WATER HEATING

RECIRCULATION PUMP TIMER, COMMERCIAL

SWWH021-01

CONTENTS

MEASURE NAME

Recirculation Pump Timer, Commercial

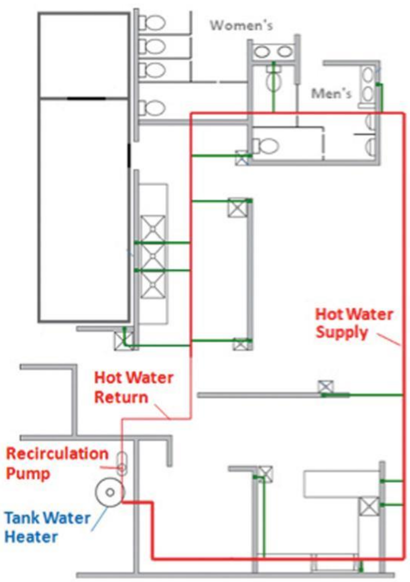
STATEWIDE MEASURE ID

SWWH021-01

TECHNOLOGY SUMMARY

This measure refers to the addition of a timer to an existing recirculation pump in a commercial building with defined operating hours. The addition of a timer to the hot water system allows the pump to shut OFF for a scheduled period when the building is unoccupied and hot water is no longer needed on demand.

Hot Water Recirculation Loop in a Commercial Building[1]



The figure depicts a simple recirculation loop that is typical of the commercial building types covered in this measure analysis. Recirculation pumps circulate hot water in buildings with central hot water heaters to provide hot water instantly or shortly after the draw is initiated, even at remote locations in the building. In typical, one-way plumbing without a recirculation pump, water is piped from the water heater through the pipes to the tap. Once the tap is shut OFF, the water remaining in the pipes cools and results in a wait for hot water the next time the tap is opened. All of the cool water in the pipe must go down the drain before the hot water from the tank reaches the fixture. Because a recirculation pump constantly circulates hot water through the pipes from the water heater to the farthest fixture and back to the heater, the water in the pipes is always hot, and no water is wasted during the wait. While a recirculation pump saves water, it uses energy by continuously operating the pump and increasing the heat loss from the system, even when hot water is not in demand.

The timer will reduce electricity use by turning OFF the recirculation pump, thereby stopping the continued supply of hot water to the system when the building is unoccupied. Once properly installed, the timer will operate without customer intervention if the occupancy hours do not change.

Any time the recirculation loop is maintained at the setpoint, heat dissipates in the surrounding air. Shutting off the pump and letting the temperature in the loop drop will reduce the heat loss.

The energy savings result from the heat that would have been lost from the hot water as it is circulated continuously through the recirculation loop during unoccupied hours. Savings are dependent on building operating hours and the characteristics of the pump and piping system.

The research that was referenced for this measure analysis is summarized below.

Recirculation Pump Time Clock Field Testing Report, Navigant Consulting, Inc. (2017).[1] This field test, conducted December 2013 through May 2014, involved the installation and data logging of timers programmed with occupancy schedules installed on service hot water recirculation pumps in a 150,000 ft^2 commercial office building. Even though this study is a field test of the same technology as this measure, it only provides a single data point of savings associated with a recirculation pump timer. Accordingly, the data is insufficient for the purposes of statistically validating the model. Further, due to the multitude of variables that impact the heat loss in a hot water recirculation system, and therefore the magnitude of the gas savings, it is difficult to compare the savings in the field test to the savings in this work paper.

The methodology defined for this measure analysis uses supported assumptions about building and piping characteristics and temperature based on knowledge of the service territory. Several inputs can be adjusted in the model, including: building type, pump horsepower range, pipe insulation thickness and water temperature setpoint. In the field report, only pump horsepower and temperature set point were confirmed. As a result, assumptions must be made for all other variables and based on the possible range of inputs and the resulting gas savings can fall above or below the logged savings value reported in the field study.

Despite these limitations, insights that can be gleaned from the final savings value, and other lessons learned from the field study can support the measure, including:

- The field data showed limited, intermittent hot water usage overnight when the pump was OFF. It is believed that this is due to either cleaning crew or security use. These unexpected draws would increase heat losses (i.e., decrease the gas savings) compared to no hot water use for the duration of the unoccupied hours because with increased hot water temperature in the pipe (drawn from the hot water heater), comes higher heat loss rates to the surrounding air. Without consistent, or predictable expectations for draws during unoccupied hours, this measure analysis assumes no hot water use during unoccupied hours.
- The observed installation from the field study found that an adapter was used between the pump and the recirculation supply line to the building. Therefore, it should be clarified that the hot water supply pipe size input variable in this measure analysis refers to the size of the piping that loops through the building and excludes the size of the adapters that may have been used to match to the pump flange size.

