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WATER HEATING

DEMAND CONTROL FOR CENTRALIZED WATER HEATER RECIRCULATION PUMP, MULTIFAMILY

SWWH015-01

CONTENTS

MEASURE NAME

Demand Control for Centralized Water Heater Recirculation Pump, Multifamily

STATEWIDE MEASURE ID

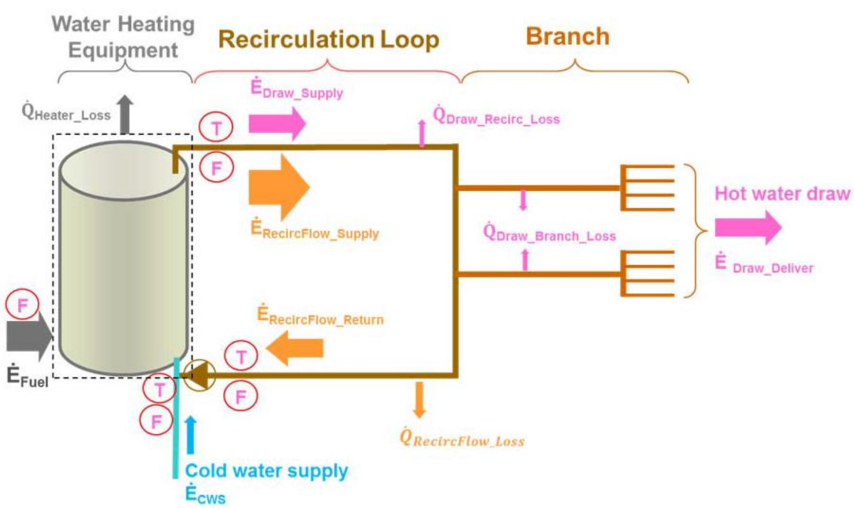
SWWH015-01

TECHNOLOGY SUMMARY

This measure pertains to an on-demand domestic hot water (DHW) recirculation pump for a multifamily building. The pump is integrated with flow control capabilities, such as a variable frequency drive (VFD) controller or on/off controls. This technology controls the recirculating pump to provide a flow rate necessary to maintain a setpoint recirculation loop temperature. Reducing system flow rate to meet demand will reduce pumping power, heat loss in the recirculation loop, and boiler input gas consumption.

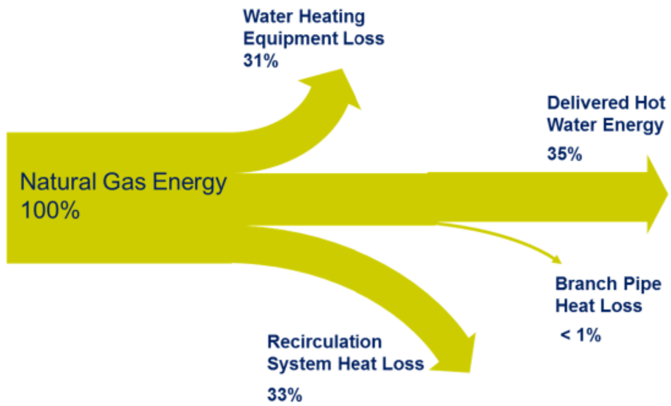
The figures below illustrate the various paths in which the DHW system loses energy to the surrounding environment. This measure reduces heat loss in the hot water recirculation loop and is directly affected by the loop characteristics such as hot water supply temperature, minimum desired loop temperature, indoor ambient temperature, as well as piping system characteristics and length.

Hot Water System and Corresponding Energy and Heat Transfer Flows [1]



[1] Heschong Mahone Group, Inc. 2013. *Public Interest Energy Research (PIER) Program, Multifamily Central Domestic Hot Water Distribution Systems – Final Project Report.* Prepared for the California Energy Commission. Gold River, CA: Heschong Mahone Group, Inc. CEC-500-2013-011.Page 21.

Average Energy Flows in Central DHW Systems[2]



A hot water recirculation loop is common for a multifamily building with a centralized, domestic hot water system. Hot water demand in a multifamily building varies throughout the day, with peaks occurring in the morning and evening hours. Demand also varies according building size, demographics, and the number and type of hot water fixtures. When the hot water demand is reduced during off-peak hours, heat in the hot water distribution system is lost to the surrounding space. This reduces the hot water supply temperature and availability of hot water at the fixtures.

A recirculation loop will increase the availability of fixture hot water by pumping hot water through the distribution system – albeit at the expense of additional pump energy consumption and increased distribution system heat losses. This measure will reduce the average hot water loop temperature while maintaining a minimum hot water loop temperature required to service connected fixtures.

MEASURE CASE DESCRIPTION

The measure case is defined as the replacement of the base case recirculation pump with a pump that utilizes flow control methods, such as variable frequency drives (VFDs), integrated or remote sensors, and control systems that respond to demand by controlling the hot water recirculation loop temperature. Annual measure savings are provided on a per-dwelling basis for each of the California climate zones.

BASE CASE DESCRIPTION

The base case is defined as a centralized, gas-fired domestic hot water (DHW) system with a recirculation pump that operates continuously, 24 hours per day, seven days per week. It ensures hot water is always available at the fixture, irrespective of hot water loop temperature or system demand.

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[2] Heschong Mahone Group, Inc. 2013. *Public Interest Energy Research (PIER) Program, Multifamily Central Domestic Hot Water Distribution Systems – Final Project Report.* Prepared for the California Energy Commission. Gold River, CA: Heschong Mahone Group, Inc. CEC-500-2013-011. Page 2.

Baseline data for this measure was obtained from a third-party source due to the lack of data available in the California Database of Energy Efficient Resources (DEER) database. Heschong Mahone Group (HMG) conducted field and modeling analysis on recirculation pumps with temperature modulation and demand control in multifamily central water heating systems to support a Public Interest Energy Research (PIER) project for the California Energy Commission (CEC).[3] Research from the PIER project was used to develop the 2013 Codes and Standards Enhancement (CASE) Study conducted by the California Statewide Codes and Standards Team.[4] Results from the research conducted in the 2013 CASE Study were used to estimate demand reduction and energy savings for this measure.

