Work Paper SCE17HC039

**Revision 1**

**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 (CHW) Pump Control  Variable Speed Drive on Condenser Water (CW) Pump Control |
| **Base Case Description** | Source: Existing Custom Equipment/Title 24  CHW Pump Control – Single speed  CW Pump Control – Single speed |
| **Units** | Per 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: 6.67 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) - CW Pump 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 |

# 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 frequency drives (VFD) in central plant applications with constant speed chillers.

This measure applies to constant speed central plant equipment including condenser water pumps and chilled water pumps not already equipped with VFD/VSDs. 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.

**Base, Standard, and Measure Cases**

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measure | Variable Speed Drive on Chilled Water (CHW) Pump Control  Variable Speed Drive on Condenser Water (CW) Pump Control |
| Existing Condition | N/A |
| Code/Standard | Source: Existing Custom Equipment/Title 24  CHW Pump Control – Single speed for REA Program Type  CW Pump Control – Single speed for REA and NEW Program Type |
| Industry Standard Practice | N/A |

Measures and Codes

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

Throughout this paper, the terms variable frequency drive (or VFD) and variable speed drive (or VSD) are used synonymously.

This measure applies to non-residential buildings in all SCE climate zones that use a central chiller plant system with constant speed condenser water pump and chilled water pumps not already equipped with VFDs. This measure should be accompanied by the installation of 2-way chilled water valves for the VFD addition to the chilled water pump measure.

Successful implementation of this measure will depend greatly on the characteristics of the installed system. For the VFD addition to the condenser water pump 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 #3 Measure Limitations Memo in the Attachments Section for more information.

In all cases, measure installation shall fully meet all applicable regulations including but not limited to the latest California Energy Standards and NEC.

All new VSD/VFD equipment supporting the measure shall be UL Listed.

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 Cooling Tower (CT) Fan Control** measure, the existing 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 future versions of the workpaper.
2. For the **Variable Speed Drive on Condenser Water (CW) Pump Control** measure, the existing equipment’s EUL is greater than the duration in which the measure has been required in code. Hence, it is highly likely for the measure NOT to have been fully adopted by industry. Therefore, this measure is expected to be feasible and to still contribute to EE savings.
3. For the **Variable Speed Drive on Chilled Water (CHW) Pump Control** measure, the EUL of the existing equipment approaches the duration that the measure has been required in code. Hence, it is likely for the measure NOT to have been fully adopted by industry. Therefore, this measure is expected to be feasible and to still contribute to EE savings for CHW pumps installed before 2006. Given that the measure is currently in Code, the Program and/or Program Implementer must include requirements for customers to confirm their existing conditions do not already have variable speed drive control.

**Measure savings on these measures were adjusted using DEER2014 Building Weights to exclude older vintages (e.g., 1975 and 1985) given that existing equipment (distribution CHW and CW water pump) for these vintages is expected to have exceeded its useful life and hence already replaced with latest technology meeting ISP and/or Code.**

## 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. Chilled water (CHW) pumps circulate water cooled by the chiller and condenser water (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 100% 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 demand conditions.

Variable frequency drives control motor speed by varying the frequency and voltage of the pump motor. VFDs are programmed to reduce pump speed to just meet actual load conditions, thus reducing pump speed when loads drop below design conditions, resulting in significant pump 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) | Above Customer Existing | N/A | EUL | N/A |
| New Construction (NEW/NC) | 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. |

**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. Such an incentive may be deemed or customized. |

**Installation Type Descriptions**

Table below lists the installation and building types for each measure. In this revision of the work paper, separate calculation templates are developed for each solution code to cover the combinations as shown below.

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

## 1.4 Measure Parameters

### 1.4.1 DEER Data

The 2017 Database for Energy Efficient Resources (DEER) [26, 49] does contain similar central plant/VFD measures (DEER ID D03-046: Variable Flow Chilled Water Loop; DEER ID D03-047: VSD Chilled Water Loop Pump). DEER does not contain a measure for installing a VSD on Condenser Water Pumps.

For the VSD measure for Chilled Water Loop pumps, DEER reports only a limited number of building types. Additionally, the DEER measure descriptions do not match the measure in this work paper; 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; 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. The measure in this work paper has three-way valves and a single-speed pump in the base case, and two-way valves and a variable-speed pump in the measure case.

Due to the differences between the DEER measures and the measures contained in this work paper, modeling was performed to determine savings for all measures and building types – all results reported in this work paper were modeled.

DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Item** | **Used for Workpaper?** |
| Modified DEER methodology | No |
| Scaled DEER measure | No |
| DEER Base Case | No |
| DEER Measure Case | No |
| DEER Building Types | Yes |
| DEER Operating Hours | Yes |
| DEER eQUEST Prototypes | Yes |
| DEER Version | N/A |
| Reason for Deviation from DEER | * DEER 2017 does include similar measures, but for a limited number of buildings. Additionally, the DEER measure descriptions do not exactly match the measures in this work paper * This work paper expands the applicable building types, assumes different baseline cases, and uses different per unit savings (kWh/hp vs. kWh/ton) |
| DEER Measure IDs Used | N/A |

**Net-to-Gross Ratio**

The NTG values were obtained using the DEER READI tool version 2.4.7. The relevant NTG values for the measures in this work paper are in the table below.

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

**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 2.4.7. 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 | 6.67 | 0 |
| 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

Current requirements for heat rejection fan speed controls in non-residential applications are contained in Title 24 2016 [496], Section 140.4(h), page 192. Each fan powered by a motor of 7.5 hp (5.6 kW) or larger shall have the capability to operate that fan at 2/3 of full speed or less, and shall have controls that automatically change the fan speed to control the leaving fluid temperature or condensing temperature or pressure of the heat rejection device.

Current requirements for variable flow hydronic loops in non-residential applications are contained in Title 24 2016, Section 140.4(k)5 Water-Cooled Air Conditioner and Hydronic Heat Pump Systems; Section 140.4(k)6A Variable Flow Controls - Variable Speed Drives, page 193. For chilled water pumps 5 hp or greater, Title 24 requires variable speed drives on hydronic loops with variable flow capability. “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.” Condenser water systems serving only water-cooled chillers are exempt from the requirements in this section.

The code requirements for hydronic loop flow controls are only for new chilled water systems and apply to this work paper.

Code Summary

|  |  |  |
| --- | --- | --- |
| **Code** | **Reference** | **Effective Dates** |
| Title 24 (2016) | 2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings,  Section 140.4(k)5 Water-Cooled Air Conditioner and Hydronic Heat Pump Systems; Section  Section 140.4(k)6A Variable Flow Controls - Variable Speed Drives, pg. 193 | 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

N/A

# Section 2. Calculation Methodology

Estimated demand and energy savings for this work paper are based on simulated variable frequency drives (VFD) in central plant chilled water pumps and condenser water pumps. Simulations were conducted using the DOE-2/eQUEST v.3.64 modeling tool (for the Refrigerated Warehouse building type, the refrigeration version of eQuest was used). Model development and savings analyses are discussed in detail in this section.

## 2.1 DEER Prototypes

Non-residential buildings that can use a central chiller plant system were included in the simulation analysis. A list of the 12 selected building types is reported in table below. The selection of the building types was based on potential program targets. Building models were generated using the eQUEST DEER batch processing tool. The DEER batch processing tool creates eQUEST building models based on existing DEER prototypes for both residential and non-residential market sectors. These building prototypes contain the building characteristics (such as HVAC equipment, construction materials, and occupancy schedules) that are used to calculate DEER measure savings. In addition, the DEER batch tool allows prototypes to be generated by desired vintages, and climate zones.

The DEER non-residential prototypes are generated in the batch processor with the HVAC configuration typical for each building type. For example, Education­ - University prototypes are automatically generated with a central chiller plant system, as this is the expected system in the majority of university settings. Some building types considered for program participation do not typically have a central chiller plant configuration in DEER. In these cases, the building prototype was generated in the DEER batch processor with its typical packaged roof-top unit (RTU) configuration. This configuration was then modified in the eQUEST detailed data edit mode to allow a central plant configuration. The table shown below reports which building prototypes include a central chiller plant configuration, and which required modification to allow this type of configuration.

Non-Residential DEER Prototype Models

|  |  |
| --- | --- |
| **DEER Building Type** | **DEER Prototype HVAC Configuration** |
| Assembly | Package RTU |
| Education - Secondary School | Package RTU |
| Education – University | Chiller Plant |
| Health/Medical – Hospital | Chiller Plant |
| Health/Medical - Nursing Home | Chiller Plant |
| Lodging – Hotel | Chiller Plant |
| Manufacturing - Bio/Tech | Package RTU |
| Manufacturing-Light Industrial | Package RTU |
| Office – Large | Chiller Plant |
| Office – Small | Chiller Plant |
| Restaurant - Sit-Down | Package RTU |
| Retail - Multistory Large | Package RTU |
| Retail - Small | Package RTU |

Once each building type was modified to allow a central plant configuration, each baseline model was then modified per the keyword changes listed in the table shown below (eQUEST Keyword Modifications) to simulate each measure.

