, and split-system heat pump equipment.

## 1.3 Installation Types and Delivery Mechanisms

The delivery methods are Financial Support – Down-stream Incentive – Deemed; Partnership – Downstream Incentive – Deemed; and Financial Support – Down-stream Incentive - EUCA.

The measure install type is Replace on Burnout (ROB).

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 |

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.

Delivery Method Descriptions

|  |  |
| --- | --- |
| **Delivery Method** | **Description** |
| Financial Support | The program motivates customers, through financial incentives such as rebates or low interest loans, to implement energy efficient measures or projects. |
| Partnership | The program implements projects through a partnership between the utility and an institutional, government, or community-based organization. |

Incentive Method Descriptions

|  |  |
| --- | --- |
| **Incentive Method** | **Description** |
| 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. |

## 1.4 Measure Parameters

### 1.4.1 DEER Data

Non-DEER measures considered in this work paper are not currently available in the DEER Database. Although DEER has measures for proper duct sealing and high efficiency HVAC, it does not cover the full range of defective installations addressed in this work paper (i.e., HVAC unit over-sized, low airflow rate, and reduced fan efficiency due to high duct system static pressure) and it does not cover the combined efficiency gain of properly installing a more efficient HVAC.

DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Item** | **Used for Workpaper?** |
| Modified DEER methodology | Yes |
| Scaled DEER measure | No |
| DEER Base Case | No |
| DEER Measure Case | No |
| DEER Building Types | Yes (SFM) |
| DEER Operating Hours | Yes (DEER Prototype) |
| DEER eQUEST Prototypes | Yes (SFM)-modified as described in Section 2 Calculation Methodology |
| DEER Version | DEER 2017 v1.0. – Duct Sealing assumptions |
| Reason for Deviation from DEER | Non-DEER measure - Only parts of the measure (equipment upgrade and duct sealing) are utilized in DEER 2017 v1.0. This work paper addresses additional installation issues not currently considered in DEER for Quality Installation of gas furnace with AC and for heat pumps. This work paper also addresses combining Quality Installation and replacement of high efficiency HVAC units. Note that gas savings from QI of gas furnaces were not evaluated nor included in this work paper |
| DEER Measure IDs Used | N/A |

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** |
| Res-Default>2 yrs | All other EEM with no evaluated NTGR; existing EEM with same delivery mechanism for more than 2 years | Res | Any | Any | 0.55 |
| All-Default<=2 yrs | All other EEM with no evaluated NTGR; new technology in program for 2 or fewer years | Res | Any | Any | 0.70 |
| Res-sAll-mDuctSeal | Duct Sealing | Res | Any | Prescriptive Rebate | 0.78 |

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

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

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)** |
| HV-ResAC | High Efficiency Air Conditioner (package and split systems) | Res | HVAC | 15 | 5 |
| HV-ResHP | High Efficiency Heat Pump | Res | HVAC | 15 | 5 |
| HV-DuctSeal | Duct Sealing | Res | HVAC | 18 | 6 |

### 1.4.2 Codes and Standards Analysis

For Quality Installation + Efficiency Upgrade:

Title 20 requires a minimum 14.0 SEER value for single phase air conditioners and heat pumps less than 65,000 Btu/h. Title 24 does require the same installation practices; however, the compliance rates for these have been historically low. Data from WO032 is utilized in this work paper to account for the most recent base and measure installation practices. Given these low compliance rates, the base case is considered non-compliant – with equipment efficiency on the base case meeting the minimum Code requirements.

Gas Furnace Equipment

Title 20 requires a minimum 80% AFUE value for non-weatherized gas furnaces less than 225,000 Btu/hour input. Title 24 identifies a minimum efficiency for warm-air gas-fired furnaces of 78% AFUE.

Code Summary

|  |  |  |
| --- | --- | --- |
| **Code** | **Reference** | **Effective Dates** |
| Title 24 (2016) | Section 110.1 requires air conditioners under 65 kBtu/h to comply with Title 20  Section 110.2 requires warm-air gas fired furnaces under 225,000 Btu/h to have minimum AFUE of 78% | 1/1/2017 |
| Title 20 (2016) | Section 1605.1 requires air-cooled split-systems and packaged air conditioners under 65 kBtu/h to have a minimum SEER of 14 and additional EER code requirements above and below 45 kBtu/h for split air conditioners only.  Section 1605.1 requires non-weatherized gas furnaces to have a minimum AFUE of 80%. | 1/1/2016 |
| Federal EPCA Amended Standard (2011) | CFR §430.32(c) Energy and water conservation standards and their compliance dates requires split-system and packaged air conditioners to have a minimum SEER of 14 | 1/1/2015 |

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

Non-DEER documentation review for preparation and development of this work paper is documented and referenced in the Reference Section.