CODE REQUIREMENTS

Neither state or federal codes regulate domestic hot water recirculation pumps in existing buildings. Recirculation systems are regulated by the California Building Energy Efficiency Standards (Title 24) for both new construction and building alterations and therefore *inform, but do not impact,* this measure.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	None.	n/a
CA Building Energy Efficiency Standards – Title 24 (2016)	None.	n/a
Federal Standards	None.	n/a

California Building Energy Efficiency Standards (Title 24). Title 24[5] provides mandatory, prescriptive and performance requirements for DHW recirculation systems in newly constructed buildings, additions to existing buildings, and alterations to existing buildings. Both the mandatory and prescriptive sections are relevant for informing this measure; they include: automatic shut off pump controls, general system installation, pipe insulation requirements for all building types, and pipe insulation requirements and demand-based controls for newly constructed low-rise residential buildings. These code requirements are summarized below:

- Section 110.3(c) 2: This section requires domestic hot water systems with recirculation pumps in all building types have automatic shut off controls to turn off the service hot water system.
- Section 110.3(c) 5: This section applies to all building types. It provides mandatory requirements for the installation of how water recirculation systems but does not address recirculation pump control.

[3] Heschong Mahone Group, Inc. 2013. *Public Interest Energy Research (PIER) Program, Multifamily Central Domestic Hot Water Distribution Systems – Final Project Report.* Prepared for the California Energy Commission. Gold River, CA: Heschong Mahone Group, Inc. CEC-500-2013-011.

[4] California Utilities Statewide Codes and Standards Team. 2011. *Codes and Standards Enhancement Initiative (CASE), Multifamily Central DHW and Solar Water Heating, 2013 California Building Energy Efficiency Standards.*

[5] California Energy Commission (CEC). 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.* CEC-400-2015-037-CMF.

- Section 120: This section provides requirements for hot water pipe insulation in all building types. It requires service hot water systems above 105°F be insulated with a material meeting a minimum level of thermal conductivity, based on nominal pipe diameter. This section is relevant insomuch as assumptions used to develop prototypical hot water systems and corresponding building energy model inputs assume that hot water circulation loop is insulated. The insulating requirements and thermal conductivity values used in development of the measure case correspond to the requirements consistent with the DEER 2003 vintage.
- Section 150.0(j) 2.iii: This section requires that all domestic hot water recirculation loop piping in low-rise residential buildings be insulated.
- Section 150.1(c) 8.C.ii: This section prescribes, as a compliance approach, that domestic hot water systems in newly constructed low-rise residential buildings that serve multiple dwelling units have a recirculation loop with hot water demand control.

NORMALIZING UNIT

Per household (dwelling unit).

PROGRAM REQUIREMENTS

Measure Implementation Eligibility

All combinations of measure application type, delivery type, and sector that are established for this measure are specified below. Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial incentives or other services) is targeted. This table also designates the broad market sector(s) that are applicable for this measure.

Note that some of the implementation combinations below may not be allowed for some measure offerings by all program administrators.

Implementation Eligibility

Measure Application Type	Delivery Type	Sector
Add on equipment	DnDeemDI	Res
Add-on equipment	DnDeemed	Res

Eligible Products

The energy efficiency measure is applicable for an existing multifamily residential building with a centralized, gas-fired, domestic hot water system with constant volume, fractional horsepower, and an uncontrolled recirculation pump.

This measure is only applicable for a building with a system that utilizes a stand-alone domestic hot water system. A hot water generation system must be used primarily for domestic hot-water heating uses.

The hot water supply and hot water return lines of the recirculation loop must maintain a temperature differential of at least 20 °F.[6] For example, for the energy modeling purposes of this measure analysis, the supply temperature was set at 135 °F and the return temperature was maintained at 105 °F.

Eligible Building Types and Vintages

This measure is eligible for existing multifamily residential buildings.

Eligible Climate Zones

This measure is applicable to all California climate zones.

PROGRAM EXCLUSIONS

This measure is not applicable for any building type other than multifamily.

A hot-water generation system used for pool or spa heating are not eligible for this measure.

DATA COLLECTION REQUIREMENTS

The various emerging technology reports and studies assessed for the development of this measure did not quantify energy savings performance over a full year. Generally, energy savings estimates have been developed over a shorter time frame, with data being extrapolated to estimate annual savings. Furthermore, none of the studies reviewed detailed savings in each of the California Building Code Zone Areas. Because hot water system performance is affected by ambient temperatures, future studies may test over longer durations and consider performing multiple demonstrations that include a greater number of climate zones.

USE CATEGORY

Service & domestic hot water

ELECTRIC SAVINGS (KWH)

The unit energy savings (UES) that result from a demand-controlled recirculation pump installed in a centralized multifamily hot water system was developed through a combination of research, engineering calculations, and building energy simulation models. The methodology described below includes the following:

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[6] Southern California Gas Company (SCG), Engineering Analysis Center – Applied Technologies. 2014. *Project Test Report - Variable Frequency Drive Hot Water Recirculation Pump Controller*. Pages 31-34.

- Base and measure case underlying parameters,
- Baseline performance,
- Measure case performance,
- Measurement and verification control volume,
- Building energy simulation models and hot water system characteristics, and
- Estimation of unit energy savings and demand reduction.

Base Case and Measure Case Underlying Parameters

The measure case is based on an analysis that utilized the prototypical DEER 2003 vintage building models to represent an average cross section of existing multifamily building stock. The buildings in these models consist of four residential stories and a total of 24 dwelling units, all of which have the same hot water fixture configuration and demand.

Measure savings were developed by simulating a single building per climate zone. Savings were extrapolated to larger and smaller cohorts of high-rise and low-rise multifamily residential buildings, but no range of acceptable sizes that deviate from the base case model has been quantified. Variances in building floor area, number of dwelling units, configuration of hot water fixtures, and hot water piping loop characteristics are some of the site-specific factors that may substantially affect energy consumption. Savings, for example, may not scale linearly with building floor area or number of dwelling units as documented in the CASE study,[7] and they may therefore produce variations between deemed savings and actual results.

The base case and measure case recirculation loop is located exclusively within the building envelope conditioned space. Placement of the recirculation loop will affect energy performance and interactive effects with other building end uses, including space heating and space cooling systems.

