Work Paper SCE17HC039

**Revision 2**

**Southern California Edison**

**VFD Retrofit to Central Plant Systems**

# At-a-Glance Summary

|  |  |
| --- | --- |
| **Measure Codes** | AC-91987, AC-55411, AC-18932 |
| **Measure Description** | Variable Speed Drive on Chilled Water Pump (CHWP)  Variable Speed Drive on Condenser Water Pump (CWP) Pump |
| **Base Case Description** | Source: Existing Custom Equipment/ Title-24  CHWP Control – Single speed  CWP Control – Single speed |
| **Units** | Per Nominal Horsepower (HP) |
| **Energy Savings** | Refer to Excel Calculation Attachment 1 |
| **Full Measure Cost ($/unit)** | Refer to Excel Calculation Attachment 1 and 5 |
| **Incremental Measure Cost ($/unit)** | Refer to Excel Calculation Attachment 1 and 5 |
| **Effective Useful Life** | NEW: 15 years (DEER EUL ID: HVAC-VSD-pump)  REA: 5 years (DEER EUL ID: HVAC-VSD-pump) in accordance with Draft Resolution E-4807 [510] |
| **Measure Installation Type** | Retrofit Add-on (REA) – All measures  New Construction (NEW) – CWP Control – (Single speed baseline only) |
| **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** |
| 0 | 12/13/2016 | Arvind Subramanya/TRC | - This work paper is an update of SCE13HC039.4  - New calculation template update for 2017 program year  - Work paper is updated with 2016 Title-24 code requirement language.  - Cost update from latest 2016 RSMeans Cost Database  - New construction (New) program type added. Measure impacts estimated and adjusted from corresponding REA measure  - Three calculation templates have been developed in this revision, one per each solution code.  - For REA measures, updated the EUL value in accordance with Draft Resolution E-4807 [510] |
| 1 | 12/06/2017 | Arvind Subramanya/TRC | - Cooling Tower fan Variable Speed Drive (VSD) measure (AC-14365) removed since determined that this technology is ISP  - Add AC-18932 Variable Speed Drive on Condenser Water Pump Control for new installations  - Three calculation templates are provided in this revision, one per each solution code  - Revised measure “baseline” per resolution E-4818 |
| 2 | 07/13/2018 | Akhilesh Endurthy/ Lincus | -Removed building types not supported (under DEER) by Central Plant Equipment e.g., Restaurant - Sit-Down  - Measures re-evaluated using DEER2017 Chiller Models  - Cost section updated using 2018 RS Means data |

# Commission Staff and Cal TF Comments

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Rev** | **Party** | **Submittal Date** | **Comment Date** | **Comments** | **WP Developer Response** |
|  |  |  |  |  |  |

Cal TF website: <http://www.caltf.org/>

# Section 1. General Measure & Baseline Data

## 1.1 Measure Description & Background

This work paper details the energy savings achieved from installing variable speed drives (VSD) on Chilled Water Pumps (CHWPs) and Condenser Water Pumps (CWPs) in water cooled central plant applications. VSDs are also called Variable Frequency Drives (VFDs) when used on equipment powered by alternating current.

VFDs reduce pump motor energy by adjusting motor speeds to meet actual load conditions. Estimated demand and energy savings for this work paper are based on DOE-2/eQUEST modeling results using DEER2017 model Prototypes.

**Base, Standard, and Measure Cases**

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measure | Variable Speed Drive on Chilled Water Pump (CHWP)  Variable Speed Drive on Condenser Water Pump (CWP) |
| Existing Condition | Existing Customer Equipment or applicable Title-24 based on vintage  CHWP Control – Single speed for REA Program Type  CWP Control – Single speed for REA and NEW Program Type |
| Code/Standard | Existing Customer Equipment or applicable Title-24 based on vintage  Measure technology is compared with current version of Title -24, 2016.  CHW Pump Control – Single speed for REA Program Type  CW Pump Control – Single speed for REA and NEW Program Type |
| Industry Standard Practice | No explicit ISP study exist but these equipment are included in Title-24 code. Applicable Title-24 code is used, wherever applicable. |

Measures and Codes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Codes** | | | | **Measure Name** |
| SCG | SDG&E | SCE | PG&E |
|  |  | AC-91987 |  | Variable Speed Drive on Chilled Water Pump (REA) |
|  |  | AC-55411 |  | Variable Speed Drive on Condenser Water Pump (REA) |
|  |  | AC-18932 |  | Variable Speed Drive on Condenser Water Pump (NEW) |