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

* Impact Evaluation of Residential Quality Installation projects; DNV GL, January 28, 2014
* 2010-12 Southern California Edison
* Site visits of 2010-12 RQI program participants in Southern California Edison homes and non-participants in Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric homes
* Data from this study were used for baseline and measure case models

## 1.6 Data Quality and Future Data Needs

Data from manufacturers was used in this work paper to account for change in system efficiency due to changes in airflow and fan efficacy. Manufacturer data is not presented consistently as it relates to inclusion of fan heat in system efficiency and output capacity of HVAC units. Future data gathering of the impact of airflow rate and its impact on bypass factor would be beneficial, so that the change in sensible and latent capacities could be accounted for properly.

Further analysis of the multiple faults that take place during standard installations would be beneficial. A study from National Institute of Standards and Technology [[[1]](#endnote-1)] provides evidence of the compounding of the impacts of improper installation on the degradation of HVAC systems performance, which is not accounted for in standard modeling methodologies.

Assumptions were made concerning the cost of implementing RQI using a combination of WO017 [[[2]](#endnote-2)] data and program implementation data. Future efforts to incorporate actual contractor costs of implementing RQI would be beneficial.

# Section 2. Calculation Methodology

**For DEER measures**, savings associated with above-code AFUE and SEER improvements have been obtained from the DEER READI v2.4.7 tool and are presented in the table below for reference. Savings from these DEER measures are adopted directly from DEER2017.

READI Data Used

|  |  |  |
| --- | --- | --- |
| **Measure Code** | **(Sample) Measure Name** | **READI Data** |
| AC-19544 | RE-HV-ResAC-lt45kBtuh-15S | See Attachment SCE17HC023.01 A3 |
| AC-19545 | RE-HV-ResAC-lt45kBtuh-16S |  |
| AC-19546 | RE-HV-ResAC-lt45kBtuh-17S |  |
| AC-19547 | RE-HV-ResAC-45to65kBtuh-15S |  |
| AC-19548 | RE-HV-ResAC-45to65kBtuh-16S |  |
| AC-19549 | RE-HV-ResAC-45to65kBtuh-17S |  |
| AC-19551 | RE-HV-ResHP-15p0S-8p7H | See Attachment SCE17HC023.01 A4 |
| AC-19552 | RE-HV-ResHP-16p0S-9p0H |  |
| AC-19553 | RE-HV-ResHP-17p0S-9p4H |  |
| AC-19554 | Res-GasFurnace-AFUE90 | See Attachment SCE17HC023.01 A5 |
| AC-19555 | Res-GasFurnace-AFUE92 |  |
| AC-19556 | Res-GasFurnace-AFUE94 |  |

**For Non-DEER measures**, measure calculation methods are primarily based upon the recommendations of Work Order 32 in addition to system efficiency (EIR) improvements per equipment manufacturer performance documentation as a function of system airflow, total cooling capacity, and system power.

A three-step process was followed to determine savings, beginning with: 1) collecting and analyzing manufacturer’s data to develop eQuest percent EIR improvement from base case to measure case, 2) apply pre-processing results to DEER prototype eQuest models to produce base and measure case models and perform batch processing of the model set, and 3) conduct post processing of the eQuest batch processing results to calculate electricity, natural gas, and demand savings. The following sections provide additional detail on each of these steps.

## 2.1 Pre-Processing

The primary objective of pre-processing was to account for changes in CFM and fan efficacy and to incorporate those values into the cooling EER and heating COP. This allowed for development of a percent improvement in EER and/or COP values from a base case to the measure case that would represent improvement from CFM and fan efficacy changes.

Two of the measured field parameters highlighted in WO32 were used in pre-processing calculations to arrive at EER and COP percent improvements that would reflect WO32 findings. Parameters used for pre-processing are fan system power and system airflow. WO32 measured field parameters used in pre-processing are summarized in the Table below.

|  |  |  |
| --- | --- | --- |
| **Input Performance Parameter** | **WO32 Findings** | **Remarks** |
| Fan system power (watts per cfm of total system airflow) | Base: 0.57  Measure: 0.49 | Fan system power is updated proportionately to findings in WO32. Measure EIR updated accordingly to account for fan power reduction of measure. |
| System Airflow  (cfm per ton of nominal cooling capacity) | Base: 300 cfm/ton  Measure: 338 cfm/ton | System airflow indirectly accounted in the model by tracking system variations on efficiency (e.g., EIR) as a function of airflow (near the low limit <400 cfm/ton), total capacity, and power. |
| System oversizing  (percent) | Base: 13.0%  Measure: 10.0% | **Excluded** - the WO32’s “equipment sizing” input parameter was excluded in the BES since conducted BES sensitivity analysis suggests that there are no significant benefits on system performance due to reductions on modeled equipment oversizing from 13% to 10%. |

Air conditioner and heat pump manufacturer data were reviewed to estimate the impact of airflow and airflow performance on system efficiency at AHRI standard conditions.