The measure case hot water heater supply temperature and the recirculation loop return temperature are set to 135 °F and 105 °F, respectively. These temperatures were derived from a combination of impact analysis of other related measures, codes and standards documents, and industry standards. The temperatures drive the hot water heating recirculation loop heat losses, energy consumption, and amount of energy savings potential.

Baseline Performance

A secondary literature review was performed to define an industry standard baseline condition for domestic hot water recirculation pump control in multifamily residential buildings. The purpose was to understand the opportunities for energy savings through the installation of enhanced system controls that reduce both pumping energy and hot water recirculation loop heat loss. Domestic hot water studies, codes and standards reports, and existing utility program deemed savings workpapers were reviewed to identify what system control schemes have been documented through field testing, survey data, and empirical studies.

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[7] California Utilities Statewide Codes and Standards Team. 2011. *Codes and Standards Enhancement Initiative (CASE), Multifamily Central DHW and Solar Water Heating, 2013 California Building Energy Efficiency Standards.*

Most resources refer to the Public Interest Energy Research (PIER) Program Study[8] as the primary data source. These include the CASE Study[9] and various emerging technology reports and multifamily deemed savings workpapers.[10] These studies consistently defined the baseline condition as a hot water recirculation system with an uncontrolled, constant-speed pump that operates continuously (with a flat load curve).

This baseline was compared with the Database of Energy Efficiency Resources (DEER) and California Building Energy Efficiency Standards (Title 24) to understand the opportunities for energy savings. DEER contains two similar measures for a central gas-fired hot water system in a multifamily residential building. These measures use an ON/OFF demand-based control scheme and were developed as an outcome of the PIER Study and subsequent workpapers and adopt the same baseline operating condition. The California Building Efficiency Standards (Title 24) regulates domestic hot water systems for new construction and existing building alteration and does not apply to this measure; however, relevant mandatory and prescriptive requirements inform the minimum level of measure efficiency. Title 24 provides general installation requirements for domestic hot water recirculation loops. The standard requires that they be insulated, have automatic system shut off controls, and prescribes demand controls that respond to the recirculation loop temperature in newly constructed low-rise residential buildings. (See Code Requirements.)

Based on research of available studies, the base case for this measure is defined as a multifamily residential building with a central gas-fired hot water recirculation system that consists of an uncontrolled, constant-speed, fractional horsepower pump that operates continuously.

Measure Case Performance

Secondary research was conducted to define the energy efficiency measure and its parameters. Studies of on-demand pump/controller emerging technology and equipment manufacturer studies and reports were reviewed, documented, and cataloged for comparison.[11] The comparison included a review of five similar hot water on-demand control pump technologies from multiple manufacturers, four of which exceed both the established baseline condition and mandatory code requirements. All technologies can provide hot water flow modulation through on/off demand controls, variable frequency drive (VFD) or electrically communicated motor (ECM) technology; however, there are discrete, yet discernable, differences in how each technology is controlled. The technologies can generally be grouped into two categories: those that have stand-alone VFD and temperature controls and control hot water flow to maintain a minimum return loop temperature, and those that have an integrated ON/OFF or VFD controls that respond to return loop temperature and/or hot water use or demand.

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[8] Heschong Mahone Group, Inc. 2013. *Public Interest Energy Research (PIER) Program, Multifamily Central Domestic Hot Water Distribution Systems – Final Project Report.* Prepared for the California Energy Commission. Gold River, CA: Heschong Mahone Group, Inc. CEC-500-2013-011.

[9] California Utilities Statewide Codes and Standards Team. 2011. *Codes and Standards Enhancement Initiative (CASE), Multifamily Central DHW and Solar Water Heating, 2013 California Building Energy Efficiency Standards.*

[10] Southern California Gas Company (SCG). 2016 "WPSCGREWH161128A-Rev00_Recirc Pump Control for MF_Technology Comparison.xlsx."

[11] Southern California Gas Company (SCG). 2016 "WPSCGREWH161128A-Rev00_Recirc Pump Control for MF_Technology Comparison.xlsx."

Although there are nuanced variations in how the technologies are installed and how their control schemes are configured, this measure includes them as a single energy efficiency measure where hot water flow is modulated based on the return loop temperature.

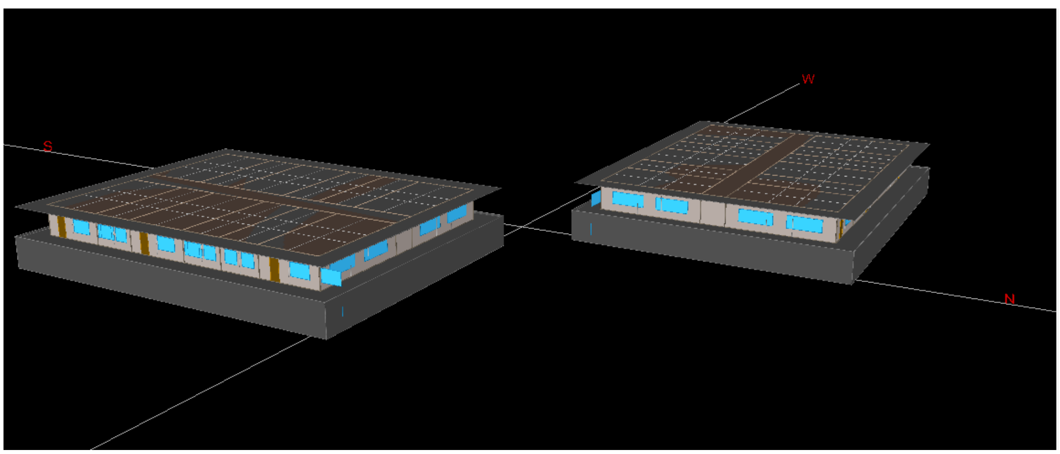
Measurement and Verification Control Volume

A control volume was developed to understand the influences of heat transfer between the domestic hot water system, building environment, and interactive effects with other building systems. A representative diagram of the control volumes that includes the domestic hot water heater, recirculation loop, and pump is illustrated in the Technology Summary. The control volume defines the environment for how heat transfer and energy consumption is defined in the analysis and is the basis for developing ad hoc engineering analyses and building energy models.

