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WATER HEATING

HOT WATER PIPE INSULATION, NONRESIDENTIAL & MULTIFAMILY

CONTENTS

MEASURE NAME

Hot Water Pipe Insulation, Nonresidential and Multifamily

STATEWIDE MEASURE ID

SWWH017-02

TECHNOLOGY SUMMARY

This measure pertains to the addition of insulation to pipe and pipe fittings (elbows, tees, valves, unions, flanges, reducers, bushings, couplings, etc.) that transport hot liquid to reduce the heat loss and offset the water heater or steam boiler energy load. Insulation adds thermal resistance and forces the heat flux to be reduced in magnitude. As a result, the fluid in the pipe system can retain its temperature due to a reduction in the heat loss gradient. This will allow the steam or hot water boiler to offset its energy demand and reduce its energy consumption.

Pipe insulation applications in the industrial sector include brine, plating solutions, steam, condensate, hot water, chilled water, and refrigerant; commercial sector applications include steam, hot water, chilled water, and refrigerant. Residential applications are hot water pipe and fittings in multifamily buildings with central water heating system that are not insulated. This measure addresses cost-effective energy efficiency opportunities and encompasses both fiberglass and heavier duty insulation systems such as Perlite and rigid Phenolic insulation.

MEASURE CASE DESCRIPTION

The measure case is defined as the installation of a layer of insulation to an existing bare pipe system that transports hot liquid to reduce the amount of heat loss throughout the pipe length or through the fitting surface area. The measure case specifications are provided for hot water and steam pipe systems in the tables below. Specifications are established by pipe diameter and assume 1-inch insulation. Note that savings are calculated for each measure offering by building type and by climate zone.

Measure Case Specification – Hot Water Pipe System

Type	Location	Pipe Diameter (inches)	Insulation Thickness (inches)
Fitting	Indoor	≤ 1.0	1.0
		> 1.0, ≤ 4.0	1.0
		> 4.0	1.0
	Outdoor	≤ 1.0	1.0
		> 1.0, ≤ 4.0	1.0
		> 4.0	1.0
Pipe	Indoor	≤ 1.0	1.0
		> 1.0, ≤ 4.0	1.0
		> 4.0	1.0
	Outdoor	≤ 1.0	1.0
		> 1.0, ≤ 4.0	1.0
		> 4.0	1.0

Measure Case Specification – Steam Pipe System

Type	Location	Pressure (psig)	Pipe Diameter (inches)	Insulation Thickness (inches)
Fitting	Indoor	< 15	≤ 1.0	1.0
			> 1.0, ≤ 4.0	1.0
			> 4.0	1.0
		≥ 15	≤ 1.0	1.0
			> 1.0, ≤ 4.0	1.0
			> 4.0	1.0
	Outdoor	< 15	≤ 1.0	1.0
			> 1.0, ≤ 4.0	1.0
			> 4.0	1.0
		≥ 15	≤ 1.0	1.0
			> 1.0, ≤ 4.0	1.0
			> 4.0	1.0
Pipe	Indoor	< 15	≤ 1.0	1.0
			> 1.0, ≤ 4.0	1.0
			> 4.0	1.0
		≥ 15	≤ 1.0	1.0
			> 1.0, ≤ 4.0	1.0
			> 4.0	1.0
	Outdoor	< 15	≤ 1.0	1.0
			> 1.0, ≤ 4.0	1.0
			> 4.0	1.0
		≥ 15	≤ 1.0	1.0
			> 1.0, ≤ 4.0	1.0
			> 4.0	1.0

BASE CASE DESCRIPTION

The base case for this measure is defined as a bare (un-insulated) pipe system used to transport hot liquid at a non-residential or multi-family facility.

CODE REQUIREMENTS

Applicable federal and state codes are shown below. The application of the pipe insulation to hot fluid piping, as required by the 2019 California Building Energy Efficiency Standards (Title 24)[1] and the federal Occupational Safety and Health Administration (OSHA) Standard[2] does not apply to this measure. While

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

[2] Code of Federal Regulations at 29 CFR 1910.261.