Cooling and (heat pump) heating performance data was collected for nominal 4 ton units for SEER 15, 16, and 17 split-system air conditioners, and for HSPF 8.7, 9.0, and 9.4 split-system heat pumps. The cooling side manufacturer models include Lennox, Carrier, Amana-Goodman, and York AC. The heating side manufacturer models include Lennox, Carrier, and York AC. See Attachment SCE17HC023.01 A6 for additional details on pre-processing calculations..

Incorporation of WO32 fan system power considerations into Pre-Processing

Manufacturer data collected on all units include capacity and power consumption at 3-4 different fan speeds (and corresponding CFM) for each specific rated combinations of outdoor and indoor components. For each CFM, EERs or COPs for base and measure cases were calculated from the data. Typically, EER is calculated as:

Where,

In cases where gross capacity was provided, net capacities for base and measure cases were calculated by adding (for COP) or subtracting (for EER) the respective watts/cfm times the fan cfm to account for the effect of fan heat on heating or cooling capacity. WO32 provides a baseline fan power efficacy of 0.57 watts per CFM of indoor fan unit flow and measure value of 0.49 watts per CFM. Example baseline fan energy and baseline net capacity equations are:

Base and measure CFM/ton were then calculated by dividing the CFM by the respective net capacities. Base and measure case COP or EER for each fan setting were calculated as the respective net capacities divided by respective total unit kW. For HVAC units where only the outdoor unit power was reported, the WO32 base or measure fan system power was used along with each CFM to find base or measure total unit power. These calculations were performed for every HVAC model at each available fan speed.

Incorporation of WO32 system airflow considerations into Pre-Processing

Results from incorporation of WO32 fan system power considerations described above were then built upon in order to implement WO32 airflow considerations. This was done by first applying a linear trend to establish a regression equation relating measure CFM/ton to measure COP or EER for all fan speed settings for each HVAC unit. Next, the measure case CFM/ton for the lowest fan speed setting for each HVAC unit was multiplied by the ratio of the measure-to-base case WO32 CFM/ton values, or 338/300. This adjusted measure CFM/ton value was then used in the regression equation to calculate a new measure COP or EER (a value which incorporates both fan system power and system airflow). This new measure COP or EER was then used to determine a percent COP or EER improvement over the base case values.

See Attachment SCE17HC023.01 A6 for details on calculation process used.

## 2.2 eQuest modeling and Batch Processing

Energy savings and demand reduction were estimated using eQUEST version 3.65 energy modeling software. SFM DEER prototypes were generated using MASControl2 v1.1.21 which leverages DOE2.3. The following table lists the DEER prototype parameter selections used to provide the full set of models utilized in this work paper.

|  |  |  |
| --- | --- | --- |
| **Prototype Parameter** | **Parameters Used for Modeling** | |
| Building Type | SFM | |
| Climate Zones | All 16 Climate Zones | |
| Vintages | Single vintage: 2015 | |
| HVAC Types | DXGF, DXHP | |
| Weather | CZ2010 | |
| Thermostat Options (to be individually modified and simulated with savings weighted using DEER methodology) | T1, T2, T3, T4, T5 (2007 Building Vintage – latest vintage available for thermostat weighting) | |
| Case Options | Measure | |
| Tech ID Options | **AC** RE-HV-ResAC-lt45kBtuh-14S  RE-HV-ResAC-lt45kBtuh-15S  RE-HV-ResAC-lt45kBtuh-16S RE-HV-ResAC-lt45kBtuh-17S | **HP\***  RE-HV-ResHP-15S-8.7H RE-HV-ResHP-16S-9H RE-HV-ResHP-17S-9.4H |

\*Note: The SEER 14 heat pump model is obtained as the initialized prototype for any of the listed HP Tech IDs with code baseline selected

As shown in the following table, a total of six general model types were generated for savings calculations including baseline and measure models for AC-gas furnace (GF) and heat pump systems. Note that a “Baseline” model run may include a baseline (“BSL”) keyword value or (eQuest) prototype (“Pr”) keyword value, as can be seen by comparing the gas furnace, Baseline, “heat” model with the gas furnace, Baseline, “cool” model.