**Eligibility Requirements:**

* The measures in this workpaper apply to the following DEER building types that use water-cooled central plant systems
  + Education – Community College, Education – Secondary School, Education – University, Health/Medical - Hospital, Lodging – Hotel, Manufacturing Biotech, Health/Medical - Nursing Home, Office Large, Office Small, Retail - Multistory Large.
* For building types not listed above but use water-cooled central plant systems, measure savings will be mapped under “Office Small,” which has the relatively lower savings. Program will track all building types incentivized under the measures.
* Constant speed Condenser Water Pump (CWP) and Chilled Water Pumps (CHWP) not already equipped with VFDs are eligible.
* CHWP VFD measure is only eligible when host equipment (CHWP), is installed before 2005 and chilled water coils are controlled by 3-way valves.
* All new Variable Speed Drive and motor equipment will be UL Listed
* All work shall be fully met all applicable regulations including but not limited to latest NEC, Mechanical Code, and Energy Standards.

**Implementation and installation requirements:**

Successful implementation of this measure will depend greatly on the characteristics of the installed system. For the VFD addition to the condenser water pump (CWP) special attention should be given to the condenser water flow turndown capabilities of the existing chiller(s). It is imperative that chiller manufacturer selection data and retrofit information be carefully reviewed to ensure that the existing chiller(s) are rated to operate at the selected minimum condenser water flow, and that the control strategy includes capability to increase the flow as needed to keep the leaving condenser temperature from exceeding an upper limit dependent on the existing chiller. Refer to the Attachment 4 Measure Limitations Memo in the Attachments Section for more information.

For the chilled water pumps (CHWP), the designers should evaluate the flow control at the cooling/ heating coil in the air-handling units and should consider potential retrofit from 3-way to 2-way valve that may be needed to adequately complete the measure.

In all cases, measure installation shall fully meet all applicable regulations including but not limited to the latest California Energy Standards, CMC, and NEC. All new VSD/VFD equipment supporting the measure shall be UL Listed.

**Other program restrictions and guidelines:**

Incentive application process requires the Program (and/or Program representative) to confirm that existing conditions do not already have variable speed drive control for CWPs and CHWPs. Additionally, for CHWPs, and given current Energy Standards requirements, it should be confirmed that the host equipment was installed before 2005.

For building types not listed above in the Eligibility Requirements but use water-cooled central plant systems, program will collect brief facility description including at a minimum: building type, building conditioned space (sqft), chiller plant capacity (tons), and operating schedule.

Measure offering is limited to central plant systems operating at standard conditions. Measure excludes central plant equipment under any type of plant optimization and/or retro-commissioning at both the central plant and/or system HVAC levels; and/or central plants supporting “process” load; and/or central plant operating with thermal energy storage. Hence, non-standard central plant applications shall be incentivized under Custom programs.

Evaluation of Existing Baselines

D.16-08-019 formally adopted a policy of existing conditions as the basis for estimating ex-ante savings of deemed energy efficiency measures. Resolution E-4818 was approved by the Commission on March 2, 2017 and directed Commission staff to update DEER to reflect revised baseline policies.

In this workpaper, existing baseline conditions were evaluated using the measures’ EUL in relation to the number of (Title 24) code cycles in which the measure has been required, with both the EUL and RUL values obtained from DEER2017.

1. For the **Variable Speed Drive on Condenser Water Pump (CWP) Control** measure, the current version or previous versions of Title-24 does not require VFDs on CWPs. Hence, it is highly likely for the measure NOT to have been fully adopted by industry. Therefore, this measure has savings potential above current practice.
2. For the **Variable Speed Drive on Chilled Water Pump (CHWP) Control** measure, this measure has been a code requirement since Title-24 2005 which is less than the effective useful life (EUL) of the host equipment, CHWP motor. Hence, this measure will be eligible for CHWP vintages before 2005.
3. For the **Variable Speed Drive on Cooling Tower (CT) Fan Control** measure, the host equipment’s EUL (e.g., Motor-pump = 15 years) is less than the duration in which the measure has been required in code. Hence, it is highly likely for the measure to have been naturally adopted by industry; therefore, expected to be ISP and consequently no longer supported in this and/or future versions of the workpaper.