Energy-Efficiency with Domestic Water Heating in Commercial Buildings, Oracle America, Inc. (2010).[2] This field test involved the installation and data logging a manually programmable timer or connection of the pump to a building energy management system to control the ON/OFF times based on building occupancy of a 267,000 ft^2 commercial office building. Although the field data collected in this study pertains to a similar measure as defined in this work paper, the savings in this report are different than the expected savings documented herein for this measure analysis. The same reasoning can be drawn from the field data in this paper as was drawn from the Navigant 2017 field report.

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[1] Navigant Consulting, Inc. 2017. *Recirculation Pump Time Clock Field Testing Report.* Prepared for the Southern California Gas Company.

[2] Khattar, M. and A. Somani (Oracle America, Inc.) 2010. "Energy-Efficiency with Domestic Water Heating in Commercial Buildings." Proceedings of the ACEEE 2010 Summer Study on Energy Efficiency in Buildings, 9.131-142. Washington, DC: American Council for an Energy Efficiency Economy (ACEEE).

MEASURE CASE DESCRIPTION

This measure is defined as a timer control added to recirculation loop in a commercial building. The measure offerings are defined by horsepower range of the recirculation pump, as shown below. Because savings are dependent on building operating hours, savings were developed for each measure offering for each of six selected building types.

Measure Case Specification

Building Type
Healthcare – outpatient
Service – fitness
Office – large
Office – small
Education – primary
Education - secondary

Recirculation Pump Horsepower Range (hp)
≤ 1/12
> 1/12 and ≤ 1/3
> 1/3 hp

BASE CASE DESCRIPTION

The base case for this measure is a continuously operating recirculation pump from which hot water is always available at the fixture, irrespective of hot water loop temperature or system demand. As shown below, the base case of this measure is defined as an industry standard, constant flow recirculation pump in operation 24 hours per day.

Baseline Scenarios

Existing Condition	Constant flow recirculation pump operating 24 hours per day.
Code/Standard	Code for newly constructed buildings, additions to existing buildings, and alterations to existing buildings: Recirculation pumps with automatic shut off controls to turn off the service hot water system.
Industry Standard Practice	Constant flow recirculation pump, operates 24 hours per day.

CODE REQUIREMENTS

There are no federal, state, or regional codes or standards that regulate commercial hot-water recirculation pumps in existing buildings. Recirculation pump 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 govern* this add-on equipment measure. Relevant sections of the standards are summarized below.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20 (2015)[3]	None.	n/a
CA Building Energy Efficiency Standards – Title 24 (2016)[4]	Recirculation systems: Section 110.3(c).2 Section 110.3(c).5 120.3	January 1, 2017
Federal Standards	None	n/a

California Building Energy Efficiency Standards (Title 24, 2016). Title 24 provides mandatory, prescriptive and performance requirements for hot water 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; the sections include: automatic shut off pump controls, general system installation, and pipe insulation requirements for all building types.

- **Section 110.3(c) 2** requires 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** applies to all building types and provides mandatory requirements for the installation of hot water recirculation systems but does not address recirculation pump control.
- **Section 120.3** 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 to inform model input assumptions, such as the assumption that the hot water circulation loop is insulated. The normal operation heat rates used in development of the measure case correspond to the requirements consistent with data from the 2015 ASHRAE Handbook on HVAC Applications.[5]

NORMALIZING UNIT

Each

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

[3] California Energy Commission (CEC). 2015. *2015 Appliance Efficiency Regulations*. CEC 400-2015-021.

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

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

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	DnDeemed	Com

Eligible Products

Eligibility requirements for this measure include the following:

- The building must have a hot water recirculation system that can be turned OFF entirely for a set period of the day and/or week.
- The building must have a centralized, gas-fired, hot-water system with a constant-flow, fractional-horsepower, uncontrolled recirculation pump.
- The timer device must have seven-day (or better) scheduling capabilities.
- There is no restriction on manufacturer or brand-naming.

Eligible Building Types and Vintages

This measure is applicable to *existing* buildings and is limited to the commercial building types specified below.

Eligible Building Types

Building Type
Healthcare – outpatient
Service – fitness
Office – large
Office – small
Education – primary
Education - secondary

Eligible Climate Zones

This measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

This measure is excluded from newly constructed buildings, additions to existing buildings, and alterations to existing buildings.

DATA COLLECTION REQUIREMENTS

Data collection requirements are to be determined.

USE CATEGORY

Service & domestic hot water

ELECTRIC SAVINGS (kWh)

See Gas Savings section.

PEAK ELECTRIC DEMAND REDUCTION (kW)

Peak demand reduction is not expected to result from this measure.

GAS SAVINGS (Therms)

The energy savings of this measure result from the heat that would have been lost from the hot water that is circulated continuously through the recirculation loop during unoccupied hours. Savings are dependent on building operating hours and the characteristics of the pump and piping system.

Gas unit energy savings (UES) were developed through a combination of research and engineering calculations. The approach and model calculations used to develop the UES estimates are summarized below.