For differentiating gas furnace heating season savings and cooling season savings in the GF models, Baseline and Measure models named “heat” and “cool” were run. Seasonal savings are determined using eQuest hourly outputs and are explained in following sections. The heat pump models are named “both” because they include both COOLING-EIR and HEATING-EIR modifications; this is also why seasonal runs were not necessary for heat pump models.

General Model Types and Relevant eQuest Keyword Categories

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Model run** | | | **eQuest Keyword** | | | | | |
| **COOLING-EIR** | **HEATING-EIR** | **SUPPLY-DELTA-T** | **SUPPLY-KW/FLOW** | **DUCT-AIR-LOSS** | **SUPPLY-FLOW** |
| GF (AC-gas furnace) | Baseline | Electric “cool” | BSL | NA | 0 | 0 | BSL | Pr |
| Gas “heat” | Pr | NA | Pr | BSL | BSL | Pr |
| Measure | Electric “cool” | MSR | NA | 0 | 0 | MSR | MSR |
| Gas “heat” | Pr | NA | Pr | MSR | MSR | MSR |
| HP | Baseline | Electric “both” | BSL | BSL | 0 | 0 | BSL | Pr |
| Measure | Electric “both” | MSR | MSR | 0 | 0 | MSR | MSR |

\*-“Categories” refers to Pr, BSL, and MSR

\*Pr-this category indicates an unmodified DEER prototype value for the keyword was used

\*BSL-this category indicates a prototype keyword value was modified to a base case value.

\*MSR- this category indicates a prototype keyword value that was modified to a measure case value.

\*0-indicates a prototype value that was modified to a zero value.

As mentioned previously, two measured field parameters highlighted in WO32 were used in pre-processing calculations to arrive at EER percent improvements. When adjusting model EIR values to correlate with pre-processing EER improvements, fan energy was included. Therefore, for eQuest models in which an EIR improvement is adopted (i.e., all HP models and cooling season gas furnace models), values for SUPPLY-DELTA-T and SUPPLY-KW/FLOW have been zeroed per DOE2 documentation for inclusion of fan energy in EIR values. However, as can be seen in the table below, for models not adopting any EIR modification (i.e., in GF heat models), the WO32 field parameter for base case and measure case fan system power has been explicitly included as keyword value changes for SUPPLY-KW/FLOW, while SUPPLY-DELTA-T has been left at its prototype value for Measure and Baseline models. This strategy of performing seasonal model runs for the gas furnace allows differentiation of heating season fan energy savings that would otherwise be unaccounted for.

The table below also shows that appropriate WO32 duct leakage and system airflow field measured value modifications are incorporated into the keywords DUCT-AIR-LOSS and SUPPLY-FLOW for all models. This means that for DUCT-AIR-LOSS, all Baseline models (“cool”, “heat” and “both”) incorporate the BSL value – and Measure models the MSR value – as shown below. However, for SUPPLY-FLOW the Baseline model value used is always the eQuest prototype value (Pr), while the Measure case is the prototype value multiplied by the WO32 finding of (338 measure case CFM)/(300 base case cfm). See Attachment SCE17HC023.01 A7 for details on Batch Input Summary.

eQuest (DOE2) Keyword Values (gas furnace with AC)

|  |  |  |  |
| --- | --- | --- | --- |
| **eQuest Keyword** | **Units** | **BSL** | **MSR** |
| COOLING-EIR | kW/Btuh | 0.2804 | SEER 15: 0.2670 (4.21% Improvement)  SEER 16: 0.2734 (3.89% Improvement)  SEER 17: 0.2573 (4.12% Improvement) |
| SUPPLY-KW/FLOW | kW/CFM | 0 for cooling models  0.00057 for heating models | 0 for cooling models  0.00049 for heating models |
| DUCT-AIR-LOSS\* | fraction | 1 Story: 0.166, 2 Story: 0.148 | 1 Story: 0.115, 2 Story: 0.103 |
| SUPPLY-FLOW | CFM | \*\*Pr (varies by system & CZ) | \*Pr x (338 cfm MSR)/(300 cfm BSL)  (varies by system & CZ) |
| Flow Capacity | CFM/Ton | \*\*Pr | \*\*Pr |