## 1.2 Technical Description

Central plant systems provide space cooling to a building by cooling water in a chiller and circulating this chilled water either through a chilled water coil in an air handler or throughout the building zones. Chillers may be air-cooled or water-cooled, and in the case of water-cooled chillers, a separate water loop absorbs heat from the chiller which is then rejected by a cooling tower. In these systems, a significant amount of energy is consumed by pumps used to circulate water. CHW pumps circulate water cooled by the chiller and CW pumps circulate the water that transfers heat between the chiller and the cooling tower.

These pumps are designed to meet peak load conditions, when the equipment must run at approximately 100% the system design capacity. However, for the majority of the time the demand for cooling is less than the peak design capacity. This presents significant energy savings opportunities if pump speed can be varied to meet actual load.

Variable frequency drives control motor speed by varying the frequency and voltage of the pump motor. VFDs are programmed to reduce pump speed to meet actual load, thus reducing pump speed when load drop below design conditions, resulting in significant pumping energy savings throughout the year.

## 1.3 Installation Types and Delivery Mechanisms

The installation type is retrofit add-on (REA) and NEW.

The delivery method is Financial Support - Down Stream Incentive – Deemed, with savings reported on a per horsepower basis.

**Installation Type Descriptions**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Installation Type** | **Savings** | | **Life** | |
| 1st Baseline (BL) | 2nd BL | 1st BL | 2nd BL |
| Retrofit Add-on (REA) | Customer Existing or applicable code, whichever is more stringent | N/A | EUL\_HOST/3 capped at the EUL of the add-on equipment | N/A |
| New Construction (NEW/NC) | Current 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 - Deemed | 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. |
| On-bill Finance – Loan (OBF) | The program offers financing for the cost of 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. |

**Installation Type Descriptions**

Table below lists the installation and applicable DEER building types for each measure. In this revision of the work paper, separate calculation templates are developed for Chilled Water Pump control and Condenser Water Pump control.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Attachment #** | **Measure Codes** | **Measure Name** | **Installation Type** | **Building Types** |
| SCE |
| 1 | AC-91987 | Variable Speed Drive on Chilled Water Pump Control | REA | ECC. ESe, EUn, Hsp, Htl, Nrs, MBT, OfL, OfS, Rt3 |
| 1 | AC-55411 | Variable Speed Drive on Condenser Water Pump Control | REA | ECC. ESe, EUn, Hsp, Htl, Nrs, MBT, OfL, OfS, Rt3 |
| 1 | AC-18932 | Variable Speed Drive on Condenser Water Pump Control | NEW | ECC. ESe, EUn, Hsp, Htl, Nrs, MBT, OfL, OfS, Rt3 |

## 1.4 Measure Parameters

### 1.4.1 DEER Data

The 2017 Database for Energy Efficient Resources’ (DEER) [26, 49] READi database does contain (DEER2005) VFD on CHWPs as a combination of the following two measures but only for certain building types.

1. D03-046 has three-way valves and a single-speed pump in the base case, and two-way valves and a single-speed pump in the measure case, and
2. D03-047 has two-way valves and a single-speed pump in the base case, and two-way valves and a variable-speed pump in the measure case.

Further, DEER does not include measure evaluation savings on CWP VFD, and DEER2017 provides latest updated chiller models; hence, savings estimates in this version of the workpaper were evaluated based on DEER2017 chiller models and documentation with model inputs and assumptions as described in Section 2.

DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Item** | **Used for Workpaper?** |
| Modified DEER methodology | No |
| Scaled DEER measure | No |
| DEER Base Case | Yes (DEER2017 Base Case model) |
| DEER Measure Case | No |
| DEER Building Types | Yes |
| DEER Operating Hours | Yes |
| DEER eQUEST Prototypes | Yes |
| DEER Version | 2017 |
| Reason for Deviation from DEER | * DEER 2017 is not updated with DEER2017 Chiller models for CHWP measure * CWP measure is not in DEER |
| DEER Measure IDs Used | N/A |

**Net-to-Gross Ratio**

The NTG values were obtained using the DEER READI tool version 2.4.8. The relevant NTG value for all measures in this work paper is 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 | 0.60 |

**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 version 2.4.7. 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 version 2.4.8. 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. For REA measures, the EUL and RUL values were obtained in accordance with Draft Resolution E-4807 [510]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| HVAC-VSD-pump  (**REA**) | Variable Flow Water Loop, VSD Pump (used for the VFD on Chilled Water Pump and VFD on Condenser Water Pump) | Com | HVAC | 5 | N/A |
| HVAC-VSD-pump  (**NEW**) | Variable Flow Water Loop, VSD Pump (used for the VFD on Condenser Water Pump) | Com | HVAC | 15 | 5 |

### 1.4.2 Codes and Standards Analysis

The code prevalent at the time of updating this work paper, Title 24 2016 [496], Section 140.4(k)1, page 193, requires “HVAC chilled and hot water pumping shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to no more than the larger of: a) 50 percent or less of the design flow rate; or b) the minimum flow required by the equipment manufacturer for the proper operation of equipment served by the system”. The exception to this requirement is systems that include no more than three control valves and total pumping power less than or equal to 1.5 hp.