Title 24 (2019) specifies requirements for pipe insulation, this measure is classified as add-on equipment for existing, uninsulated pipe systems and therefore does not trigger Title 24 compliance.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20 (2019)	None.	n/a
CA Building Energy Efficiency Standards – Title 24 (2019)	Section 120.3	January 1, 2019
Federal Standards: OSHA	1910.261(k)(11)	August 19, 1998

OSHA 1910.261(k)(11):

> ***Steam and hot-water pipes.*** *All exposed steam and hot-water pipes within 7 feet of the floor or working platform or within 15 inches measured horizontally from stairways, ramps, or fixed ladders shall be covered with an insulating material, or guarded in such manner as to prevent contact.*

OSHA 1910.262(c)(9):

> ***Steam pipes.*** *All pipes carrying steam or hot water for process or servicing machinery, when exposed to contact and located within seven feet of the floor or working platform shall be covered with a heat-insulating material, or otherwise properly guarded.*

NORMALIZING UNIT

Piping: linear foot (len-ft).

Fitting: 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 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	Ag
Add-on equipment	DnDeemDI	Com
Add-on equipment	DnDeemDI	Ind
Add-on equipment	DnDeemDI	Res
Add-on equipment	DnDeemed	Ag

Measure Application Type	Delivery Type	Sector
Add-on equipment	DnDeemed	Com
Add-on equipment	DnDeemed	Ind
Add-on equipment	DnDeemed	Res

Eligible Products

Program eligibility requirements for hot water pipe insulation include:

- The pipe must transfer hot water, low-pressure steam, or medium-pressure steam directly from gas-fired equipment, and the fluid type must be indicated. If the fluid is steam, the pressure of the steam must also be indicated.
- The minimum qualifying pipe diameter is ½-inch.
- A minimum of one inch of pipe insulation must be added to existing bare commercial or industrial steel or copper pipe.
- Acceptable types of insulation for hot water pipes include elastomeric foam rubber, polyethylene foam, UV-resistant polyethylene foam, and rigid polyurethane foam.
- Acceptable types of insulation for steam pipes include silicone foam rubber, melamine foam, rigid urethane-based foam, cellular glass, rigid fiberglass, and rigid mineral wool.

Current data collection requirements include:

- The length of insulation to be installed with each pipe size must be indicated.
- The hours of operation must be indicated on the top of the application.
- The manufacturer specification sheet must be submitted with the application.

Eligible Building Types and Vintages

This measure is applicable to any existing commercial, agriculture, industrial, or multi-family facility of any vintage. For residential applications, only hot water pipe and fittings in Multifamily Common area building type are eligible.

Eligible Climate Zones

This measure is applicable to any California climate zone.

PROGRAM EXCLUSIONS

The following conditions are excluded:

- This measure is not eligible for new construction applications.
- Insulation required by California Building Energy Efficiency Standards (Title 24) or employee safety laws (Occupational Safety and Health Administration, OSHA) is not eligible.
- Replacement of damaged (existing) insulation is not eligible.
- Residential steam pipe and fittings are not available.

DATA COLLECTION REQUIREMENTS

The data found in the relevant studies presented is adequate and provides a reliable source for energy savings calculations. The data was acquired through a diligent effort and the tools used were appropriate for the data that was collected.

A section that could improve is with respect to the California Building Energy Efficiency Standards (Title 24)[3] Section 120.3 section b, which states:

> *"(b)* **Insulation Protection:** *Insulation shall be protected from damage, including that due to sunlight, moisture, equipment maintenance, and wind, including but not limited to, the following:*
>
> *1. Insulation exposed to weather shall be installed with a cover suitable for outdoor service. The cover shall be water retardant and provides shielding from solar radiation that can cause degradation of the material."*

Future data collection requirements could include assessments of the quality of the installation and if the insulation is well-protected, as stipulated by Title 24. This could be a factor in the lifecycle gross savings due to insulation deterioration affecting the thermal resistance effectiveness.

USE CATEGORY

Service & domestic hot water

ELECTRIC SAVINGS (kWh)

Not applicable.

PEAK ELECTRIC DEMAND REDUCTION (kW)

Not applicable.