\*- DEER defaults are 0.15 for 1 story and 0.134 for 2 story

\*\*-Pr indicates unmodified DEER prototype value

eQuest (DOE2) Keyword Values (heat pump)

|  |  |  |  |
| --- | --- | --- | --- |
| **eQuest Keyword** | **Units** | **BSL** | **MSR** |
| COOLING-EIR | kW/Btuh | 0.2804 | SEER 15: 0.2670  SEER 16: 0.2734  SEER 17: 0.2573 |
| HEATING-EIR | kW/Btuh | 0.2874 | HSPF 8.7: 0.2562 (5.7% Improvement)  HSPF 9.0: 0.2631 (6.3% Improvement)  HSPF 9.4: 0.2542 (5.1% Improvement) |
| SUPPLY-KW/FLOW | kW/CFM | 0 | 0 |
| DUCT-AIR-LOSS\* | fraction | 1 Story: 0.166, 2 Story: 0.148 | 1 Story: 0.115, 2 Story: 0.103 |
| SUPPLY-FLOW | CFM | \*\*Pr (varies by system & CZ) | \*Pr x 338/300  (varies by system & CZ) |
| Flow Capacity | CFM/Ton | \*\*Pr | \*\*Pr |

\*- DEER defaults are 0.15 for 1 story and 0.134 for 2 story

\*\*-Pr indicates unmodified DEER prototype value

## 2.3 Post-Processing

Consumption Savings

eQuest hourly outputs for end use energy categories were used to determine HVAC energy use in all models. The table below presents the eQuest energy end use categories used. A macro was developed that extracted heating season vent fan end use energy from all models by summing each hour’s end use energy for which there was also a demand for heating. The same macro simultaneously extracted unconditional, annual sums for space cooling, space heating, and supplemental heat pump end use energy, thus providing a set of raw post-processing energy end use data which is available in Attachment SCE17HC023.01 A8.

eQuest Energy End Uses Summed for Annual Modeled HVAC Energy

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model Run** | | | **kWh** | **Therms** |
| GF | Baseline | “cool” | Space cooling | N/A |
| “heat” | Vent fan\* | Space heating |
| Measure | “cool” | Space cooling | N/A |
| “heat” | Vent fan\* | Space heating |
| HP | Baseline | “both” | Space cooling, Space heating, Supp. HP heat | N/A |
| Measure | “both” | Space cooling, Space heating, Supp. HP heat | N/A |

\*hourly kWh for Vent/fan energy is summed over the year for each model only during periods (hours) where there was a non-zero demand for heating.

The table below illustrates that the annual HVAC electrical energy use for a gas furnace model (Baseline or Measure) is calculated as the summation of energy end use for space cooling in the “cool” model, and the heating-season-only vent fan energy use in the “heat” model. The table also shows that the annual HVAC energy use for all heat pump models (Baseline or Measure) was calculated as the summation of energy end uses for space heating, space cooling, and supplemental heat pump heating.

Consumption savings were then calculated by subtracting the Measure model kWh (HP and GF “cool”; SEER 15, 16, and 17 model runs) and therm (GF, “heat”; SEER 15, 16 & 17) consumption values from the corresponding Baseline (SEER 14) model consumption values. Specific savings calculation examples for GF and HP models for a SEER 15 measure case are provided:

Gas Furnace Model Energy Savings Calculation Example for SEER 15 Measure Case

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Case** | **Model Name** | **Space Cooling**  **(kWh)** | **Vent fan, Heating**  **Only**  **(kWh)** | **Total HVAC Electricity**  **(kWh)** | **Total HVAC Natural Gas**  **(Therm)** |
| Base Case | SFM-wCZ09-v2015-rDXGF-t1-S14-BSLcool | 3,159 | N/A | 3,159 + 266 = 3,425 | 350 |
| SFM-wCZ09-v2015-rDXGF-t1-S14-BSLheat | N/A | 266 |
| Measure Case | SFM-wCZ09-v2015-rDXGF-t1-S15-MSRcool | 2,731 | N/A | 2,731 + 239 = 2,970 | 333 |
| SFM-wCZ09-v2015-rDXGF-t1-S15-MSRheat | N/A | 239 |
| **Total Savings** | **SFM-wCZ02-v2015-rDXGF-t1-S15** | | | **3,425 -2,970 = 455** | **350 - 333**  **= 17** |
| CZ09 Tonnage | 11.22 tons (GF and HP models) | | | | |
| **Savings/Ton** |  | | | **40.6** | **1.5** |

To obtain savings on a per ton basis, the total aggregated savings were divided into total aggregated modeled tonnages which are climate zone dependent for the modeled residential building type per given vintage.