## 2.2 Energy Savings

### 2.2.1 eQUEST Energy Simulations

Over 2000 energy simulations were performed to account for the baseline, two measures, 13 building types, eight climate zones (CZ) in SCE service territory, and applicable DEER building vintages. The DEER vintages (with their single-reference year in parentheses) are included in the table shown below.

1. 1993 – 2001 (1996 – shown in the table below as 96)
2. 2001 – 2005 (2003 – shown in the table below as 03)
3. 2005 – 2009 (2007 – shown in the table below as 07)
4. 2009 – 2013 (2011 – shown in the table below as 11)
5. 2013 – 2014 (2014 – shown in the table below as 14)

**Measure savings on these measures were adjusted using DEER2014 Building Weights to exclude older vintages (e.g., 1975 and 1985) given that existing equipment (distribution CHW and CW water pump) for these vintages is expected to have exceeded its useful life and hence already replaced with latest technology meeting ISP and/or Code.**

The simulated prototype building with chiller plant for each vintage and CZ was considered the baseline model. The energy and demand consumption from these simulated models represents the base case consumption. Each measure was then modeled using individual model runs. VFDs on chilled water loop pumps were not modeled for 2007 or later vintage buildings. Since they are required by code, the prototype models for these vintages have VFDs already installed in the base case. The table shown below reports the eQUEST keywords used for the model runs, including the input values for both the base case and the measure conditions. The resulting energy and demand consumption from the measure simulations represent the measure case consumption.

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 #6) achievable flow turndown was chosen for the measure case. For the maximum leaving condenser temperature the limit was set to be the condenser temperature at the rated conditions for the baseline model (keyword CHILLER:RATED-COND-T).

eQUEST Keyword Modifications

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure** | | | |
| **Vintage(s)** | **Keyword** | **Baseline Design Value** | **Measure Design Value** |
| **CHW\*  Loop Pump EEM\*\*** | | | |
| 96,03 | PUMP:CAP-CTRL | N/A | VAR-SPEED-PUMP |
| 96,03 | SYSTEM:CHW-VALVE-TYPE | N/A | 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)

While the Health/Medical - Nursing Home prototype included a chiller plant, it utilized an air-cooled condenser instead of a cooling tower. Thus, the VFD on Condenser Water Pump measures were not modeled for this building type. The Warehouse-Refrigerated model does not include a chiller plant, as space cooling is provided by a refrigeration system. Thus, the VFD on Chilled Water Pump and VFD on Condenser Water Pump measures were not modeled for this building type.

The difference in energy consumption between the baseline simulation run and the measure runs represents the energy savings.

### 2.2.2 Multiple Chillers and VFD Towers

The prototypes in the DEER model included only single chiller plants and cooling towers. Since many buildings have multiple chillers and cooling towers, some of the buildings were modeled to include multiple chiller plants and cooling towers. Additional models in three separate climate zones were created for the following building types listed in the table shown below. The three climate zones were selected as a comparison to ensure that energy savings amounts found were consistent with savings from models with single chiller plants taking into account a wide range of climates.

Buildings Modeled with Multiple Chillers and Cooling Towers

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **DEER Building Type** | **Cooling Tons** | **Vintage** | **CZ** | **Number of Modeled Chillers/Towers** |
| Education - University | 2500 | 85 | 6, 8, 13 | 3 |
| Health/Medical - Hospital | 625 | 85 | 6, 8, 13 | 2 |
| Lodging - Hotel | 500 | 85 | 6, 8, 13 | 2 |
| Retail – Multistory Large | 300 | 85 | 6, 8, 13 | 2 |

To add the multiple systems, a second tower identical to the existing DEER one was added to the condenser water loop. Variable speed control was added to both towers. As required by the equipment configuration one or two chillers and the associated pumps were created based on the baseline chiller and pumps. The only variable that was modified was the capacity ratio, such that the chillers were equally sized and with a total capacity equal to the baseline chiller. This resulted in modeling chillers that would not normally be found in practice. For example, the DEER prototype for the hospital building type had 625 cooling tons of capacity and was modeled with 2 chillers of 312.5 tons. For the chilled water pump, the chilled water loop can only have one pump assigned. This pump, however, may consist of a single pump or multiple pumps (set by keyword “NUMBER”).