GAS SAVINGS (Therms)

Gas unit energy savings (UES) were calculated based on standard engineering formulae of the energy loss through the bare pipe/fitting and through the insulated pipe/fitting. Separate calculations were completed for indoor locations and outdoor locations in each climate zone. The methodology uses several involved engineering formulae and iterative calculations to converge on the correct insulated pipe heat loss value. The insulated heat loss is less than 5% of the bare pipe heat loss.

The energy savings due to the installation of insulation on bare pipes and fittings is a function of the pipe diameter, insulation thickness, boiler efficiency, annual operating hours, and other factors such as fluid

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

properties and ambient temperature. The energy savings for this measure are expressed in per linear foot of straight pipe or per fitting.

To calculate the UES from adding insulation to existing uninsulated pipes, three modes of heat transfer were considered: convection, conduction, and radiation. Convection was considered between the inside film and inside wall. Conduction was then analyzed through the wall (pipe) with a constant thermal conductivity. To finalize the calculation of the heat flux value, both radiation and convection were considered for both the bare pipe and insulated pipe heat loss to the environment.

The calculations for the pipe heat loss (both with and without insulation) follow a process that begins at the hot fluid to either the outer bare pipe surface or the outer insulation surface. The inside fluid analysis calculations determine the bare pipe temperature. However, the 2014 and 2015 Deemed ESPI Pipe Insulation Impact Evaluation reports published by Itron, Inc. provide the bare pipe temperature.[4] This value adequately captures the bare pipe temperature thus there is no need for further analysis of heat flow from the inside fluid to the outer bare pipe surface. Rather, the focus was on the heat flux from the outer insulation surface to the environment.

Results of Relevant Studies

The key findings of several studies relevant to pipe insulation measures are summarized below.

2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report (Itron, Inc. and ERS, 2017).[5] The ESPI study was completed by Itron, Inc. and ERS to estimate the ex post impacts relative to the ex ante deemed savings and measure-parameters associated with pipe insulation measures. Several parameters for this measure analysis were drawn from this ESPI study, including operating hours, net-to-gross ratio, pipe surface temperature, ambient air temperature, and boiler efficiency.

2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report (Itron, Inc. and ERS, Inc., 2016).[6] This study estimated the impacts of deemed savings and updated measure-parameters associated with pipe insulation measures.

Steam Trap Survey and Billing Analysis Report (kW Engineering, 2006).[7] This study estimated the potential savings from steam trap replacements in dry cleaner facilities. The operating hours of the boiler systems that were surveyed are relevant to the hot water line insulation and utilized in this or future analyses.

Steam Trap Survey (Enbridge 2002-2005).[8] The savings calculations to derive savings of hot water line insulation utilized the average steam pressures were derived from this steam trap survey. The sites that participated in the on-site survey represented a number of different building types, including

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

Itron, Inc. and ERS, Inc. 2016. *2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report.* Prepared for the California Public Utilities Commission.

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

[6] Itron, Inc. and ERS, Inc. 2016. *2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report.* Prepared for the California Public Utilities Commission.

[7] kW Engineering. 2006. *Steam Trap Survey and Billing Analysis Report.* Prepared for the Southern California Gas Company.

[8] Southern California Gas Company (SCG). 2005. “WPSCGWP110812A_Rev4_Enbridge Steam Trap Survey.xls”

pharmaceutical manufacturing facilities, universities, and paper mills. The steam pressures of the surveyed facilities were used to determine the average pressure for steam systems less than or equal to 15 psig and greater than 15 psig.

Key Parameters

The energy savings due to insulation are dependent on pipe and insulation characteristics, as well as boiler efficiency, annual operating hours, fluid temperatures, fluid flowrates, and ambient temperature. Pipe and insulation parameters are discussed below; additional parameters are specified in the table below.