Total Model Tonnage by Climate Zone

|  |  |
| --- | --- |
| **Climate Zone** | **Aggregate Model Tonnage** |
| 1 | 8.23 |
| 2 | 9.46 |
| 3 | 11.41 |
| 4 | 11.17 |
| 5 | 12.51 |
| 6 | 13.37 |
| 7 | 10.70 |
| 8 | 12.57 |
| 9 | 11.22 |
| 10 | 10.84 |
| 11 | 11.41 |
| 12 | 10.57 |
| 13 | 10.95 |
| 14 | 15.83 |
| 15 | 16.98 |
| 16 | 12.74 |

Attachment SCE17HC023.01 A8 details the calculations performed on the raw post-processing data up to and including final, thermostat-weighted, per ton consumption and demand savings. Thermostat weighted, kWh per ton savings are summarized in Attachment SCE17HC023.01 A1..

Demand Savings

Demand reduction estimates must consider the DEER peak demand period, which is 2:00 PM to 5:00 PM during specific weekday periods and varies by climate zone as shown below. Since demand periods are a cooling season phenomenon, only the demand associated with cooling end use energy in the heat pump and gas furnace “cool” models are considered to determine demand savings. Thermostat weighted, kW per ton savings are summarized in Attachment SCE17HC023.01 A9.

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

Thermostat Weighting

Thermostat weighting factors per DEER2017 documentation was used to determine final per ton kWh and kW savings and examples are provided. Detailed calculations for determining final weighted kWh and kW savings can be accessed on Attachment SCE17HC023.01 A9.

Table 20: DEER 2017 Thermostat Weighting Factors (Building Vintage 2007)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Climate Zone** | **Thermostat Type** | | | | |
| **t1** | **t2** | **t3** | **t4** | **t5** |
| CZ01 | 44% | 12% | 22% | 11% | 11% |
| CZ02 | 40% | 24% | 10% | 9% | 17% |
| CZ03 | 9% | 27% | 29% | 14% | 21% |
| CZ04 | 39% | 15% | 21% | 21% | 4% |
| CZ05 | 4% | 22% | 2% | 70% | 3% |
| CZ06 | 21% | 37% | 2% | 2% | 38% |
| CZ07 | 64% | 30% | 2% | 2% | 2% |
| CZ08 | 63% | 2% | 11% | 12% | 12% |
| CZ09 | 2% | 83% | 2% | 2% | 11% |
| CZ10 | 32% | 19% | 16% | 25% | 8% |
| CZ11 | 56% | 3% | 23% | 4% | 14% |
| CZ12 | 10% | 19% | 31% | 21% | 18% |
| CZ13 | 21% | 5% | 24% | 5% | 45% |
| CZ14 | 44% | 2% | 2% | 2% | 50% |
| CZ15 | 44% | 20% | 20% | 2% | 13% |
| CZ16 | 2% | 39% | 53% | 4% | 2% |

Example Thermostat Weighting Calculation for Heat Pump kWh Savings in CZ09

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure Run Name** | **kWh/ton** | **Weighting** | **kWh/ton x Weighting** |
| SFM-wCZ09-v2015-rDXHP-t1-S15 | 78.4 | 2% | 1.6 |
| SFM-wCZ09-v2015-rDXHP-t2-S15 | 90.4 | 83% | 75.4 |
| SFM-wCZ09-v2015-rDXHP-t3-S15 | 60.2 | 2% | 1.2 |
| SFM-wCZ09-v2015-rDXHP-t4-S15 | 51.6 | 2% | 1.0 |
| SFM-wCZ09-v2015-rDXHP-t5-S15 | 64.8 | 11% | 6.9 |
| **SFM-wCZ09-v2015-rDXHP-tw-S15:** | | | **86.1** |

# Section 3. Load Shapes

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** |
| Residential Single Family | DEER: HVAC\_Eff\_AC | RES |

# Section 4. Costs

The gross measure cost (GMC) is the measure equipment material costs plus installation labor. WO017 measure and labor costs were used to calculate the costs to deliver all equipment and tasks associated with RQI. The total cost using data from WO017 and assumptions in hours of labor is $4,307.63 as shown in the table below.