Approach

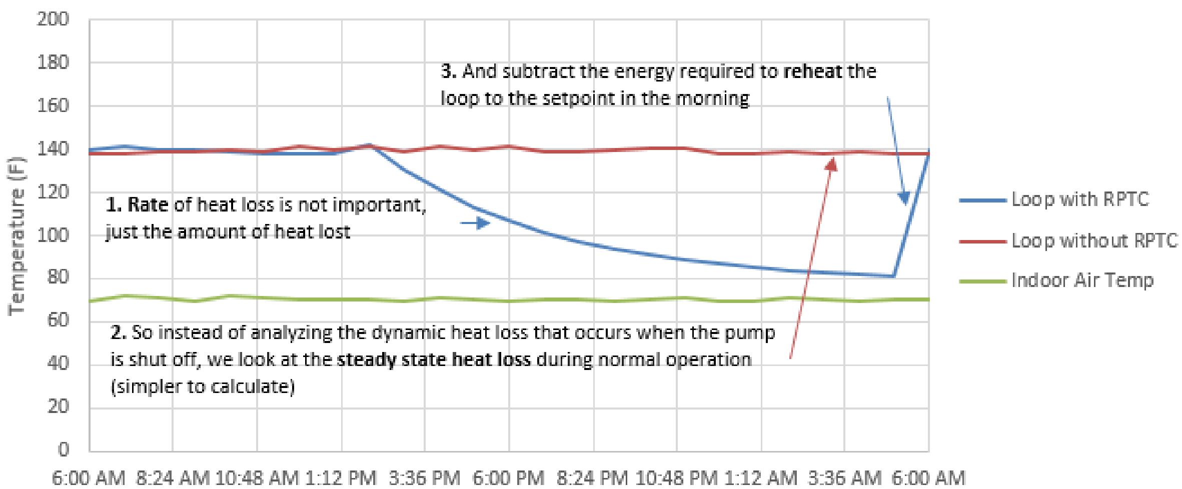
The annual gas UES of this measure is dependent on the amount of heat lost from the recirculation loop when the recirculation pump is turned OFF versus the amount of heat lost during normal pump operation. The rate of heat loss changes over time based on the difference in temperature between the pipe and the ambient air. It is assumed that the savings are independent of the rate of heat loss (Btu/hr) because the unoccupied hours are sufficiently long that the loop temperature will approach the ambient air temperature by the time the pump restarts. Therefore, instead of analyzing the dynamic heat loss that occurs when the pump is shut OFF, it is simpler to calculate the steady state heat loss during baseline operation (pump constantly circulating) and then subtract the energy required to reheat the recirculation loop when the system is turned back ON.

The analysis is implemented in an engineering model that calculated the final energy savings for all possible measures. The resulting final gas UES calculation used is shown below.

$$UES_{therms} = UEC_{OFF} - UEC_{ON}$$

$UES_{therms} =$	*Gas unit energy savings (therms)*
$UEC_{OFF} =$	*Gas unit energy consumption for normal OFF hours (therms)*
$UEC_{ON} =$	*Gas unit energy consumption for reheat after pump is turned ON (therms)*

The figure below depicts the approach used for this measure to calculate the annual gas UES with illustrative water and air temperatures.



Model Methodology

Navigant Consulting, Inc. developed a model to run the necessary engineering calculations for all variables of this measure.[6] The model uses three inputs to characterize the application: building type, hot water supply pipe diameter, and pump horsepower. The model determines estimated unit energy consumption (UEC) for the measure as the estimated energy lost during nighttime hours if the pump is fully operating, minus the energy required to bring the system back up to the temperature in the morning.

Because there are numerous variables that can impact the heat loss of an operational hot water recirculation system, some inputs were fixed based upon knowledge of the subset of building types. The following table summarizes the inputs (variables and constants) required for the model.

UEC Inputs

System Parameters		Value(s)	Source
Variable Building Inputs *(varies by customer)*	Building Type	Primary Education Secondary Education Fitness Centers Small Office Large Office Outpatient Healthcare	See "Building Type Characteristics" below.
	Recirculation Pump Range (hp)	≤ 1/12 hp > 1/12 and ≤ 1/3 hp > 1/3 hp	See below.

[6] Navigant Consulting, Inc. (2017). "Recirculation Pump Time Clock Engineering Calculations and Savings Model. V3.1." Prepared for the Southern California Gas Company. Developed in support of workpaper WPSCGNRWH170313A. Last updated on September 12, 2017.