Pipe Parameters. Steam and hot water pipe diameter sizes ranging from one-half to four inches are commonly found in commercial and industrial facilities. Consistent with findings of the 2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation, this measure includes a larger diameter size offering (pipe diameter > 4-inch). Key parameters specific to steam and hot water pipes include:

- Pipe sizes were divided into three ranges: ≤ 1-inch, > 1-inch and ≤ 4-inches, and > 4-inches. The physical dimensions of a Schedule-40 standard pipe size of ¾-inch was selected to represent ½-inch, ¾-inch, 4-inch, and 1-inch pipe sizes. As recommended by the Energy Division of the California Public Utilities Commission (CPUC)[9] the assumed pipe diameter for a pipe greater than 1 inch was revised from the assumed 2 inches to 1.7 inches.
- The Schedule-40 was also chosen to represent a pipe with an outside diameter of five inches.
- The thermal conductivity and surface emittance of black steel pipe were applied in all cases. The thermal conductivity of steel (314.4 Btu-in/hr-ft^2-°F or 26.2 Btu/hr-ft-°F) is required to calculate the outside wall temperature of the steel pipe.
- The radiation from the bare pipe surface is characterized by an emittance of 0.94.

Insulation Parameters. Acceptable types of pipe insulation for hot water pipes include polyethylene foam (up to 180 °F), UV-resistant polyethylene foam, and elastomer foam rubber. Key parameters specific to the pipe insulation include:

- Acceptable types of insulation for steam pipes include silicone foam rubber (to 425 °F), melamine foam (to 400 °F), rigid urethane-based foam (to 300 °F), cellular glass (to 400 °F), fiberglass, and mineral wool.
- The protection offered by jacketing is also recommended, especially outdoors. Only some jacket materials are suitable for outdoor use, such aluminum and UV-resistant PVC.
- The parameters used to describe the insulation (thermal conductivity, surface emittance) are generally based on prefabricated 1-inch thick fiberglass pipe insulation with paper or aluminum wrap (paper for indoor locations and aluminum for outdoor locations).
- The energy savings analysis is based on adding 1-inch thick insulation around bare, Schedule 40 black steel pipe and fittings.
- It is also necessary to know the thermal conductivity of the insulation and the thermal radiation emittance of the insulation wrap. The thermal conductivity of pipe insulation varies somewhat by

[9] California Public Utilities Commission (CPUC). 2011. *D 11-07-030 in the Consolidated Application of Southern California Edison Company (U338E) for Approval of its 2009-2011 Energy Efficiency Program Plan and Associated Public Goods Charge (PGC) and Procurement Funding Requests. And Related Matters. (A.08-07-021).* Issued July 14, 2011. Appendix A, page A2.

material and temperature rating. A thermal conductivity value of 0.29 Btu-in / hr-ft^2-°F (0.024 Btu/hr-ft-°F) was assumed for both hot water and steam pipe insulation (based on ASHRAE Handbook[10] and a vendor catalog[11]).

- The insulation surface participates in radiative heat transfer. Pipe insulation used indoors typically has a paper wrap (with an emittance of about 0.90) and pipe insulation used outdoors typically has an aluminum wrap (with an emittance of about 0.10). These emittances are not critical parameters, since the heat loss is not very sensitive to radiative heat loss from the rather cool surface of the insulation; an average value of 0.5 was applied.

Boiler Efficiency. Boiler efficiencies by fluid type were drawn from the 2014 and 2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation studies conducted by Itron, Inc.

Weather Data. For outside pipe insulation, weather data was utilized to calculate the average wind speed and ambient outside air temperature for each climate zone.

Annual Hours of Operation. The annual hours of operation was derived from the 2014 and 2015 pipe insulation impact evaluations noted in the table below. To simplify the analysis and minimize inaccurate assignment of project applications to the wrong building type, a single value – the average of the annual hours of operation estimated for industrial facilities – was adopted for this measure. This value is reasonable and close to the average operating hours across all three facility types.

Annual Hours of Operation, by Facility Type

Parameter	Small Commercial	Large Commercial	Industrial	Source
Annual hours of operation	7,003	6,552	6,106	Itron, Inc. and ERS. 2017. *2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation.* Prepared for the California Public Utilities Commission.
	n/a	5,560	6,560	Itron, Inc. and ERS, Inc. 2016. *2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report.* Prepared for the California Public Utilities Commission.
Average	**7,003**	**6,056**	**6,333**	

UES Inputs

Parameter	Value	Source
Boiler efficiency – hot water	83.49%	Itron, Inc. and ERS. 2017. *2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation.* Prepared for the California Public Utilities Commission.
Boiler efficiency – low-pressure steam	80.71%	
Boiler efficiency – high pressure steam	82.55%	
Annual operating hours	6,333	
Bare pipe temperature – hot water (°F)	135.45	

[10] American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2005. *2005 ASHRAE Handbook Fundamentals.* Atlanta (GA): ASHRAE.