For the VFD on the chilled water pump measure the savings are on average 11% greater (with a minimum of 7% and a maximum of 15%) for the multiple chiller models and for the VFD on the cooling tower fans measure the savings are on average 25% less (with a minimum of 5% and a maximum of 49%) for the multiple chiller models; these differences are explained further in the eQUEST Simulation Issues section that follows. The savings difference for the VFD on the chilled water pump is within an acceptable range, and so no adjustment was made to the modeled savings for this measure. To account for the relatively high difference in savings for the cooling tower fan measure, the modeled savings for this measure were decreased by 25%.

Costs for installing multiple VFDs in these applications will not increase as the costs are calculated on a per horsepower basis as discussed in Section 4.

### 2.2.3 eQUEST Simulation Issues

After performing simulations on the “normal operation” buildings, discrepancies were observed in the resulting fan sizes for all buildings. The cooling loads and the resulting equipment sizing were determined by eQUEST without any modifications of the original defaulted DEER and BDL inputs. For example, results on the part load ranges generated by eQUEST for the cooling tower fans and chilled water pumps are not consistent with expectations.

In the models used for this analysis, the cooling towers are significantly oversized (see the table below; for University, CZ 6, V85, the tower is sized at 226.4 kW, while the actual peak load is only 148.9 kW). As a result, the towers are operating at between 40 and 50% load for 99% of hours in the baseline case. This over-sizing is greater in the single tower case (baseline peak load is 65.8% of tower size in the single tower model as opposed to 83.6% in the multiple tower scenario). Thus, the savings potential for adding a variable speed drive on the fan is slightly higher in the single tower case. Reducing the tower capacity in the model increases the ratio between peak load and equipment size but results in warnings that the capacity is less than demand.

**Equipment Sizing Results for University Building Type**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model: University, CZ6, v85** | | | | |
|  | **Equipment Sizing**  **(PV-A)\***  **(kW)** | **Equipment Peak**  **(PS-C)\*\***  **(kW)** | **Equipment Sizing**  **(PV-A)**  **(kW)** | **Equipment Peak**  **(PS-C)**  **(kW)** |
|  |  | | **Chilled Water Pump** | |
| **Multiple Chilled Water Pumps/Cooling Towers** | | | | |
| Baseline | 79.69 | 66.6, 62.9, 53.9 | 202 | 202 |
| Chilled Water Pump VSD | - | - | 202 | 74.7 |

\*PV-A is the Plant Design Parameters report available in the eQUEST SIM (simulation) file

\*\*PS-C is the Equipment Loads and Energy Use report available in the eQUEST SIM file

For the chilled water pumps, the baseline pumps have a peak load consistent with the equipment sizing, and they operate at 100% loading for all operating hours. The modeled pumps with variable speed drives are operating for a significant number of hours in the 0 to 10% load range, particularly when the specified turndown ratio is set at 0.40. This is due to the methodology used in eQUEST for sizing. This sizing issue results in significantly higher savings for installing a VFD on the chilled water pump than installing a VFD on the cooling tower fans. In the baseline model, the cooling tower fan operates at less than 60% load for most hours while the chilled water pump operates at 100%. Savings potential is, therefore, greater for the chilled water pump. The lower savings potential of the cooling tower fan is then divided by a larger motor HP due to over sizing, thereby further increasing the difference in savings on a per HP basis. Engineering review of the energy and demand savings values determined that the energy savings reported by the model are reasonable.

The part load operating hours for the variable speed pumping options are the same in both the single and multiple pump options. What does change is the number of hours in the part load bins for the electrical consumption. For the multiple pump option, only one of the three pumps is required for low load operation. For the single pump option, the majority of hours (80%) are in the 20-30% load range, as the single pump cannot turn down as far. Hence the slightly increased savings potential for the multiple pump model.

### 2.2.4 Weighted Average Methodology

To create a single value for each building type and climate zone, the Attachment #2 SCE17HC039.1 Savings\_Spreadsheet\_v1 was used to create a weighted average of each vintage represented in the climate zone. The weighted average was applied to the combined base cases to create a single savings amount for each measure and climate zone. The weighted average baseline for the CHW measure was calculated separately from the weighted average baseline for the CT and CW measures, as it did not include the 07 or later vintages (as VFDs on CHW loop pumps are required for these vintages).

Measure savings on these measures were adjusted using DEER2014 Building Weights to exclude older vintages (e.g., 1975 and 1985) given that existing equipment (distribution CHW and CW water pump) for these vintages is expected to have exceeded its useful life and hence already replaced with latest technology meeting ISP and/or Code.