System Parameters		Value(s)	Source
Required Building Characteristics *(based off of variable inputs)*	Hot Water Supply Pipe Diameter[7] – Assumed	1.25" 1.50" 2.00"	Value based on input pump range selected, based on the head loss calculator and horsepower-to-loop-length overlay. See Recirculation Loop Length below.
	Pipe Insulation	0.50"	Ayala, G. and D. Zobrist (Enovative Group, Inc.) 2012. "Best Practices for Efficient Hot Water Distribution in Multifamily Buildings." Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings, 2-14. Washington DC: American Council for an Energy-Efficient Economy (ACEEE).
	Gas Water Heater Efficiency ($Efficiency_{Boiler}$)	83.49%	Itron, Inc. and ERS, Inc. 2017. *2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report.* Prepared for the California Public Utilities Commission.
	Annual Hours of Vacancy ($Hours_{Vacancy}$)	6180, 6180, 2936, 5479, 3973, 5900	See "Building Type Characteristics" below.
	Days open per week (days)	5, 7	
	Annual Number of Shutdown Periods (*Events*)	260, 364	
Hot Water System Characteristics *(based off of variable inputs)*	Pump Horsepower – Assumed (hp)	1/25, 1/6, 1/2	Value based on input pump range selected, see below.
	Return Pipe Nom Diameter – Assumed (in.)	0.75, 1.00, 1.25	Value based on input pump range selected, based on the head loss calculator and horsepower-to-loop-length overlay. See Recirculation Loop Length below.
	Supply Pipe ID (*SupplyPipeID*)	0.785, 1.025, 1.265, 1.505, 1.985	American Society for Testing and Materials (ASTM). 2016. *ASTM B88-16: Standard Specification for Seamless Copper Water Tube.* West Conshohocken (PA): ASTM International.
	Return Pipe ID (*ReturnPipeID*)		
	Supply Pipe OD (*SupplyPipeOD*)	0.875, 1.125, 1.375, 1.625, 2.125,	
	Return Pipe OD (*ReturnPipeOD*)		
	Pipe Heat Loss - Supply Pipe ($q_{SupplyPipe}$)	23.4, 25.4, 29.6	Lookup based on supply pipe diameter, see below.
	Pipe Heat Loss - Return Pipe ($q_{ReturnPipe}$)	15.2, 17.4, 20.1	
	Estimated Total Pipe Length (*PipeLength*)	620, 1500, 2600	Lookup based on input pump range selected, see below.
	Pump Average Input Power ($Pump_{kW}$)	0.072, 0.216, 0.441	Hagermann, J. (U.S. Department of Energy, Building Technologies Program). 2016. "Circulator Pumps: Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) Working Group." Ninth Meeting, November 3-4, 2016.

[7] The hot water supply pipe diameter input refers to the size of the piping that loops through the building to the hot water demand points. It excludes the size of any adapters that may be used to match the circulation piping to the pump flange size.

Building Type. The building types included in this measure were selected based on the criteria specified below.

Building Type Criteria

Criteria	Detail
Existing hot water recirculation loop	The building type is likely to have a recirculation loop (i.e., large number of bathrooms and/or sinks). Excluding building types that would be reasonably believed to have a loop that is less than approximately 150-feet long.
Hours of vacancy	The building type has approximately 50 or more hours per week of non-operating time.
Defined operating hours	The building type has defined operating hours that could be programmed in the timer.

Annual Hours of Operation. For Primary and Secondary Education and Large and Small Office building types, operating hours were based on data from the DEER 2015 Small Storage and Small Instantaneous Water Heater Energy Use Calculator.[8] The data provides hot water load (gallons per minute) at a set tank temperature by building type for each hour of the year. Operating hours were calculated based on the hours per year that the hot water load was greater than zero, assuming hot water load is greater than zero for all occupied hours. This source did not have data for Outpatient Healthcare and Fitness Center building types.

For Outpatient Healthcare and Fitness Center building types, annual hours of vacancy and days open per week are based on the Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS) data.[9] Annual hours of vacancy used in the model were adjusted from the original CBECS data for two reasons: 1) to be conservative in model calculations of energy savings as the energy saved is directly proportional to the hours that the pump is OFF, and 2) to account for the fact that the recirculation pump should be turned ON in advance of operating hours to allow the water in the loop to reach the set point before occupants arrive. The values used are presented in table below.

[8] California Public Utilities Commission (CPUC), Energy Division. 2017. DEER2015 Small Storage and Small Instantaneous Water Heater Energy Use Calculator. "DEER-WaterHeater-Calculator-v2.1.xlsm." Updated July 10, 2017.

[9] U.S. Energy Information Administration (EIA). *2012 Commercial Buildings Energy Consumption Survey (CBECS).* “Table B1. Summary table: total and means of floorspace, number of workers, and hours of operation.”

Building Type Characteristics

Building Type	Vacant Hours per Year	Days Open per Week	Hours Open per Day	Source
Outpatient Healthcare (Cnc)	5,900	5	11	U.S. Energy Information Administration (EIA). *2012 Commercial Buildings Energy Consumption Survey (CBECS).* "Table B1. Summary table: total and means of floorspace, number of workers, and hours of operation."
Service – Fitness (Fhc)	2,936	7	16	
Large Office (OfL)	3,973	5		California Public Utilities Commission (CPUC), Energy Division. 2017. DEER2015 Small Storage and Small Instantaneous Water Heater Energy Use Calculator. "DEER-WaterHeater-Calculator-v2.1.xlsm." Updated July 10, 2017.
Small Office (OfS)	5,479	5		
Education Primary (EPr)	6,180	5		
Education Secondary (ESe)	6,180	5		

CBECS does not provide data for fitness centers specifically, so the annual hours of vacancy and days open per week were derived from the CBECS data for service buildings (which includes fitness centers) based on a sample of operating hours from local businesses.