Building Energy Models and Hot Water System Characteristics

The energy simulation models for this measure utilized the DEER prototypical multifamily residential building energy models, illustrated below. Modifications to these models were necessary to describe the central domestic hot water system and define its various systems characteristics.

DEER Prototypical Multifamily Building Model in eQUEST



The Measure Analysis Software (MASControl2) was used to generate multifamily model input files compatible with eQUEST. The prototypical multifamily model domestic hot water system consisted of individual hot water heaters for each dwelling unit. These systems were removed and replaced with a centralized domestic hot water system with a recirculation loop and pump. The hot water fixture descriptions and schedules, however, were retained and used in this analysis to develop hot water demand profiles.

Ad hoc engineering analyses were performed to define values for several pertinent system parameters, including piping loop heat loss coefficients, return loop minimum water flow rate, and pump horsepower. System inputs used to develop these factors and the corresponding outputs are provided in the following table.[12] The inputs were developed from data obtained from the translated eQUEST files, code and standard studies, and assumptions from industry standards, such as the American Society of Heating and Refrigeration Engineers (ASHRAE) Handbooks.

In general, the analysis indicated that the hot water recirculation loop flow and head pressure requirements were outside the operating range of traditional hot water recirculation pump curves. In cases where this occurred, the pump was upsized to the lowest available fractional horsepower size. This is consistent with the aforementioned CASE Study, where the recirculation system pumps are sized larger than flow rate requirements.

Domestic Hot Water System Characteristics

System Parameters		Value	Sources
Building Characteristics	Gross Floor Area (ft2)	29,000	eQUEST building energy model
	Number of Floors	4	eQUEST building energy model
	Floor to Ceiling Height	10	California Utilities Statewide Codes and Standards Team. 2011. *Codes and Standards Enhancement Initiative (CASE), Multifamily Central DHW and Solar Water Heating, 2013 California Building Energy Efficiency Standards.*
	Number of Units	24	eQUEST building energy model
Required Hot Water System Inputs	DEER Vintage	2003	-
	Number of Hot Water Loops	1	eQUEST building energy model
	Hot Water Flow Rate (GPM)	22.00	eQUEST building energy model
	Supply Pipe Length (ft)	334	California Utilities Statewide Codes and Standards Team. 2011. *Codes and Standards Enhancement Initiative (CASE), Multifamily Central DHW and Solar Water Heating, 2013 California Building Energy Efficiency Standards.*
	Supply Pipe Water Velocity (FPS)	4	American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2016. *2016 ASHRAE Handbook – HVAC Systems and Equipment.* Atlanta (GA): ASHRAE.
	Hot Water Supply Pipe	Steel Pipe	
	Hot Water Supply Temp	135	
	Return Pipe Water Velocity (FPS)	2	
	Hot Water Return Pipe	Copper Pipe	
	Hot Water Return Temp	105	
	Pipe Insulation Type	Cellular Glass	
	Ambient Air Temp	70	
Outputs (calculated)	UA (btu/hr-ft-F) - Supply pipe	0.4064	American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2016. *2016 ASHRAE Handbook – HVAC Systems and Equipment.* Atlanta (GA): ASHRAE.
	UA (btu/hr-ft-F) - Return pipe	0.1340	American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2016. *2016 ASHRAE Handbook – HVAC Systems and Equipment.* Atlanta (GA): ASHRAE.
	Estimated Total Pump Head (ft)	10.9	
	Pump Size (hp)	1/6	

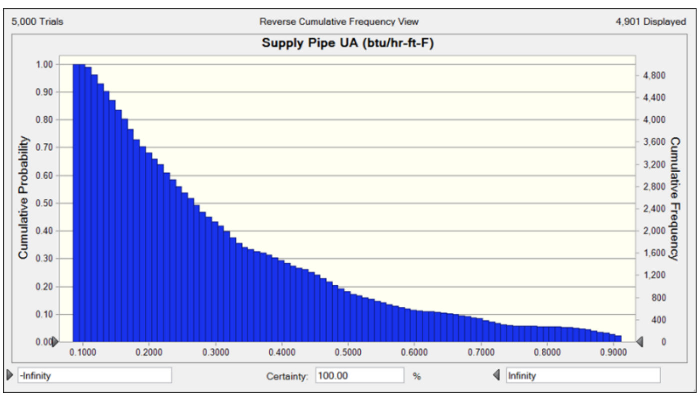
[12] Southern California Gas Company (SCG). 2016. "WPSCGREWH161128A-Rev00_Recirc Pump Control for MF_DHW System Characteristics.xlsx."

A select number of building energy models were simulated to assess annual hot water energy consumption sensitivity to building age and construction, using the 11 DEER building vintages. The objective was to determine if a single DEER vintage would be sufficient to describe the energy efficiency measure for a population of existing buildings. The analysis yielded less than a 5% variation in domestic hot water consumption across all DEER vintages, suggesting that the domestic hot water systems were not inherently sensitive to building characteristics described in the vintage models. As a result, DEER 2003 was selected as a single vintage for developing energy savings.

A sensitivity analysis was also conducted on the recirculation loop heat loss coefficients. The analysis showed that larger UA values produce higher hot water recirculation loop energy consumption and that those results are materially dependent on piping loop characteristics.

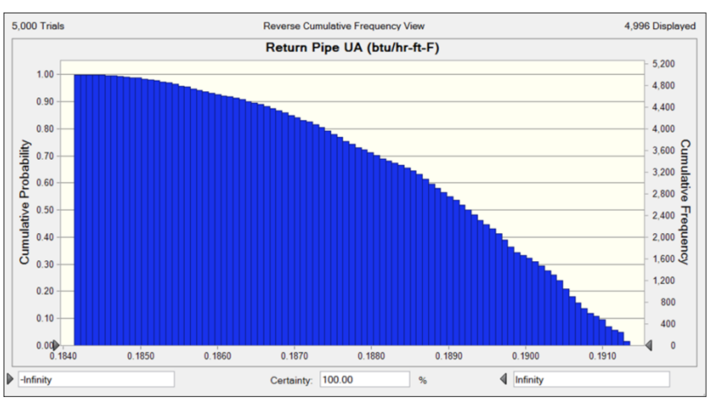
Outputs from the analysis were compared to the input references to corroborate the integrity of these assumptions. Piping heat loss coefficients for example, were developed by adjusting relevant inputs to correspond to parameter values in the ASHRAE tables. The factors were then simulated over a range of hot water flow rates and pipe insulation thermal conductivity values to estimate their mean values and as well as probability distribution (illustrated in figures below) for both the recirculation loop supply and return piping. The mean values were then compared to the ASHRAE tables for an order-of-magnitude comparison.