2.2.5 Energy Savings Results

Energy savings are calculated as the difference between the baseline model energy use and the energy use as modeled with the VFD installed. To convert savings to kWh/HP, the HP is first calculated by taking the demand (kW) as reported in the Plant Design Parameters (PV-A) Report available in the SIM file. This is then converted by dividing by the constant 0.746 kW/HP. Energy values from the model output are then divided by HP, resulting in kWh/HP. The table shown below shows the energy savings for the Hospital building type.

**Energy Savings for Hospital**

|  |  |  |
| --- | --- | --- |
|  | **Energy Savings (kWh/HP)** | |
| **Climate Zone** | **CHW Loop Pump VSD** | **CW Loop Pump VSD** |
| CZ06 | 5,432 | 2,214 |
| CZ08 | 5,552 | 2,256 |
| CZ09 | 5,504 | 2,202 |
| CZ10 | 5,110 | 2,090 |
| CZ13 | 4,897 | 2,000 |
| CZ14 | 4,727 | 1,930 |
| CZ15 | 5,101 | 2,066 |
| CZ16 | 4,502 | 1,779 |

As Energy Savings for Hospital table shows, energy savings for the VFD on Chilled Water Pump measure are the most significant as the savings include reductions in space cooling energy (including the constant volume chiller) and heat rejection energy in addition to the reduced pumping energy. For example, for the 2003 vintage Hospital building type in climate zone 6, the VFD on Chilled water pump measure results in a 20% reduction in pump energy, 4% reduction in heat rejection energy, and 3% reduction in space cooling energy. Pumping savings account for 83.2% of total measure savings, space cooling savings account for 16.7%, and heat rejection savings account for 0.3% (there is a slight energy penalty for ventilation fan energy).

The addition of a VFD on the condenser water pump results in reduced pumping power during part-load conditions, but there is an increase in space cooling energy (due to higher chiller consumption); however, the reduction in pumping energy is great enough to provide energy savings overall.

## 2.3 Demand Savings

The peak demand results from eQUEST do not conform to the DEER methodology for determining demand across a three-day peak heat wave. To ensure the DEER methodology was applied to determine peak demand savings, the hourly reports included in the eQUEST simulation runs

eQUEST simulation runs include hourly consumption reports. These reports were utilized to extract the demand from the 2-5pm peak period for the DEER-defined three-day peak heat waves. DEER reports the beginning date of the expected three-day heat wave for each climate zone, as follows:

**Peak Demand Period used for DEER 2014**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Start of 3 Day Period** | | |
| **Climate Zone** | **Month** | **Day** | **Week Day** |
| CZ06 | Sept | 1 | Tue |
| CZ08 | Sept | 1 | Tue |
| CZ09 | Sept | 1 | Tue |
| CZ10 | Sept | 1 | Tue |
| CZ13 | July | 8 | Wed |
| CZ14 | Aug | 26 | Wed |
| CZ15 | Aug | 25 | Tue |
| CZ16 | Jul | 8 | Wed |

Once the data was extracted for the three-days selected, the hourly results from 2-5pm on the three consecutive days (9 data points) were averaged to provide peak demand estimates. The difference between the baseline and measure peak demand estimates results in the peak demand savings. To create a single demand savings value for each building type in each climate zone, the same methodology as was used for energy savings was applied. The table below shows the demand savings for the Hospital building type.

**Demand Savings for Hospital**

|  |  |  |
| --- | --- | --- |
|  | **Energy Savings (kW/HP)** | |
| **Climate Zone** | **CHW Loop Pump VSD** | **CW Loop Pump VSD** |
| CZ06 | 0.52 | 0.20 |
| CZ08 | 0.51 | 0.18 |
| CZ09 | 0.48 | 0.09 |
| CZ10 | 0.45 | 0.09 |
| CZ13 | 0.45 | 0.12 |
| CZ14 | 0.48 | 0.16 |
| CZ15 | 0.46 | 0.11 |
| CZ16 | 0.52 | 0.23 |

As is explained in Section 2.2.5, savings are most significant for the VFD on Chilled Water Pump measure, as it results in savings for pump energy, space cooling energy, and heat rejection energy.

# 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** |
| Assembly | 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 |
| Manufacturing-Light Industrial | DEER:HVAC\_Chillers | NON\_RES |
| Office – Large | DEER:HVAC\_Chillers | NON\_RES |
| Office – Small | DEER:HVAC\_Chillers | NON\_RES |
| Restaurant - Sit-Down | DEER:HVAC\_Chillers | NON\_RES |
| Retail - Multistory Large | DEER:HVAC\_Chillers | NON\_RES |
| Retail - Small | 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/unit for all three measures because the base case refers to the existing equipment, which does not require replacement.