Annual Number of Shutdown Periods. The number of shutdown periods is equivalent to the number of times the pump turns back ON. This is calculated in the model by multiplying the number of days per week the building type is open by 52 weeks per year.

Pump Horsepower. As of January 2019, manufacturer materials (websites, catalogs, data sheets) indicate the vast majority of pumps used for hot water recirculation applications are ≤ 1 hp. The analysis for this measure suggests that the distribution is heavily weighted towards units that are ≤ 1/3 hp. Both points are supported by the data that was available and compiled from multiple studies on building recirculation characteristics,[10] including the Navigant 2017 Recirculation Pump Time Clock Field Testing Report. Therefore, the pump horsepower ranges selected for this analysis support an even distribution of the likelihood of pump size:
≤ 1/12 hp, > 1/12 hp and ≤ 1/3 hp, and > 1/3 hp.[11]

The representative (assumed) horsepower values for each pump range aim to be representative of the entire group, but, if anything, are slightly conservative in terms of resulting energy savings.

Pipe Diameter. The representative (assumed) hot water supply pipe diameter selected for each representative pump was based on the head loss calculator and horsepower-to-loop-length overlay (described below). The pipe diameters selected for this analysis represent a balance of the head loss and the flow rate at the three representative pump sizes. The values selected represent the midpoint of the potential size range of available flange sizes and fall along the moderately sloped portions of the performance charts, ensuring that errors due to estimation of the pipe diameter do not dramatically change the results.

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[10] Hagermann, J. (U.S. Department of Energy, Building Technologies Program). 2016. "Circulator Pumps: Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) Working Group." Ninth Meeting, November 3-4, 2016.

[11] The analysis was conducted for the Southern California Gas Company (SCG), thus the building characteristics pertain specifically to buildings in the SCG service territory.

The return diameters also align with the pipe specifications for the pumps sizes selected.

Pipe Insulation. A conservative estimated insulation thickness of 0.5 inch was assumed in the model. According to a past research,[12] most multifamily residences do not have insulation on the recirculation system, as it has only recently been included in code and retrofits can be cost-prohibitive and impractical due to pipe access. Although the California Building Energy Efficiency Standards (Title 24) requires thicker insulation, this measure is not eligible for new construction and the baseline is not assumed to meet code.

Gas Water Heater Efficiency. The 2015 Nonresidential Downstream ESPI Deemed Pipe Insulation Impact Evaluation prepared by Itron, Inc.[13] provides a general hot water boiler combustion efficiency for units in California. The mean ex post combustion efficiency, including skin losses, is 83.49% for hot water boilers.

Supply and Return Pipe ID and OD Specifications. Supply and return pipe specifications follow the ASTM B88 Standard for seamless copper water tube[14] based on the supply and return nominal diameter selected.

Pipe Heat Loss. Pipe heat loss values were drawn from ASHRAE[15] and are a factor of supply pipe diameter and water temperature. The approximate heat loss values (Btu/hr-ft) presented by ASHRAE are based on copper tubing with 0.5-inch glass fiber insulation. The temperature at the inlet of the pipe is 140 °F and ambient temperature is 70 °F.[16] All heat loss calculations from the supply pipe assume fixed hot water temperature 140 °F and fixed indoor air temperature 70 °F.

The return pipe for this measure was assumed to be at a temperature of 130 °F. The 10-degree temperature drop is based on a common approximation used to estimate head loss when sizing recirculation pumps. A 10-degree drop was assumed for all head loss calculations performed for this measure. As a result, the heat loss values from ASHRAE were proportionately de-rated to determine the return-pipe heat loss.

Total Pipe Length. The total length of the recirculation loop was estimated based on the pump size and supply pipe diameter through a series of two separate models:

- *Head Loss Calculator* - The expected head loss was calculated by summing the head loss from an estimated number of fittings, fixtures, valves, and other restrictions throughout the loop along with the head loss per foot of piping. The model determined total head loss in the loop and flow rate based on the density and viscosity of water, the flow velocity through the pipe, the Reynolds

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[12] Ayala, G. and D. Zobrist (Enovative Group, Inc.) 2012. "Best Practices for Efficient Hot Water Distribution in Multifamily Buildings." Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings, 2-14. Washington DC: American Council for an Energy-Efficient Economy (ACEEE).

[13] Itron, Inc. and ERS, Inc. 2017. *2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report.* Prepared for the California Public Utilities Commission.