RQI Measure Costs Contributions Based on WO017

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Measure** | **Equipment Cost** | **Labor Hours** | **Labor Rate** | **Total Labor** | **WO017**  **Measure Cost** | **Unit** | **Cost Contribution %** |
| Split System DX 16 SEER | $2,097.69 | 7.26 | $91.34 | $663.13 | $2,760.82 | Per 3 Tons | 64.1% |
| Residential Gas Furnace  AFUE 80 | $640.51 | 4.26 | $68.34 | $291.13 | $931.64 | 60,000 Btuh | 21.6% |
| Duct Sealing and Testing | $71.45 |  |  | $181.24 | $252.69 | Per Project | 5.9% |
| ACCA Manual J, D, S |  | 4 | $91.34 | $181.24 | $181.24 | 4 hours | 4.2% |
| Airflow and Refrigerant Check  1 hour labor @ $91.34/hr |  | 1 | $91.34 | $181.24 | $181.24 | 1 hour | 4.2% |
| **Total** |  |  |  |  | $4,307.63 |  |  |

Costs from program year 2013-2014 implementation data detailed in Attachment SCE17HC023.01 A10 show an average cost for the installation of a 16 SEER air conditioner with RQI at $10,982.38. These include the total costs for new air conditioning systems and RQI. Costs are not directly available from program implementation data to disaggregate between standard installation and quality installation tasks. The cost contributions developed using data from WO017 were used to disaggregate and estimate RQI costs and then applied to the average installation cost from program implementation data to acquire a cost for the RQI tasks.

Costs are calculated for performing RQI using a combination of 2010-2012 WO017 Ex Ante Measure Cost data, assumed labor time, and program implementation data. The incremental cost of performing RQI is assumed to be for duct sealing material costs and additional labor and is added to the incremental cost of equipment upgrades.

## 4.1 Base Case Cost

RQI:

The base cost for installation without RQI is (64.1% + 21.6%) x $10,892 = $9,337

The referenced air conditioner size in WO017 and from program data is 3 tons. Base case cost per ton is $9,337/3 tons = $3,112/ton.

DEER Measures:

Referenced base costs for existing DEER measures are found in WO017.

The base cost for installation of a 36,000 MBH 14 SEER split-system air conditioner is $2,207.70. This includes $1,544.93 for equipment and $662.77 for labor.

The base cost for installation of a 24,000 MBH 14 SEER split-system heat pump is $2,465.96. This includes $1,738.35 for equipment and $727.62 for labor.

The base cost for installation of a 60,000 MBH AFUE 80 furnace is $931.64. This includes $640.51 for equipment and $291.13 for labor.

## 4.2 Measure Case Cost

RQI:

The measure case for installation with RQI is $10,892

Measure case cost per ton is $10,892/3 tons = $3,660/ton

DEER Measures:

Referenced measure costs for existing DEER measures are found in WO017\*.

DEER Measure Costs (WO017)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Total Installation Costs** | | |  |  |
| **Measure** | **Equipment Cost** | **Labor Cost** | **Full Installed Cost** | **Units** | **MBH** |
| RE-HV-ResAC-lt45kBtuh-15S | $ 1,821.31 | $ 662.77 | $ 2,484.08 | MBH | 36,000 |
| RE-HV-ResAC-lt45kBtuh-16S | $ 2,097.69 | $ 662.77 | $ 2,760.46 | MBH | 36,000 |
| RE-HV-ResAC-lt45kBtuh-17S | $ 2,374.07 | $ 662.77 | $ 3,036.84 | MBH | 36,000 |
| RE-HV-ResAC-45to65kBtuh-15S | $ 1,821.31 | $ 662.77 | $ 2,484.08 | MBH | 36,000 |
| RE-HV-ResAC-45to65kBtuh-16S | $ 2,097.69 | $ 662.77 | $ 2,760.46 | MBH | 36,000 |
| RE-HV-ResAC-45to65kBtuh-17S | $ 2,374.07 | $ 662.77 | $ 3,036.84 | MBH | 36,000 |
| RE-HV-ResHP-15p0S-8p7H | $ 2,286.64 | $ 727.62 | $ 3,014.26 | MBH | 24,000 |
| RE-HV-ResHP-16p0S-9p0H | $ 2,834.93 | $ 727.62 | $ 3,562.55 | MBH | 24,000 |
| RE-HV-ResHP-17p0S-9p4H | $ 3,384.06 | $ 727.62 | $ 4,111.68 | MBH | 24,000 |
| Res-GasFurnace-AFUE90 | $ 911.91 | $ 291.13 | $ 1,203.04 | MBH | 60,000 |
| Res-GasFurnace-AFUE92 | $ 1,086.18 | $ 291.13 | $ 1,377.30 | MBH | 60,000 |
| Res-GasFurnace-AFUE94 | $ 1,140.46 | $ 291.13 | $ 1,431.58 | MBH | 60,000 |

\*17 SEER heat pump cost is not available in WO017. Installation cost above baseline was found in READI v2.4.7

## 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 |

MEC = Measure Equipment Cost; MLC = Measure Labor Cost

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

Calculate FMC and IMC and insert into the table below.