[11] This reference is no longer available.

Parameter	Value	Source
Bare pipe temperature – low pressure steam (°F)	239.60	Itron, Inc. and ERS, Inc. 2016. *2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report.* Prepared for the California Public Utilities Commission. The Southern California Gas Company (SCG). 2018. “WPSCGWP110812A_Rev05__Itron_2014_2015 WP Parameters.xlsx”
Bare pipe temperature – medium pressure steam (°F)	291.50	
Fluid temperature – hot water (°F)	136.80	
Fluid temperature – low-pressure steam (°F)	242.00	
Fluid temperature – high-pressure steam (°F)	294.42	
Air temperature (°F) – low-pressure steam, averaging 10.9 psig	97.85	
Air temperature (°F) – medium-pressure steam, above 15 psig, averaging 85.9 psig	83.60	
Ambient air temperature – indoor (°F)	75.15	
Ambient air temperature– outdoor (°F)	Varies by climate zone	The Southern California Gas Company (SCG). 2018. “WPSCGWP110812A_Rev05_Weather Data.xlsm.”

Bare Pipe Heat Loss Analysis

To determine the heat loss from the bare pipe, the convective and radiation heat transfer coefficients were first be estimated with the provided bare pipe surface temperature. The convective heat transfer coefficient calculation is represented below.

Convective Heat Transfer Coefficient

$$Nu = \frac{h \times d}{k}$$

$$h = Convective\ heat\ transfer\ coefficient\ (Forced, Free)\ \left(\frac{Btu}{hr*ft*°F}\right)$$

$$d = Characteristic\ length\ (diameter)(ft)$$

$$k = Thermal\ conductivity\ \left(\frac{Btu}{hr*ft*°F}\right)$$

The heat transfer coefficient is derived by finding the Nusselt Number twice, once for free convection and the other for forced convection, the two values were then normalized and the resultant is used in the convective heat transfer coefficient calculation to solve for the convective heat transfer coefficient.

Free Convection. The Nusselt Number equation is shown below,[12] which includes the Rayleigh Number and Prandtl Number terms.

[12] American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2005. *2005 ASHRAE Handbook Fundamentals.* Atlanta (GA): ASHRAE.

Nusselt Number

$$\mathrm{Nu} = \left\{ 0.6 + \frac{0.387 \times \mathrm{Ra}^{\frac{1}{6}}}{\left[1 + \left(\frac{0.559}{\mathrm{Pr}}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}} \right\}^2$$

$$Ra = Rayleigh\ Number = \frac{g \times \beta \times \rho \times C_p \times \Delta T \times D^3}{\nu \times k_f}$$

$$Pr = Prandtl\ Number = \frac{\nu \times \rho \times C_p}{k_f}$$

g = *gravity,* $\left(\frac{ft}{hr^2}\right)$
β = *volumetric thermal expansion coefficient of ambient fluid,* $\left(\frac{1}{°R}\right)$
ρ =*density of ambient fluid,* $\left(\frac{lb}{ft^3}\right)$
C_p = *specific heat of ambient fluid,* $\left(\frac{Btu}{lb * °R}\right)$
ΔT = *absolute temperature difference between fluid and surface,* $(°F)$
D = *pipe diameter,* (ft)
ν = *kinematic viscosity,* $\left(\frac{ft^2}{hr}\right)$
k_f =*thermal conductivity of ambient fluid,* $\left(\frac{Btu}{hr * ft * °F}\right)$

Forced Convection. The Nusselt Number is calculated as follows:[13]

Nusselt Number

$$Nu = 0.3 + \frac{0.62 \times Re^{\frac{1}{2}} \times Pr^{\frac{1}{3}}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{\frac{2}{3}}\right]^{\frac{1}{4}}} \left[1 + \left(\frac{Re}{282{,}000}\right)^{\frac{5}{8}}\right]^{\frac{4}{5}}$$

$$Re = \frac{V \times D}{\nu}$$

V = *free stream velocity of ambient fluid,* $\left(\frac{ft}{hr}\right)$

For the radiation effect, the radiation heat transfer coefficient was calculated as follows:[14]

[13] American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2005. *2005 ASHRAE Handbook Fundamentals.* Atlanta (GA): ASHRAE.