Probability for Hot Water Supply Pipe UA Factor



UA (btu/hr-ft-F) Percentile	
0%	0.0947
10%	0.1297
20%	0.1567
30%	0.1819
40%	0.2207
50%	**0.2583**
60%	0.3074
70%	0.3765
80%	0.4745
90%	0.6500
100%	1.0435

Probability for Hot Water Return Pipe UA Factor



UA (btu/hr-ft-F) Percentile	
0%	0.1842
10%	0.1863
20%	0.1873
30%	0.1879
40%	0.1887
50%	**0.1892**
60%	0.1896
70%	0.1901
80%	0.1905
90%	0.1909
100%	0.1914

Piping Heat Loss Coefficient Tables [13]

Table 2 Approximate Heat Loss from Piping at 140°F Inlet, 70°F Ambient

Nominal Size, in.	Bare Copper Tubing, Btu/h·ft	Bare Copper *UA*, Btu/h·ft·°F	0.5 in. Glass Fiber Insulated Copper Tubing, Btu/h·ft	0.5 in. Glass Fiber Insulated Copper *UA*, Btu/h·ft·°F
0.75	30	0.43	17.7	0.25
1	38	0.54	20.3	0.29
1.25	45	0.64	23.4	0.33
1.5	53	0.76	25.4	0.36
2	66	0.94	29.6	0.42
2.5	80	1.14	33.8	0.48
3	94	1.34	39.5	0.56
4	120	1.71	48.4	0.69

Table 1 Piping Heat Loss Factors for Foam Insulation with Thermal Conductivity of 0.02 Btu/h·ft^2·°F

Nominal Pipe Size, in.	Foam Insulation Thickness, in.	$UA_{zero\ flow}$, Btu/h·ft·°F	High-Value $UA_{flowing}$, Btu/h·ft·°F
1/2 rigid copper	0	0.226	0.36
	0.5	0.128	0.20
	0.75	0.116	0.19
3/4 rigid copper	0	0.388	0.44
	0.5	0.150	0.25
	0.75	0.142	0.24
3/4 PEX-AL-PEX*	0	0.550	0.546
	0.5	0.199	0.199
	0.75	0.158	0.18

Sources: Hiller (2005a, 2005b, 2006b).
*High-density cross-linked polyethylene, aluminum, high-density cross-linked polyethylene multilayer pipe.

A limited number of building energy models were then simulated to derive preliminary estimates of energy savings. These estimates were compared with the CASE study[14] low- and high-rise multifamily building savings estimates to corroborate the integrity of the building energy models. These initial estimates generated results similar to the low-rise case in the figure above.

Domestic Hot Water Energy Savings (from CASE Study) [15]

Control Technology	Low-Rise			High-Rise		
	Electricity Savings (kWh)	Demand Reduction (kW)	Natural Gas Savings (Therms)	Electricity Savings (kWh)	Demand Reduction (kW)	Natural Gas Savings (Therms)
Temperature Modulation	0	0	405	0	0	535
Continuous Monitoring	0	0	461	0	0	771
Temperature Modulation + Continuous Monitoring	0	0	785	0	0	1,199
Demand Control	1,228	0.104	1,014	2,035	0.233	1,255

After the building model integrity had been validated, the engineering calculations were adjusted by resetting the input factors back to the conditions specific for this analysis. The purpose of this analysis

[13] American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2015. *2015 ASHRAE Handbook - HVAC Applications.* Atlanta (GA): ASHRAE. Page 49.6.

[14] California Utilities Statewide Codes and Standards Team. 2011. *Codes and Standards Enhancement Initiative (CASE), Multifamily Central DHW and Solar Water Heating, 2013 California Building Energy Efficiency Standards.*

[15] California Utilities Statewide Codes and Standards Team. 2011. *Codes and Standards Enhancement Initiative (CASE), Multifamily Central DHW and Solar Water Heating, 2013 California Building Energy Efficiency Standards.*

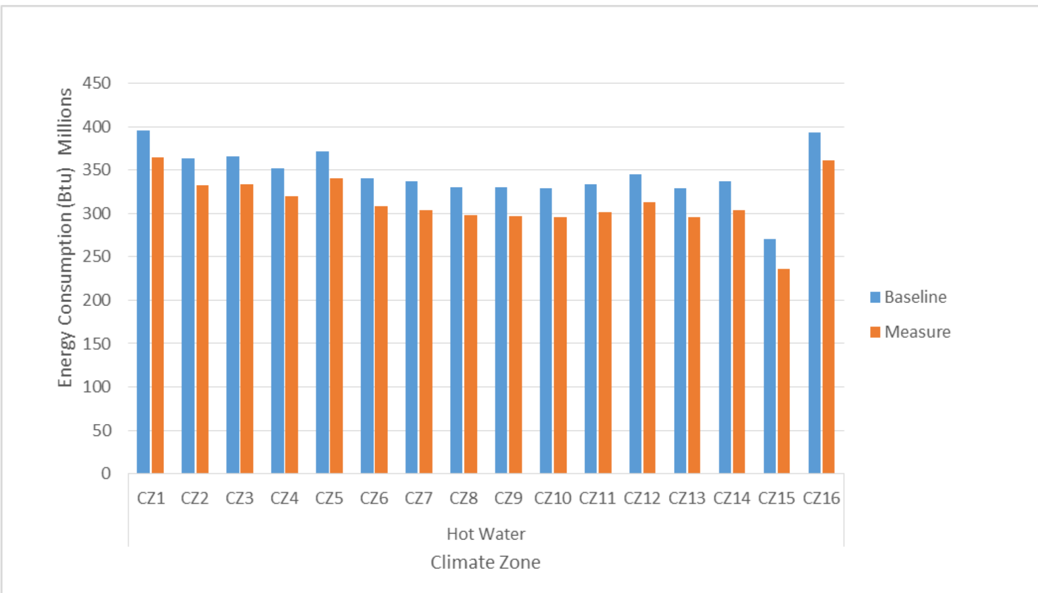
was to confirm that the engineering assumptions and calculations were reasonable when compared to industry standards and empirical studies.