Section 140.4(k)6A, has requirements for Variable Flow Controls, “Individual pumps serving variable flow systems and having a motor horsepower exceeding 5 hp shall have controls or devices (such as variable speed control) that will result in pump motor demand of no more than 30 percent of design wattage at 50 percent of design water flow. The pumps shall be controlled as a function of required differential pressure.” Additionally, Section 140.4(k)6B, provides requirements for pressure sensor location and setpoint. The exception to Section 140.4(k)6 are heating hot water pumps and condenser water pumps (CWPs) serving only water-cooled chillers.

Code Summary

|  |  |  |
| --- | --- | --- |
| **Code** | **Reference** | **Effective Dates** |
| Title 24 (2016) | 2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings,  Section 140.4(k)1 and 140.4(k)6. Page 193 and 194. | January 1, 2017 |

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

N/A

## 1.6 Data Quality and Future Data Needs

DEER2017 Chiller Models are used to evaluate and estimate the savings for measures savings. Any future updates to the DEER Chiller models may trigger work paper updates. Additionally, chilled water pumping system EUL of 15 years is approaching the years since variable flow on chilled water pumps has been a code requirement. Hence, CHWP VFD measure may require an industry standard practice evaluation in the near future.

The simultaneous operation of the two measures in this WP has interactive effects and impacts energy savings. If in case, both the measures are implemented for vintages 96 and 03, then the measures must be cascaded, and the total (aggregated) estimated savings will be slightly lower than sum of individual measure savings. This version of the workpaper, given vintage restrictions on the CHWP VFD, is expected to primarily support CWP VFD measure adoptions. In future workpaper updates, this will not be a problem once the CHWP measure is removed from offering due to ISP.

# Section 2. Calculation Methodology

Estimated demand and energy savings for this work paper are based on building energy simulations of variable frequency drives (VFD) serving central plant chilled water (distribution) and condenser water pumps. Simulations were conducted using the DOE-2/eQUEST v.3.65 modeling tool using latest DEER2017 Chiller Models. The following describes step-by-step calculation methodology.

1. DEER2017 Chiller Models were retrieved from DEER including models for WCChlrBase among others such as WtrCent1/2/3 Path A/B, WtrRecip, WtrScrew chiller equipment.
2. Reviewing the associated DEER documentation, it was determined that the WCChlrBase are the appropriate DEER baseline prototypes to model CHWP and CWP VFD measures as parametric runs.
3. Building Types: All building types in DEER2017 Chiller Models are considered as eligible building types. Please refer to Eligibility Requirements in Section 1.1 for eligible building types.
4. Vintages: For CWP VFD measure, the models corresponding to following vintages are considered. For building vintages before 1993, the condensed water pumping system is past its effective useful life and assumed to have been replaced with newer pumping system, hence older vintages would not apply to the pump equipment.

For CHWP VFD measure, only vintages 1996 and 2003 are considered (and allowed) since this measure is not eligible for vintages after 2005 as detailed in Section 1.1.

* **1993 – 2001 (1996 – shown in the table below as 96)**
* **2001 – 2005 (2003 – shown in the table below as 03)**
* 2005 – 2009 (2007 – shown in the table below as 07)
* 2009 – 2013 (2011 – shown in the table below as 11)
* 2013 – 2014 (2014 – shown in the table below as 14)