[14] American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). 2005. *2005 ASHRAE Handbook Fundamentals.* Atlanta (GA): ASHRAE.

Radiation Heat Transfer Coefficient

$$h_{rad} = \frac{[\varepsilon * \sigma * (T_{amb}^4 - T_s^4)]}{(T_{amb} - T_s)}$$

$\varepsilon = surface\ emissivity$

$\sigma = Stefan\text{-}Boltzmann\ constant, \left(0.1713 \times 10^{-8} \frac{Btu}{hr * ft^2 * °R^4}\right)$

Combining the radiation heat transfer and the convective heat transfer coefficients will yield the total heat transfer coefficient represented below.

Total Heat Transfer Coefficient

$$h_{pipe} = h_{rad} + h_{cv}$$

The calculation of the heat flux from the bare pipe into the environment is represented by the following calculation:

Heat Flux

$$q_{pipe} = (h_{pipe}) \times \pi \times (d_{outer}) \times L \times (T_{amb} - T_s)$$

$d_{outer} = Outer\ pipe\ diameter$

$L = reference\ pipe\ length\ (ft)$

For a sample calculation, consider the heat loss in a bare pipe transporting hot water, the following is known:

Inside pipe water temperature = 136.65 °F

Ambient air temperature = 51.50 °F

Wind Speed = 29,783 ft/hr

Pipe Outer Diameter = 0.0875 ft

$$Ra = \frac{417312000 \times 0.001955 \times 0.07489 \times 0.2404 \times ((460 + 135.45) - (460 + 51.50)) \times 0.0875^3}{0.5915 * 0.01457} = 95{,}861$$

$$Pr = \frac{0.5915 \times 0.07489 \times 0.2404}{0.01457} = 0.7309$$

$$Re = \frac{29783 \times 0.0875}{0.5915} = 4{,}406$$

$$Nu = \left\{ 0.6 + \frac{0.387 \times 95861^{\frac{1}{6}}}{\left[1 + \left(\frac{0.559}{0.7309}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}} \right\}^2 = 8$$

The forced convection Nusselt Number is calculated:

$$Nu = 0.3 + \frac{0.62 \times 4406^{\frac{1}{2}} \times 0.7309^{\frac{1}{3}}}{\left[1 + \left(\frac{0.4}{0.7309}\right)^{\frac{2}{3}}\right]^{\frac{1}{4}}}\left[1 + \left(\frac{4406}{282{,}000}\right)^{\frac{5}{8}}\right]^{\frac{4}{5}} = 35$$

Combining the Nusselt Number and solving for the heat transfer coefficient:

$$Nu = \sqrt[4]{(8^4 + 35^4)} = 35$$

The heat transfer coefficient due to convection:

$$Nu = \frac{h \times d}{k} \rightarrow h = \frac{Nu \times k}{d} = \frac{35 \times 0.01457}{0.0875} = 5.80$$

The heat transfer coefficient due to radiation is then determined:

$$h_{rad} = \frac{[0.94 * .000000001713 \times ((460 + 135.45)^4 - (460 + 51.50)^4)]}{(135.30 - 51.50)} = 1.10$$

The total heat transfer coefficient:

$$h_{pipe} = 1.10 + 5.80 = 6.90$$

Finally, the calculation of heat loss for the bare pipe:

$$q_{pipe} = \left(6.90 \frac{Btu}{hr \times ft^2 \times °F}\right) \times \pi \times (.0875\, ft) \times 1ft \times (135.45 - 51.50)°F = 159 \frac{btu}{hr - ft}$$

Insulated Pipe Analysis

The analysis for an insulated pipe follows the same procedure as the bare pipe heat loss analysis. However, the calculation required numerous iterations because the temperature of the outer insulation surface is unknown. The iterative approach varied the insulation surface temperature until the difference of the conducted heat through the insulation, and the sum of the radiated and convective heats are equal to zero. The following expression shows that the heat conducted from the inner-pipe to the outer insulation surface will also equal the heat that will be lost to the environment.