Develop Energy Savings and Demand Reduction Estimates

The building energy models described above were simulated in each of the 16 California Building Climate Zone Areas using representative location weather files. They were simulated for both the base case and measure case scenarios using eQUEST. The base case was developed by modifying the baseline case domestic hot water circulation loop properties and pump characteristics in eQUEST. They were then further modified to represent a VFD variation of the measure case described preceding sections. The recirculation loop hot water flow and minimum flow ratios were adjusted, and the recirculation loop pump was changed from a standard motor class with one speed pump capacity control to a premium pump operating with a variable speed drive. The base case and measure case models were then simulated to produce estimates of energy consumption.[16] Energy savings were then calculated as the difference in domestic hot water and pump energy consumption between the base case and measure case.

Simulated outputs were processed to derive annual natural gas and electricity savings for whole-building, domestic hot water and pump end uses. The figure below illustrates the aggregate domestic hot water energy consumption for both the base case and efficiency measure case, for each of the 16 climate areas.

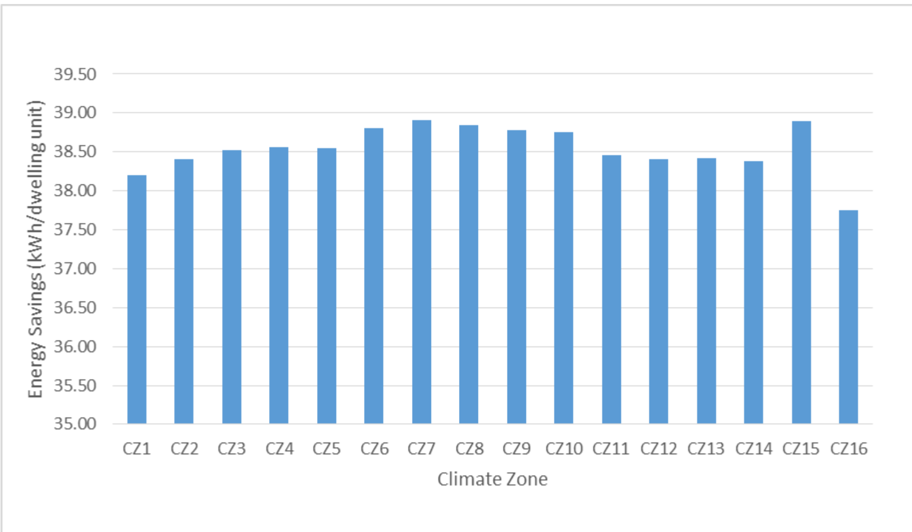
Baseline and Measure Domestic Hot Water Consumption, by Climate Zone



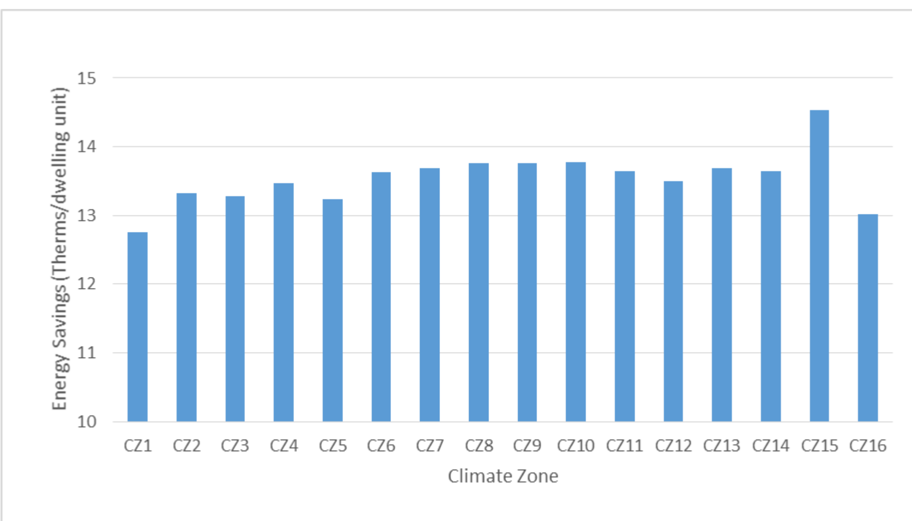
[16] Southern California Gas Company (SCG). 2016. "WPSCGREWH161128A-Rev00_Recirc Pump Control for MF_Building Energy Model Results.xlsx."

The two figures below illustrate the recirculation pump (electricity) and hot water system (natural gas) savings across these same climate areas on a per dwelling unit basis, exhibiting similar trends to one another. Domestic hot water savings are inversely proportional to the system demand schedule. That is, the greatest energy savings are realized during periods of lowest system demand; although energy is saved over the entire annual load profile. Similarly, recirculation pump consumption is inversely proportional to the hot water demand schedule. Greater requirements for pump operation occur during periods of lower hot water system demand, with energy savings approximately constant over the annual load profile.