1. Batch processing is run for the selected vintage and all climate zones using CZ2010 weather files for the models in WCChlrBase. The output file of the batch processing provides the annual end-uses and total usage for electricity (kWh/year), fuels, non-coincident peak, and utility charges – See Attachment 2 for details.
2. Additionally, in the DEER 2017 Chiller models, the electric rates are set-up with $1 per kWh for the DEER peak period of each climate zone and $0 for the reaming hours. Hence, the electric utility charges from the batch processing output file is the kWh during the (9) DEER peak hours. Dividing this by 9 provides the DEER peak usage for each climate zone.
3. The batch processing derivatives files that comes along with DEER2017 models is ran with only the location and CZ2010 weather files to estimate the baseline energy usage and DEER peak kW. Please note that the baseline usage is the same for both the measures.
4. For the proposed energy usage, the following keyword charges are made in the applicable tables in the batch processing derivatives files. Separate batch files are run for CWP VFD and CHWP VFD measure. The resulting output file provides the proposed energy usage and DEER peak kW.

eQUEST Keyword Modifications

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure** | | | |
| **Vintage(s)** | **Keyword** | **Baseline Design Value (Defaulted)** | **Measure Design Value** |
| **CHW\*  Loop Pump EEM\*\*** | | | |
| 96,03 | PUMP:CAP-CTRL | ONE-SPEED-PUMP | VAR-SPEED-PUMP |
| 96,03 | SYSTEM:CHW-VALVE-TYPE | THREE-WAY | TWO-WAY |
| **CW\*\*\* Loop Pump EEM** | | | |
| 96,03,07,11,14 | PUMP:CAP-CTRL | N/A | VAR-SPEED-PUMP |
| 96,03,07,11,14 | CHILLER:CW-FLOW-CTRL | CONSTANT-FLOW | VARIABLE-FLOW |
| 96,03,07,11,14 | CHILLER:CW-MIN-FLOW | N/A | 0.70 (ratio) |
| 96,03,07,11,14 | CHILLER:MAX-COND-T | N/A | 85.0 (degF) |

\*Chilled Water (CHW)

\*\* Energy Efficiency Measure (EEM)

\*\*\*Condenser Water (CW)

For the VFD on condenser water pump measure, it is important to define a minimum condenser water flow rate and a maximum allowable leaving condenser temperature. For the minimum flow rate, the determinants are the minimum flow required by the chiller and the minimum flow required by the tower. Based on research a conservative estimate of 70% (References [65] and [359], and Attachment 5) achievable flow turndown was chosen for the measure case. For the maximum leaving condenser temperature, the limit was set to 85 oF, the condenser temperature at the rated conditions for the modeled chiller.

1. The difference between energy usage and DEER peak kW between baseline and measure batch output files for the “total building energy” provided the energy savings and peak kW Savings for each building type, vintage, and climate zone.
2. To calculate the savings per horse power (HP), base case and measure case pump design (hp) capacities were determined from the eQuest/SIM (PV-A, design parameter report) files, per building type, vintage, and climate zone. This provides the “design” kW of the pumps, which is converted to HP by dividing it by 0.746. The nominal HP for the motors is determined by comparing the (hp) design capacity to the industry standard motor sizes available from NEC 2008 Table 430.250.
3. To create a single savings value for each building type and climate zone combination, a weighted average was calculated using DEER2014 Building Weights for vintages. For certain climate zones that fall in more than one IOU, the sum of weights is considered as the total weight.
4. The DEER peak kW setup in DEER2017 models discussed in Step 6 above uses CZ2 DEER peak definitions. Since the latest DEER peak definition is DEER14, the DEER peak kW savings from DEER2017 models are adjusted. The variation (% increase or decrease) in DEER peak kW using CZ2 and DEER14 peak kW definition is calculated for all climate zones, for Office Large Building type, the building with highest weight per DEER14 weights table, and for vintages 2007 for CWP and 2003 for CHWP. This variation is applied to all the building types. Please refer to DEER kW analysis folder with-in Attachment 2 for peak kW adjustment calculations.