[14] American Society for Testing and Materials (ASTM). 2016. *ASTM B88-16: Standard Specification for Seamless Copper Water Tube.* West Conshohocken (PA): ASTM International.

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

[16] The 70-degree indoor air temperature is the standard value used by ASHRAE to develop the heat loss rates that were used in the engineering calculations for this work paper.
American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2015. *2015 ASHRAE Handbook – HVAC Applications.* Atlanta (GA): ASHRAE.

number of the fluid flow, and roughness and friction factor of copper tubing. The model calculated values for the full range of potential loop lengths and pipe diameters.

- *Horsepower-to-loop-length Overlay* - The total head loss values from the Head Loss Calculator model were overlaid with pump performance curves from a circulator manufacturer (two different sets of common pumps). This overlay allowed the estimation of loop length for each given combination of pipe diameter and pump horsepower. The overlay accounted for modest oversizing of pumps, which is common in the industry to ensure that pressure and temperature are maintained in the system (and leads to more conservative savings calculations).

Pump Average Input Power. The recirculation pump average input power was used to calculate the electricity saved while the pump is turned OFF. The average input power of the pump is a fixed value associated with each horsepower rating. These values were derived from data presented at the U.S. Department of Energy (DOE) Circulator's Rulemaking Negotiation Working Group Meetings.[17,18]

Circulator Input Power Analysis - To determine the average wattage for each pump horsepower rating, the pump curves (see Horsepower-to-loop-length Overlay), were compared to the pump curves of the DOE working group representative units.[19] When pump curves were similar, the pump energy rating wattage from the analogous DOE representative units was used. When pump curves fell well between DOE representative unit curves, the wattages were interpolated based on horsepower.

Model Calculations

Gas Unit Energy Savings Calculations

The calculations below represent the intermediate calculations performed by the model prior to determining the final UES.

The calculated **vacancy gas** (in Btu), represents the gas that would have been used to maintain the water temperature in the loop during vacancy hours. The same equation was used to calculate the supply and return vacancy gas, but the heat loss variable of the pipes differs. For vacancy gas calculations, the supply and return pipe were each assumed to be 50% of full length, which is why the pipe length variable is divided by two.

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[17] Raw data from the U.S. DOE Circulator's Rulemaking Negotiation Working Group Meetings was used for this measure analysis. Navigant, Inc. owns this data, but the meeting presentation is publicly available.

[18] Hagermann, J. (U.S. Department of Energy, Building Technologies Program). 2016. "Circulator Pumps: Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) Working Group." Ninth Meeting, November 3-4, 2016.

[19] As a part of the negotiations, the Working Group defined a variety of "representative units" and "efficiency levels." Efficiency levels ranged from bottom of the market efficiency to maximum achievable efficiency. Navigant posits that Efficiency level 1, which represents single-speed induction motor-driven circulators, represents the majority of recent-year shipments, and therefore appropriately represents the equipment appropriate for this analysis. For each combination of representative unit and efficiency level, the working group defined a "pump energy rating" (PER), which represents the average power draw at 25%, 50%, 75%, and 100% of best efficiency flow. Navigant posits that this PER value is representative of typical power draw, as circulator pumps are designed to operate over a wide range of flows.

Gas saved when the pump is OFF, Supply

$$vacancy\ gas_s = \left(q_{SupplyPipe}\ x\ \frac{Pipe\ Length}{2}\right) x\ \frac{hours_{vacancy}}{Efficiency_{boiler}}$$

$vacancy\ gas_s$	= Gas that would have been used to maintain water temperature in supply pipe during vacancy hours (Btu)
$q_{SupplyPipe}$	= Heat loss in supply pipe (Btu/hr/ft)
$Pipe\ Length$	= Pipe length
$Hours_{vacancy}$	= Hours of vacancy (hours)
$Efficiency_{boiler}$	= Efficiency rating of boiler

Gas saved when the pump is OFF, Return

$$vacancy\ gas_r = \left(q_{ReturnPipe}\ x\ \frac{Pipe\ Length}{2}\right) x\ \frac{hours_{vacancy}}{Efficiency_{boiler}}$$

$vacancy\ gas_r$	= Gas that would have been used to maintain water temperature in return pipe during vacancy hours (Btu)
$q_{ReturnPipe}$	= Heat loss in return pipe (Btu/hr/ft)
$Pipe\ Length$	= Pipe length
$Hours_{vacancy}$	= Hours of vacancy (hours)
$Efficiency_{boiler}$	= Efficiency rating of boiler

The **mass of water in the supply and return pipe** in pounds is calculated similarly except the inner diameter values differ between supply and return. The mass of water is required to calculate the reheat gas.