Recirculation Pump Savings, by Climate Zone



Domestic Hot Water System Savings, by Climate Zone

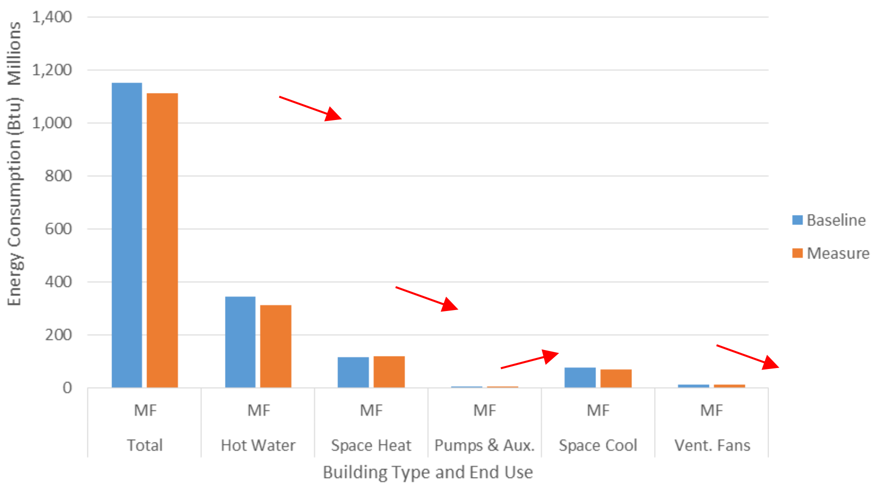


There is a significant variance in energy savings (on a unit basis) between the low- and high-rise building. This is likely a result of the nonlinear relationship between the hot water distribution piping length to either building floor area or number of dwelling units. That is, the hot water distribution piping length varies by building type, size, and architectural and engineering design factors and has a significant impact on the total hot water system consumption and available energy savings. The amount of heat loss in the distribution system is proportional to the piping length, piping heat loss coefficients, and difference between the indoor ambient and hot water temperatures. These factors are influenced by location of the recirculation loop, pipe material, size, insulation, and hot water demand. In addition, these factors underscore the importance of validating the assumptions—an understanding that variations from the validated assumptions may have a material impact on energy savings.

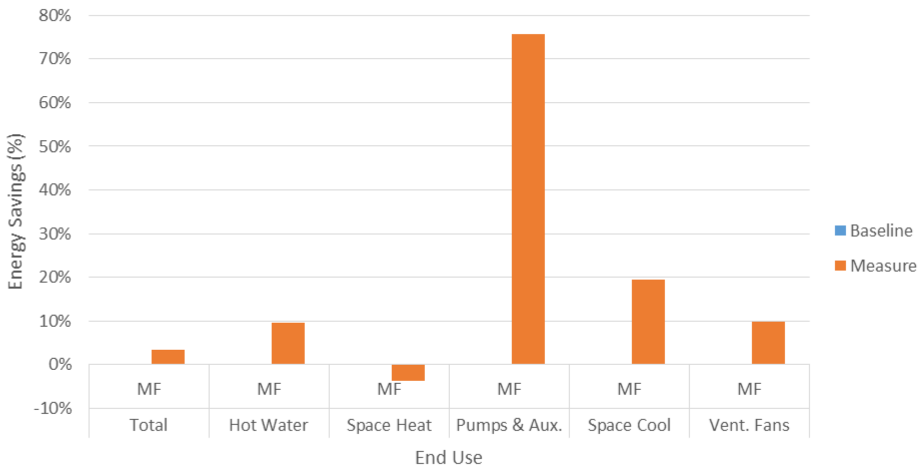
The figures above illustrate that domestic hot water system energy consumption varies by climate zone. The figure below, on the other hand, illustrates that hot water savings in the measure case impacts the energy consumption and performance of other building end uses. Specifically, space heating consumption increases while space cooling consumption decreases, due to reduction of heat loss from the domestic hot water recirculation loop, as whole building energy consumption decreases.

The figures below illustrate the circulation pump total energy consumption is relatively small, the relative pump energy savings is large (respectively). This contrasts with domestic hot water, which requires more total energy but smaller percentage of savings. A detailed review of the pump savings load shape shows a small variation in the amount of savings across climate zones and over the annual load profile.

End Use Energy Consumption, All Fuels, All Climate Zones



End Use Energy Savings, All Fuels, All Climate Zones



PEAK ELECTRIC DEMAND REDUCTION (kW)

Demand reduction from this measure was developed from an analysis of the "Pump & Aux" end use electric load shapes, which were derived from simulation of building energy models (see Energy Savings section). The measure case load shape was subtracted from the base case load shape during each of the stipulated peak demand time intervals. In general, there is a small variance in the amount of demand reduction that occurs by time of year, climate zone, or during the peak demand period. The measure case produces savings for every hour of the year by reducing pumping power requirements compared to the base case recirculation pumps that run continuously with no control.

GAS SAVINGS (Therms)

The gas unit energy savings (UES) that result from a demand-controlled recirculation pump installed in a centralized multifamily hot water system were developed through a combination of research, engineering calculations, and building energy simulation models. See Electric Savings section.

LIFE CYCLE

Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention not caused the replacement or alteration. The RUL is only applicable to the first baseline period for a retrofit measure with an applicable code baseline. The methodology to calculate the RUL conforms with Version 5 of the Energy Efficiency Policy Manual, which recommends "one-third of the effective useful life in DEER as the remaining useful life until further study results are available to establish more accurate values."[17] This approach provides a reasonable RUL estimate without requiring any a priori knowledge about the age of the equipment being replaced.[18]

The EUL specified for the VFD demand control for a centralized water heater recirculation pump are specified below. The EUL was derived from the 2013 CASE study estimated demand control equipment and is consistent with a similar DEER measure (Circulation Pump Timeclock Retrofit). The EUL of the host motor pump was derived from numerous retention studies and was documented for the Database for Energy Efficient Resources (DEER) 2008 update.

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs)	15.0	California Utilities Statewide Codes and Standards Team. 2011. *Codes and Standards Enhancement Initiative (CASE), Multifamily Central DHW and Solar Water Heating, 2013 California Building Energy Efficiency Standards.*
EUL (yrs) – host motor pump	15.0	California Public Utilities Commission (CPUC). 2008. "EUL_Summary_10-1-08.xls."
RUL (yrs)	5.0	-

BASE CASE MATERIAL COST ($/UNIT)

The base case domestic hot water recirculation system includes an uncontrolled, constant speed, fractional horsepower pump. Because this measure is applicable only for add-on equipment installations, the base case cost is $0.