Please refer to Attachment 2 for the savings analysis and Attachment 6 for the eQuest models and batch files for both CHWP and CWP VFD measures. Sample measure savings for building type, Education – Community College (ECC), are included below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Building Type** | **CZ** | **CWP**  **kWh/year/HP** | **CWP**  **DEER14 Peak kW/HP** | **CHWP**  **kWh/year/HP** | **CHWP**  **DEER14 Peak kW/HP** |
| ECC | CZ01 | 159.4 | 0.09 | 828.5 | 0.48 |
| ECC | CZ02 | 233.1 | 0.10 | 1,274.3 | 0.27 |
| ECC | CZ03 | 248.4 | 0.06 | 1,362.1 | 0.27 |
| ECC | CZ04 | 281.3 | 0.08 | 1,600.5 | 0.35 |
| ECC | CZ05 | 251.1 | 0.07 | 1,479.3 | 0.38 |
| ECC | CZ06 | 350.0 | 0.08 | 1,643.5 | 0.31 |
| ECC | CZ07 | 346.8 | 0.07 | 1,721.8 | 0.23 |
| ECC | CZ08 | 321.8 | 0.07 | 1,672.3 | 0.18 |
| ECC | CZ09 | 374.2 | 0.05 | 1,973.9 | 0.12 |
| ECC | CZ10 | 350.5 | 0.08 | 1,966.2 | 0.17 |
| ECC | CZ11 | 319.9 | 0.07 | 1,740.5 | 0.33 |
| ECC | CZ12 | 308.8 | 0.07 | 1,573.7 | 0.18 |
| ECC | CZ13 | 324.3 | 0.09 | 1,669.6 | 0.28 |
| ECC | CZ14 | 360.5 | 0.07 | 1,766.4 | 0.43 |
| ECC | CZ15 | 452.5 | 0.08 | 2,474.3 | 0.29 |
| ECC | CZ16 | 169.5 | 0.05 | 1,149.9 | 0.21 |

# 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** |
| Education – Community College | DEER:HVAC\_Chillers | NON\_RES |
| Education - Secondary School | DEER:HVAC\_Chillers | NON\_RES |
| Education - University | DEER:HVAC\_Chillers | NON\_RES |
| Health/Medical - Hospital | DEER:HVAC\_Chillers | NON\_RES |
| Health/Medical - Nursing Home | DEER:HVAC\_Chillers | NON\_RES |
| Lodging – Hotel | DEER:HVAC\_Chillers | NON\_RES |
| Manufacturing - Bio/Tech | DEER:HVAC\_Chillers | NON\_RES |
| Office – Large | DEER:HVAC\_Chillers | NON\_RES |
| Office – Small | DEER:HVAC\_Chillers | NON\_RES |
| Retail - Multistory Large | DEER:HVAC\_Chillers | NON\_RES |

# Section 4. Costs

## 4.1 Base Case Cost

**Retrofit add on**

For this measure category, the base case cost is assumed to be zero because these are discretionary modifications (retrofit) to the customers’ existing equipment. Their alternative is to make no changes to their existing system.

**Base Case Cost**

The base case cost is $0/hp for all three measures because the base case refers to the existing equipment, which does not require replacement.

## 4.2 Measure Case Cost

The cost documentation for the measures are update using 2018 RS Means Electrical Cost Data Handbook [504]. The installed equipment will be new VFD, 3-Phase, 460 volts, with enclosed (NEMA 1) or custom engineered VFD. The total costs include material and labor. Reference Line Numbers from RS Means 2018 are 262923100100 and 262923101100 for enclosed and customer engineered VFD respectively.

The average total cost of VFD per Nominal HP ($/HP) of CHWP and CWP motor is calculated by taking the average $/HP cost for nominal motor HPs ranging from 3HP to 200HP for enclosed and custom engineered VFDs. The average bare material and labor costs are $288.02/hp and $90.60/hp respectively.

Please refer to Attachment 3 for detailed cost analysis.

## 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** |
| REA | MEC + MLC | MEC + MLC | N/A |
| NEW | (MEC + MLC) – (BEC + BLC) | (MEC + MLC) – (BEC + BLC) | N/A |

MEC = Measure Equipment Cost; MLC = Measure Labor Cost

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

For NEW, the BEC and BLC costs are zero in this case since there is no VFD in the base case. Essentially, the measure cost for both REA and NEW install types are same for the CWP VFD measure.

**Full and Incremental Costs**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure** | **Installation Type** | **Incremental Measure Cost [$/hp]** | **Full Measure Cost [$/hp]** | |
| **1st Baseline** | **2nd Baseline** |
| AC-91987 | REA | $378.62 | $378.62 | N/A |
| AC-55411 | REA | $378.62 | $378.62 | N/A |
| AC-18932 | NEW | $378.62 | $378.62 | N/A |

# Attachments

1. SCE17HC039.2 - Calculation Templates
2. SCE17HC039.2 - Savings Analysis
3. SCE17HC039.2 - MeasureCost2018
4. SCE17HC039.2 - Limitations Memo
5. SCE17HC039.2 - Optimizing Design & Control of Chilled Water Plants
6. SCE17HC039.2 – Sim Files

# References

References in this version of the work paper is based on the references file References\_07112018\_101102

[26]

[49]

[65]

[359]

[496]

[504]

[510]