Mass of Water, Supply

$$m_{water,s} = \rho_{water}\ x \left(\frac{Pipe\ Length}{2}\ x\ \pi\left(\frac{\frac{SupplyPipe\ ID}{12}}{2}\right)^2\right)$$

$m_{water,s}$	= Mass of water (lbs)
ρ_{water}	= Water density (lb/ft³)
$Pipe\ Length$	= Pipe length
$SupplyPipe\ ID$	= Inner diameter of supply pipe (inches)

Mass of Water, Return

$$m_{water,r} = \rho_{water}\ x \left(\frac{Pipe\ Length}{2}\ x\ \pi\left(\frac{\frac{ReturnPipe\ ID}{12}}{2}\right)^2\right)S$$

$m_{water,s}$	= Mass of water (lbs)
ρ_{water}	= Water density (lb/ft³)
$Pipe\ Length$	= Pipe length
$ReturnPipe\ ID$	= Inner diameter of return pipe (inches)

The **mass of copper in the supply and return pipe** is calculated similarly except the inner and outer diameter values differ between supply and return. The mass of copper is required to calculate the reheat gas.

Mass of Copper, Supply

$$m_{copper,s} = \rho_{copper}\ x\ \left(\frac{Pipe\ Length}{2}\ x\ \pi\left(\frac{\frac{SupplyPipe\ OD}{12}}{2}\right)^2 - \left(\frac{\frac{SupplyPipe\ ID}{12}}{2}\right)^2\right)$$

$M_{copper,s}$	= *Mass of copper (lbs)*
ρ_{copper}	= *Copper density (lb/in³)*
Pipe Length	= *Pipe length*
SupplyPipe ID	= *Inner diameter of supply pipe (inches)*
SupplyPipe OD	= *Outer diameter of supply pipe (inches)*

Mass of Copper, Return

$$m_{copper,r} = \rho_{copper}\ x\ \left(\frac{Pipe\ Length}{2}\ x\ \pi\left(\frac{\frac{ReturnPipe\ OD}{12}}{2}\right)^2 - \left(\frac{\frac{ReturnPipe\ ID}{12}}{2}\right)^2\right)$$

$m_{copper,r}$	= *Mass of copper (lbs)*
ρ_{copper}	= *Copper density (lb/in³)*
Pipe Length	= *Pipe length*
ReturnPipe OD	= *Outer diameter of return pipe (inches)*
ReturnPipe ID	= *Inner diameter of return pipe (inches)*

The calculated **reheat gas** (Btu/yr), represents the gas required to reheat the water in the loop after the pump has been turned off during hours of vacancy. The same equation was used to calculate the supply and return reheat gas, but the mass variables differ.

Reheat Gas, Supply

$$reheat\ gas_s = (T_{set} - T_{\min})\ x\ (cp_{water}\ x\ m_{water,s} + cp_{copper}\ x\ m_{copper,s})\ x\ \left(\frac{Events}{Efficiency_{boiler}}\right)$$

Reheat Gas, Return

$$reheat\ gas_r = (T_{set} - T_{\min})\ x\ (cp_{water}\ x\ m_{water,r} + cp_{copper}\ x\ m_{copper,r})\ x\ \left(\frac{Events}{Efficiency_{boiler}}\right)$$

reheat gas =	*Reheat gas, supply or return, (Btu/yr)*
T_{set} =	*Temperature setpoint (°F)*
T_{min} =	*Minimum water temperature of return loop (°F)*
cp_{water} =	*Water specific heat (Btu/lb/°F)*
$m_{water,s}$ =	*Mass of water (lbs)*
cp_{copper} =	*Copper specific heat (Btu/lb/°F)*
$m_{copper,r}$ =	*Mass of copper (lbs)*
Events =	*Annual number of shutdown periods per year*
Efficiency =	*Efficiency rating of boiler*

The inputs and assumptions are specified below.

UES Inputs

Definition	Value	Source
Hot Water Heater Setpoint (°F)	140 °F	U.S. Department of Labor, Occupational Safety and Health Administration (OSHA). (n.d.) "Legionellosis." Accessed at "https://www.osha.gov/SLTC/legionnairesdisease/control_prevention.html#hotwater" on February 25, 2019. See "Domestic Hot Water Systems."
Pipe Temperature Prior to Reheat (°F)	78 °F	Navigant Consulting, Inc. 2017. *Recirculation Pump Time Clock Field Testing Report.* Prepared for the Southern California Gas Company.
Annual number of shutdown periods per year	260	See above.
Water Density (lb/ft³)	62.4	Constant
Water Specific Heat (Btu/lb/°F)	1.0	Constant
Copper Density (lb/in³)	557.9	Constant
Copper Specific Heat (Btu/lb/°F)	0.092	Constant

The minimum water temperature was the minimum temperature that the return loop reached per data from the Recirculation Pump Time Clock field test performed by Navigant.

The calculations below represent the final calculations for annual gas and electric UES.

Annual Gas Unit Energy Savings

$$UES_{Btu} = \frac{(vacancy\ gas_s + vacancy\ gas_r) - (reheat\ gas_s + reheat\ gas_r)}{100{,}000\ btu/therm}$$

Annual Electricity UES

$$UES_{kWh} = pump_{kW}\ x\ hours_{vacany}$$

Electric UES does not rely on the steady state heat loss through the system. The electric UES accounts for the power of the pump (a fixed value associated with each horsepower rating) and the number of hours the pump is shut OFF. This measure generates electric savings as load is being removed from the grid.