$$q_{cond} = q_{rad} + q_{cv}$$

The equation to calculate the conducted heat from the inner surface to the insulation surface is represented below:

$$q_{cond} = \frac{T_{amb} - T_s}{\frac{LN\left({r_{outer}}/{r_{inner}}\right)}{2 * \pi * k * L}} \cdots$$

$T_{amb} = Ambient\ air\ temperature$
$T_s = Insulation\ surface\ temperature$
$r_{outer} = outer\ insulation\ radius$
$r_{inner} = bare\ pipe\ outer\ radius$

$$k = Insulation\ thermal\ conductivity$$

For a sample calculation, consider an insulation layer of 1-inch thickness. Using values that apply to the insulation outer surface, the following is observed.

$$q_{pipe-insulated} = \left(4.40 \frac{Btu}{hr * ft^2 * °F}\right) \times \pi \times (.2542\ ft) \times 1ft \times (54.7 - 51.50)°F = 11.4 \frac{btu}{hr * ft}$$

Insulation savings are as follows.

$$q_{savings} = q_{no-insulatio} \ - q_{insulation} = 159 - 11.4 = 147.60 \ \frac{Btu}{hr \times linear\ ft}$$

The added layer of 1-inch of insulation will increase the thermal resistance; the effect is evident in the outer insulation surface temperature (54.7 °F). The bare pipe surface temperature in this example is (135.3 °F), enabling more heat to be lost without the insulation layer.

For indoor savings, the forced convection heat transfer coefficient will equal zero. This is due to the Nusselt Number for this portion being a function of Reynolds number, which is a function of velocity. For indoor applications the air velocity is assumed to equal zero.

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. EUL is often, but not always, derived from measure persistence or retention studies. 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 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."[15] This approach provides a reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced.[16] Further, as per Resolution E-4807 and E-4818, the California Public Utilities Commission (CPUC) revised add-on equipment measures so that the EUL of the measure is equal to the lower of the RUL of the modified system or equipment or the EUL of the add-on component." [17]

The EUL and RUL specified for pipe and fitting insulation are presented below. The estimates of life expectancy of pipe exceed 20 years (estimates range from 20 to 70 years).[18] However, the CPUC has stipulated the maximum limit of 20 years, which will be adopted for the host EUL.

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

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

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

[18] See the following references:

Effective Useful Life and Remaining Useful Life

Parameter	Value (yrs)	Source
EUL (yrs) – WtrHt-PipeIns-Gas	11	California Public Utilities Commission (CPUC), Energy Division. 2003. Energy Efficiency Policy Manual v 2.0.
RUL (yrs) – WtrHt-Piping	6.67	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 32.

BASE CASE MATERIAL COST ($/UNIT)

Insofar as this is an add-on equipment measure and there is no requirement to install insulation on bare water or steam pipes, the base case cost is equal to $0.

MEASURE CASE MATERIAL COST ($/UNIT)

Pipe Insulation. The material cost for pipe insulation was derived as the average of the material costs of projects tracked by the Southern California Gas Company[19] and costs reported in the 2016 RSMeans Plumbing Cost Data.[20] The data used from this handbook is for the material and labor cost of pipes ranging from ½-inch to 4 inches in diameter.

The pipe insulation cost calculated for this measure is representative of high-temperature (850 °F) fiber glass insulation; the same insulation can be used for steam.

Fitting Insulation. Fitting insulation costs were primarily derived from two industry leading industrial supply companies, Grainger and McMaster-Carr. Online research utilizing these two databases allowed for the most up-to-date pricing on insulation to fittings for Elbows and Tees. To obtain an average price for the measure offerings defined for this measure, two temperature range specifications were taken into consideration, 0 °F to 450 °F and -297 °F to 220 °F. These temperature ranges coincide with two types of material, Fiberglass and Nitryl Rubber/Polyvinyl Chloride (NBR/PVC), respectively. For the purposes of this measure, the pricing for fittings that utilize fiberglass insulation will be applied to high-temperature applications such as high-pressure steam, while the lower temperature hot water applications will utilize NBR/PVC material. Another material used for lower temperature applications was Polyurethane, having a temperature range that was similar to NBR/PVC.