MEASURE CASE MATERIAL COST ($/UNIT)

Implementation of the on-demand domestic hot water recirculation pump controller requires removal of the base case pump and the installation of a new recirculation pump with VFD and controllers. The measure cost was derived from data obtained from an equipment manufacturer of the demand control recirculation pump.[19] At the time the analysis was undertaken, only a 1/6-hp pump is commercially available by the manufacturer. The average cost for a new recirculation pump was calculated as the average of the cost for the basic "T" size and larger "T" size pumps.

This average cost was then divided by the number of dwelling units (in increments of five units up to 50 units) to derive the measure case material cost per multifamily dwelling unit.

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[17] California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 32.

[18] KEMA, Inc. 2008. "Summary of EUL-RUL Analysis for the April 2008 Update to DEER." Memorandum submitted to Itron, Inc.

[19] Southern California Gas Company. 2011. "WPSCREWP0002.0_11_17_11 Cost Analysis.xlsx."

Material Cost Inputs

Pump Model	Pump Cost	Source
Basic "T" size	$1,595.00	Southern California Gas Company. 2011. "WPSCREWP0002.0_11_17_11 Cost Analysis.xlsx."
Larger "T" size	$1,670.00	
Average Pump Cost	**$1,632.00**	

BASE CASE LABOR COST ($/UNIT)

The base case domestic hot water recirculation system includes an uncontrolled, constant speed, fractional horsepower pump. Because this measure is applicable only for add-on equipment installations, the base case labor cost is $0.

MEASURE CASE LABOR COST ($/UNIT)

The labor cost assumptions are specified in the table below. The labor hours required to install this measure were provided by a representative of a manufacturer of the demand control recirculation pump.[20] The labor rate is the "base wage rate" for "NR-DWH-SWH" specified in the Database for Energy Efficient Resources (DEER) Measure Cost Summary published in 2008.

This labor cost is based only on incremental labor and assumes the labor to install the base case recirculation pump and measure case recirculation pump will be the same. Therefore, the resultant measure case labor cost represents the *additional* labor required to install demand control sensors and commission the new system. Furthermore, the labor sot is assumed to be the same for both pump size categories for the measure case as there is currently no other data for different pump sizes.

The total labor cost (hours multiplied by rate) was then divided by the number of dwelling units (in increments of five units up to 50 units) to derive the measure case labor cost per multifamily dwelling unit.

Labor Cost Inputs

Parameter	Value	Source
Labor hours	2.0	Southern California Gas Company. 2011. "WPSCREWP0002.0_11_17_11 Cost Analysis.xlsx."
Labor rate ($/hr)	$59.00	California Public Utilities Commission (CPUC). 2008. "Revised DEER Measure Cost Summary (05_30_2008) Revised (06_02_2008).xlsx." See "Res NR DHW" tab.

NET-TO-GROSS (NTG)

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. The NTG value is the "default" value assigned to measures that have been promoted by residential programs for more than two years for which evaluation results are not available, as documented in the 2011 DEER Update Study conducted by Itron, Inc. The value was

[20] Southern California Gas Company. 2011. "WPSCREWP0002.0_11_17_11 Cost Analysis.xlsx."

approved by the California Public Utilities Commission in the "Workpaper Disposition for On-Demand Pump Control for Central Domestic Hot Water Systems" issued in June 2013.[21]

Net-to-Gross Ratio

Parameter	Value	Source
NTG – residential	0.55	Itron, Inc. 2011. *DEER Database 2011 Update Documentation.* Prepared for the California Public Utilities Commission. Section 15, Table 15-3. California Public Utilities Commission (CPUC), Energy Division. 2013. "Workpaper Disposition for On-Demand Pump Control for Central Domestic Hot Water Systems." February 28. Revised June 20, 2013. Page 2.

GROSS SAVINGS INSTALLATION ADJUSTMENT (GSIA)

The gross savings installation adjustment (GSIA) rate represents the ratio of the number of verified installations of the measure to the number of claimed installations reported by the utility. This factor varies by end use, sector, technology, application, and delivery method. This GSIA rate is the current "default" rate specified for measures for which an alternative GSIA has not been estimated and approved.

Gross Savings Installation Adjustment Rates

Parameter	Value	Source
GSIA	1.0	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 31.

NON-ENERGY IMPACTS

Non-energy impacts for this measure have not been quantified.

DEER DIFFERENCES ANALYSIS

This section provides a summary of Database of Energy Efficiency Resources (DEER)-based inputs and methods, and the rationale for inputs and methods that are not DEER-based. The demand control for centralized domestic hot water recirculation pump is not included in DEER, though the measure analysis utilizes DEER building prototypes for the energy performance simulations.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	No
Scaled DEER measure	No
DEER Base Case	No
DEER Measure Case	No

[21] California Public Utilities Commission (CPUC), Energy Division. 2013. "Workpaper Disposition for On-Demand Pump Control for Central Domestic Hot Water Systems." February 28. Revised June 20.

DEER Item	Comment / Used for Workpaper
DEER Building Types	No
DEER Operating Hours	No
DEER Version	n/a
DEER eQuest Prototypes	Yes, DEER 2003 eQuest prototypes
Reason for Deviation from DEER	DEER does not contain this type of measure.
DEER Measure IDs Used	n/a
NTG	The NTG of 0.55 is associated with NTG ID: *Res-Default>2yrs*, and is adopted in conformance with the following disposition: California Public Utilities Commission (CPUC), Energy Division. 2013. "Workpaper Disposition for On-Demand Pump Control for Central Domestic Hot Water Systems." February 28. Revised June 20, 2013. Page 2.
GSIA	The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: 2013 CASE Study and DEER 2011 (EUL_Summary_10-1-08.xls). The value of 15 years is associated with EUL ID: *WtrHt-Timeclock*. The RUL is based upon 15 years and EUL ID: *Motors-pump.*

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Completion Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision Effective Date and Approved By
01	03/31/2018	Jennifer Holmes, Cal TF Staff	Draft of consolidated text for this statewide measure is based upon: WPSCGREWH161128A, Revision 0 (February 14, 2017) PGECODHW126, Revision 2 (uploaded to WPA on May 18, 2018) PGECODHW126, Revision 1 (September 27, 2016) Consensus reached among Cal TF members.
	02/28/2019	Jennifer Holmes, Cal TF Staff	Revisions for submittal of version 01.