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.

As per Resolution E-4807, the California Public Utilities Commission (CPUC) defined the EUL of add-on equipment as the minimum of the EUL of the measure itself and the RUL of the host equipment.[20] The

[20] California Public Utilities Commission (CPUC). 2016. *Resolution E-4807*. December 16. Page 13.

RUL of the host equipment is calculated as one-third of the EUL of a pump motor. The methodology to calculate the RUL of the host equipment 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." This approach provides a reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced.[21]

The EUL for this measure originated in the Database for Energy Efficient Resources (DEER) 2005; the EUL and RUL are specified below.

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs) – recirc. pump timer	15.0	California Public Utilities Commission (CPUC). 2008. "EUL_Summary_10-1-08.xls."
EUL (yrs) – host pump motor	15.0	
RUL (yrs) – host pump motor	5.0	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 32.

BASE CASE MATERIAL COST ($/UNIT)

The base case hot water recirculation system includes a constant flow recirculation pump, operating 24 hours per day. Insofar as this measure is add-on equipment, base case cost is equal to $0.

MEASURE CASE MATERIAL COST ($/UNIT)

The range in pricing is due to the extent of programming capabilities that the products offer. The minimum programming capabilities for this measure would be seven-day independent scheduling.

The material cost for a recirculation pump timer was derived as the average of available costs of a range of products shown below. Costs were obtained from online pricing and catalogs for various timer product options.

BASE CASE LABOR COST ($/UNIT)

Insofar as this measure is add-on equipment, base case labor cost is equal to $0.

MEASURE CASE LABOR COST ($/UNIT)

The installation of a hot water recirculation pump timer requires an electric connection between the timer and the existing pump. The installation cost includes the cost of electrician labor associated with the installation of the timer including mounting, electrical connection, and programming.

The installation labor hours and labor rates were drawn from the 2008 measure cost summary for the Database of Energy Efficient Resources (DEER). Because the domestic hot water timer measure is not specified in this source, the labor hours for installing a timer for heating and cooling equipment was

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

adopted under the assumption that the installation time would be similar. The labor rate is the hourly rate assumed for nonresidential miscellaneous (NR-MISC) installations, also drawn from DEER.

Labor Cost Inputs

Parameter	Value	Source
Labor Hours	2.50	California Public Utilities Commission (CPUC). 2008. "Revised DEER Measure Cost Summary (05_30_2008) Revised (06_02_2008).xlsx." See "NR – MISC & HVAC" tab.
Labor Rate ($/hour) – NR-MISC	$67.88	Summit Blue Consulting, LLC. 2008. *2008 DEER Measure Cost Documentation Revision 3.*

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 value was derived by Itron Inc. as part of the 2011 Update to the Database for Energy Efficient Resources (DEER). This NTG is a "default" NTG that is applicable to all energy efficiency measures that have been offered through commercial sector programs for more than two years and for which impact evaluation results are not available.

Net-to-Gross Ratios

Parameter	Value	Source
NTG – commercial	0.60	Itron, Inc. 2011. *DEER Database 2011 Update Documentation.* Prepared for the California Public Utilities Commission. Page 15-4 Table 15-3.

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. This installation rate reflects the fact that customers typically install the timer rather than store the equipment after purchase.

Gross Savings Installation Adjustment

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

NON-ENERGY BENEFITS

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

DEER DIFFERENCES ANALYSIS

This section provides a summary of DEER-based inputs and methods, and the rationale for inputs and methods that are not DEER-based. The existing data in the Database for Energy Efficient Resources (DEER) for Circulation Pump Time clock Retrofit measure (DEER ID D03-095) was referenced but was found to only calculate electricity savings and has not been updated since 2005.

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
DEER Building Types	Yes, except for Fitness Centers
DEER Operating Hours	Yes, except for Outpatient Healthcare and Fitness Centers
DEER eQUEST Prototypes	No
DEER Version	n/a
Reason for Deviation from DEER	DEER calculates electricity savings only
DEER Measure IDs Used	n/a
NTG	Source: DEER. The NTG of 0.60 is associated with NTG ID*: Com-Default>2yrs*
GSIA	Source: DEER. The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: DEER 2005, 2008, 2011, 2014. The value of 15 years is associated with EUL ID: *Wtr-Ht-Timeclock.* RUL ID: *Motors-pump*

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Completion Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision
01	03/31/208	Jennifer Holmes, Cal TF Staff	Draft of consolidated text for this statewide measure is based upon: Workpaper WPSCGNRWH170313A, Revision 0 (September 12, 2017) Consensus reached among Cal TF members.
	02/28/2019	Jennifer Holmes, Cal TF Staff	Revisions for submittal of version 01.