Please refer to Attachment #5 Cost Calculations for details.

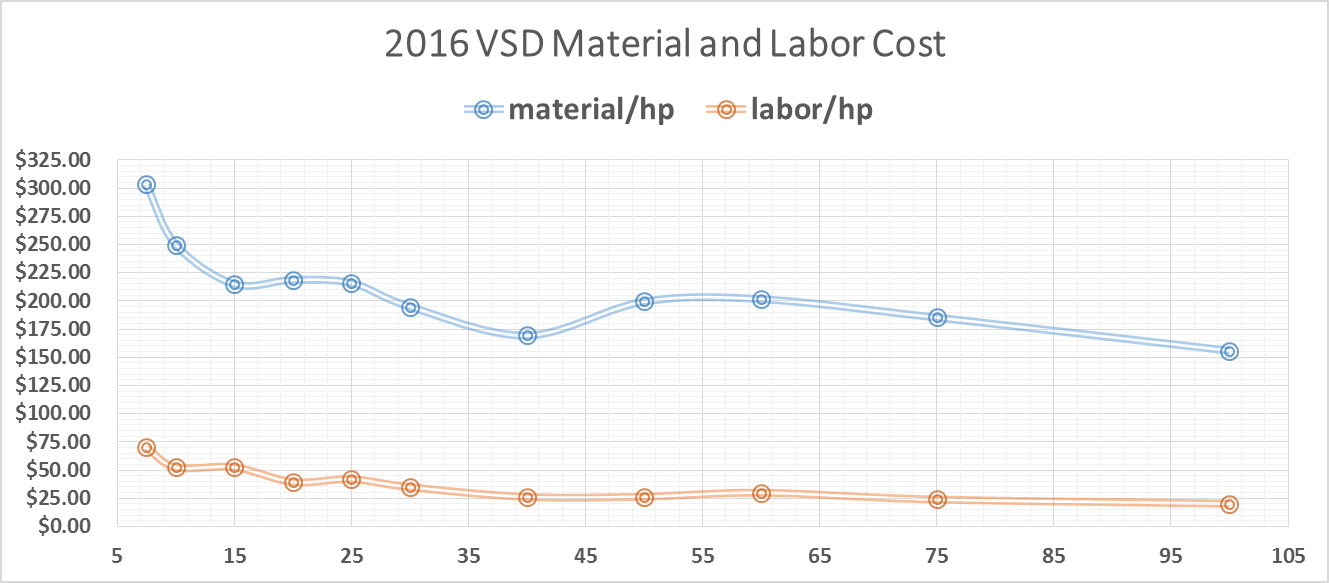
## 4.2 Measure Case Cost

All Measure and Labor Cost documentation on the measures was update using 2016 RS Means Mechanical Cost Data Handbook [504]. Measure cost assumes new VFD with NEMA 1 Enclosure, 460 Volts applications, and electrical work in full compliance with latest NEC. Cost documentation assumes that Chilled and Condensing pump control applications will generally require higher capacity (HP) drivers compare to that of Cooling Tower Fan control applications.

Measure and labor cost for VFD’s Chilled Water and Condenser Water pump control was estimated averaging cost for driver sizes 7.5-hp through 100-hp in terms of $/hp. See Attachment 5 and figure below.

**VSD Chilled Water and Condenser Water Pump Control - Full Measure Cost**

Full Measure Cost ($/HP) = Measure Case Cost + Labor Cost = $248.07 = $210.0 + $38.07



## 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

**Full and Incremental Costs**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure** | **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| AC-91987 | REA | $248.07 | $248.07 | N/A |
| AC-55411 | REA | $248.07 | $248. 07 | N/A |
| AC-18932 | NEW | $248.07 | $248. 07 | N/A |

# Attachments

1. SCE17HC039.1 - Calculation Templates
2. SCE17HC039.1 - Savings\_Spreadsheet\_v1
3. SCE17HC039.1 - Limitations Memo
4. SCE17HC039.1 - ED Discussion on WPSCNRHC0039\_with
5. SCE17HC039.1 - MeasureCost2016
6. SCE17HC039.1 - Optimizing Design & Control of Chilled Water Plants

# References

References in this version of the work paper is based on the references file *“[References\_11152017\_131456]”*.

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