The average material cost was calculated as the average cost of all fittings for both sources, in respect to the outside pipe diameter pools specified for this measure.

Baird, G. 2011 "The Epidemic of Corrosion Part 1 Examining Pipe Life." Journal AWWA. December 2011. Pp 14-21.

Bousquin, J. 2019. "Types of Plumbing Pipes and Their Lifespans." *Houselogic*, by the National Association of Realtors.

International Association of Certified Home Inspectors (InterNACHI). "InterNACHI's Standard Estimated Life Expectancy Chart for Homes." https://www.nachi.org/life-expectancy.htm

Essentra. 2015. "What is the Life Expectancy of Your Pipes?" August 18.

[19] Southern California Gas Company. 2018. "WPSCGWP110812A_Rev5__Pipe Cost.xls"

[20] Gordian Group. 2016. *Plumbing Cost Data*. 39th Annual Edition. Page 129.

BASE CASE LABOR COST ($/UNIT)

Insofar as this is an add-on equipment measure and there is no requirement to install insulation on bare water or steam pipes, the base case labor is equal to $0.

MEASURE CASE LABOR COST ($/UNIT)

Pipe Insulation. The labor cost for pipe insulation was derived as the average of installation costs documented for projects tracked by the Southern California Gas Company[21] and labor costs reported in the 2016 RSMeans Plumbing Cost Data.[22] The data used from this handbook is for the material and labor cost of pipes ranging from ½-inch to 4 inches in diameter.

Fitting Insulation. Labor costs for fittings were calculated as the average of installation costs for all pipe sizes and applied to all measure bins. These costs were obtained from RSMeans Plumbing Cost Data.[23]

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. This NTG was recommended in the 2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation conducted by Itron, Inc.

Net-to-Gross Ratios

Parameter	Pipe Insulation	Source
NTG	0.45	Itron, Inc. and ERS. 2017. *2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation.* Prepared for the California Public Utilities Commission. Table 1-1.

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.

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[21] Southern California Gas Company. 2018. "WPSCGWP110812A_Rev5__Pipe Cost.xls"

[22] Gordian Group. 2016. *Plumbing Cost Data*. 39th Annual Edition. Page 129.

[23] Mossman, Melville J. 2016. *RSMeans Plumbing Cost Data.* Pp 146-147.

Gross Savings Installation Adjustment Rates

Parameter	Value	Source
GSIA	1.0	Itron, Inc. and ERS. 2017. *2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation.* Prepared for the California Public Utilities Commission. Page 1-3. California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 31.

NON-ENERGY IMPACTS

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.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	Yes
Scaled DEER measure	No
DEER Base Case	No
DEER Measure Case	No
DEER Building Types	Yes
DEER Operating Hours	Yes
DEER eQUEST Prototypes	No
DEER Version	DEER 2019
Reason for Deviation from DEER	DEER does not contain this type of measure
DEER Measure IDs Used	n/a
NTG	Source: Itron ESPI Pipe Insulation Report. NTG of 0.45 is associated with NTG IDs: *NonRes-sAll-mPipeIns-deemed*
GSIA	Source: Itron ESPI Pipe Insulation Report. The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: EUL ID: *WtrHt-PipeIns-Gas*. RUL ID: *WtrHt-Piping*

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Complete 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: Workpaper WPSCGWP110812A, Revision 4 (December 26, 2017) Workpaper WPSCGWP110812A, Revision 3 (May 16, 2014) Consensus reached among Cal TF members.
	02/21/2019	Jennifer Holmes Cal TF Staff	Updated based upon: Workpaper WPSCGWP110812A, Revision 5 (December 28, 2018)
	02/27/2018	Jennifer Holmes Cal TF Staff	Revisions for submittal of version 01.
02	12/15/2020	Andy Danryd SoCalGas	Updated workpaper to add offerings for MFmCmn area central DHW system, adopting commercial savings.
	01/27/2021	Anders Danryd SoCalGas	Fixed miscellaneous errors in the text, reformatted EAD Table to the correct order