Full and Incremental Costs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure** | **Installation Type** | **Incremental Measure Cost (per ton)** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| Quality Installation + Efficiency Upgrade- Split Air Conditioner SEER 15.0 Replacing SEER 14.0 | ROB | $610.64 | $610.64 | N/A |
| Quality Installation + Efficiency Upgrade- Split Air Conditioner SEER 16.0 Replacing SEER 14.0 | ROB | $702.77 | $702.77 |  |
| Quality Installation + Efficiency Upgrade- Split Air Conditioner SEER 17.0 Replacing SEER 14.0 | ROB | $794.89 | $794.89 |  |
| Quality Installation + Efficiency Upgrade-Split Heat Pump SEER 15.0 Replacing SEER 14.0 | ROB | $792.66 | $792.66 |  |
| Quality Installation + Efficiency Upgrade-Split Heat Pump SEER 16.0 Replacing SEER 14.0 | ROB | $1,066.80 | $1,066.80 |  |
| Quality Installation + Efficiency Upgrade-Split Heat Pump SEER 17.0 Replacing SEER 14.0 | ROB | $1,341.37 | $1,341.37 |  |
| RE-HV-ResAC-lt45kBtuh-15S | ROB | $92.13 | $92.13 |  |
| RE-HV-ResAC-lt45kBtuh-16S | ROB | $184.25 | $184.25 |  |
| RE-HV-ResAC-lt45kBtuh-17S | ROB | $276.38 | $276.38 |  |
| RE-HV-ResAC-45to65kBtuh-15S | ROB | $92.13 | $92.13 |  |
| RE-HV-ResAC-45to65kBtuh-16S | ROB | $184.25 | $184.25 |  |
| RE-HV-ResAC-45to65kBtuh-17S | ROB | $276.38 | $276.38 |  |
| RE-HV-ResHP-15p0S-8p7H | ROB | $274.15 | $274.15 |  |
| RE-HV-ResHP-16p0S-9p0H | ROB | $548.29 | $548.29 |  |
| RE-HV-ResHP-17p0S-9p4H | ROB | $822.86 | $822.86 |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure** | **Installation Type** | **Incremental Measure Cost (per MBH)** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| Res-GasFurnace-AFUE90 | ROB | $4.52 | $4.52 | N/A |
| Res-GasFurnace-AFUE92 | ROB | $7.43 | $7.43 |  |
| Res-GasFurnace-AFUE94 | ROB | $8.33 | $8.33 |  |

# Attachments

1. SCE17HC023.0 A1 - DEER2017-SingleFamily\_Tstat-Weights-2016-07-20
2. SCE17HC023.0 A2 - DNV GL. (January 28, 2014) HVAC Impact Evaluation FINAL Report WO32 HVAC – Volume 1: Report, Prepared for California Public Utilities Commission, Energy Division
3. SCE17HC023.01 A3 - EnergyImpacts dxAC Equipment
4. SCE17HC023.01 A4 - EnergyImpacts dxHP Equipment
5. SCE17HC023.01 A5 - EnergyImpacts GasFurnace Equipment
6. SCE17HC023.0 A6 - Pre-processing Calcs\_SCE17HC023.0.xlsx
7. SCE17HC023.0 A7 - Batch Processing Input Summary.xlsx
8. SCE17HC023.0 A8 - HourlyPostProcess\_SCE17HC023.0.xlsx
9. SCE17HC023.0 A9 - Calculation Template.xlsm
10. SCE17HC023.0 A10 - RQI and DEER Cost.xlsx

# References

1. [] Domanski, P, Henderson, H, Payne, W. (September, 2014) Sensitivity Analysis of Installation Faults on Heat Pump Performance, Retrieved from http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1848.pdf [↑](#endnote-ref-1)
2. [] Itron, Inc. (May 24, 2014) 2010-2012 WO017 Ex Ante Measure Cost Study Final Report, Retrieved from <http://www.deeresources.com/files/DEER2016/download/2010-2012_WO017_Ex_Ante_Measure_Cost_Study_-_Final_Report.pdf>

   [C] https://www.energystar.gov/index.cfm?c=hvac\_install.hvac\_install\_index [↑](#endnote-ref-2)